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Preface

In recent decades, new technologies’ rapid advancements and their significant cost reduction have spurred the development of increasingly flexible, customizable technological solutions for different user needs. This development had a particular impact on the progress of ambient assisted living (AAL) technological solutions such as human monitoring, smart living services, biomedical and robotic solutions, and design for all that aim to improve the health, psycho-physical well-being, and independent living of users with different needs or with disabilities. With a population that is becoming steadily older with over half the EU’s population predicted to be over 65 by 2070, AAL technologies are recognized by the European Commission as the enabling drivers to build the quality of life of our current and future society to address the challenges of demographic changes, sustaining people in productive and healthy work, improving the delivery of care where and when needed. The importance of the AAL solutions has been well highlighted by the COVID-19 pandemic, where when many older people were more isolated than ever before, and thus, families and care organizations were increasingly relying on AAL technology to stay connected, while keeping older people more safe and secure at home.

All these aspects were explored during the Eleventh Italian Forum on Ambient Assisted Living (ForItAAL), hosted in Padova, Italy, and held online due to the pandemic situation about COVID-19 in December 2020. ForItAAL is the annual Italian event on the theme of technologies for ambient assisted living. At ForItAAL, companies, stakeholders and policymakers, associations, universities, and research institutions discuss the challenges associated with demographic changes and people’s independence in different life scenarios: at home and in the workplace, in the cities where we live and in means of transport we use, in tourism and sport. The objectives of our community are to promote the design, development, and adoption of innovative technologies and services and thus support active ageing, disabilities, and the well-being of citizens. The book presents the refereed proceedings of the Forum and reviews the status of research, technologies, and recent achievements on AAL. The coverage is wide-ranging, with topical sections devoted to tailoring products and services to the ageing society, bio-data and artificial sensing in AAL.
scenarios, cognition and technologies, and designing for inclusion and well-being, including different case studies and real-world examples where AAL technologies are successfully applied. By using a multidisciplinary approach and several points of view, the volume conveys results, prototypes, products, and services as well as provides interesting insights, from research to practice, for anyone directly or indirectly involved in the field of AAL.

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## Contents

**Tailoring Products and Services for the Aging Society**

**Tailoring a Forward Looking Vocal Assistant to Older Adults** ........................ 3  
Riccardo De Benedictis, Claudia Tagliaferri, Gabriella Cortellessa, and Amedeo Cesta

**Design and Development of a Telepresence and Monitoring Service to Empower the Older Adults** .............................................................. 18  
Alessandra Sorrentino, Lorenzo Radi, Filippo Cavallo, Claudia Becchimanzi, Mattia Pistolesi, Francesca Tosi, Erika Rovini, and Laura Fiorini

**Assistive Technology for Active Ageing: The NATIFLife Project** .......... 37  
Bruno Andò, Salvatore Baglio, Salvatore Castorina, Ruben Crispino, Vincenzo Marletta, Giovanni Muscato, Luca Porcaro, Sebastiano Salupo, Carl J. Debono, and Nadia Theuma

**Personalized Integrated Care for Frail Seniors Within the Pharaon Project: The Italian Pilot Site** .............................................................. 50  
Laura Fiorini, Erika Rovini, Grazia D’Onofrio, Sergio Russo, Filomena Ciccone, Francesco Giuliani, Daniele Sancarlo, Lara Toccafondi, Gianna Vignani, Marco Di Girolamo, Manuele Bonaccorsi, Cristiano Paggetti, Elena Tamburini, Pietro Dionisio, Simona Geli, and Filippo Cavallo

**Preliminary Studies of a Model for a Robot that Creates an Interactive Communication with Elderly People to Satisfy Their Clothing Item Requests** .............................................................. 73  
Olivia Nocentini, Jaeseok Kim, and Filippo Cavallo
Vision-Based Heart Rate Monitoring in the Smart Living Domains  . . .  205
Andrea Caroppo, Alessandro Leone, Andrea Manni, and Pietro Siciliano

Combined Vision and Wearable System for Daily Activity Recognition  . . .  216
Federica G. C. Loizzo, Laura Fiorini, Alessandra Sorrentino, Alessandro Di Nuovo, Erika Rovini, and Filippo Cavallo

Novel Cloud-Based ICT Solution for Real-Time Heart Rate Variability Analysis: A Technical Essay  . . .  235
Massimo Pistoia, Paolo Casacci, and Gianfranco Raimondi

Integrated Measurement and Management System for Sarcopenia Diagnosis  . . .  249
Luigi Accetta, Filomena Addante, Andrea Caroppo, Francesco Ciliberti, Francesco Giusto, Alessandro Leone, Luigi Patrono, Gabriele Rescio, Ilaria Sergi, and Daniele Sancarlo

An Innovative Telemonitoring System for Older Adults Based on Low Power Wide Area Networks  . . .  259
Lisa Cesario, Arianna Gherardini, Massimiliano Malavasi, Carlo Montanari, Maria Rosaria Motolese, Antonio Iossa, Stefania Nanni, and Lorenzo Desideri

Tele-Monitoring and Tele-Rehabilitation of the Hand in Hemiplegic Patients: A Preliminary Study  . . .  272
Luca Vismara, Claudia Ferraris, Valerio Votta, Roberto Nerino, Daniela Clerici, and Alessandro Mauro

Cognition and Technologies

Comparison of Computerized Testing Versus Paper-Based Testing in the Neurocognitive Assessment of Seniors at Risk of Dementia  . . .  291
Simona Gabriella Di Santo, Flaminia Franchini, Giuseppe Sancesario, Massimo Pistoia, and Paolo Casacci

Clinical Decision Support System for Multisensory Stimulation Therapy in Dementia: A Preliminary Study  . . .  315
Giovanni Diraco, Alessandro Leone, and Pietro Siciliano

A Sensing Platform to Monitor Sleep Efficiency  . . .  335
Antonino Crivello, Davide La Rosa, Elisabeth Wilhelm, and Filippo Palumbo
Are Wearable Sensors Useful to Assess the Psychophysical Fatigue Due to Physical Activity in Elderly People with Mild Cognitive Impairment? A Preliminary Study ................................................................. 346
Alessandro Tonacci, Jorilda Biba, Francesco Sansone, Lucia Billeci, Gennaro D’Angelo, Immacolata Minichiello, Raffaele Conte, and Lorenza Pratali

Therapeutic Exercise Protocols for People Recovering After Covid-19: A Tele-Health Approach ................................................................. 355
Lucia Pepa, Martina Pigliapoco, Paola Bisoglio, Alice Lambertucci, Michela Coccia, Lauredana Ercolani, Michela Aringolo, Margherita Hibel, Anna Gastaldi, Elisa Andrenelli, Rossella Cima, Luca Spalazzi, Maria Gabriella Ceravolo, and Marianna Capecci

An Edge Ambient Assisted Living Process for Clinical Pathway ............ 363
Carmelo Ardito, Tommaso Di Noia, Corrado Fasciano, Domenico Lofù, Nicola Macchiarulo, Giulio Mallardi, Andrea Pazienza, and Felice Vitulano

Author Index ........................................................................................................ 375
Tailoring Products and Services for the Aging Society
Tailoring a Forward Looking Vocal Assistant to Older Adults

Riccardo De Benedictis(✉), Claudia Tagliaferri, Gabriella Cortellessa(✉), and Amedeo Cesta

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Abstract. Human-machine speech and interaction is becoming increasingly important. In particular, one of the aspects that is gaining attention concerns the possibility to interact in a natural way and, more specifically, in natural language. Being able to support a believable speech-based conversation is particularly relevant especially for tools that assist older people in their daily life. This paper introduces our goal to develop a vocal assistant for different assistive scenarios such as information point and cognitive rehabilitation. In particular, the article describes a planning-based system which integrates the natural language understanding features of a state-of-the-art tool in the attempt of obtaining forward-looking functionalities to support end-users longer in time. Our planning-based system is able to both achieve forward-looking functionalities and embrace elements related to the user’s personality and current mood, helping older users to maintain a natural communication flow and become more confident with the technology.

Keywords: Conversational agents · Planning · Look-ahead dialogues

1 Introduction

The attention towards the aging society has grown considerably in recent years. Consequently, several research programs have concentrated interest in creating technological solutions that can facilitate a more autonomous and self-determined life for older people.

In order to improve the quality of life of the older adults, several products and services there exist developed as part of the Active and Assisted Living (AAL)1 EU program to promote active and healthy ageing. These technologies

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1 http://www.aal-europe.eu/.

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also aim to support and help those who assist the elderly and, at the same time, to support the sustainability of care systems. Research in this domain has focused on different areas of intervention: supporting physical tasks [6,7] (for example, recovering or lifting objects, support in moving around), cognitive stimulation [12], lifestyle monitoring [17], support for daily activities [20], promotion of social participation [4] and also on various aspects of technology acceptance [21].

Over the last two decades, a solid body of evidence has shown the potential benefits of using conversational agents for health-related purposes [14]. Several randomized controlled trials of interventions, involving embodied conversational agents, have shown significant improvements in these health purposes. However, the majority of these agents only allowed for constrained user input (e.g., multiple-choice of utterance options), not having the capability to fully understand natural language input. For this reason, one of the aspects that is gaining importance today concerns the possibility to interact in a natural way and, more specifically, in natural language. As a consequence, almost all nowadays’ assistive systems rely on a central actor that can be a virtual assistant, an avatar, a chatbot or a robot that acts as a focal point of interaction often exploiting vocal interaction in addition or in alternative to touch, video or textual messages. In this context, the AAL sector is intertwining with the research area of Vocal Assistants or Conversational Agents (CA) adopting stable solutions from these research areas but also dwelling on the challenges that are still open, specializing them to the aging population context.

Among the emerging challenges of such systems, the need to support contextualized dialogues, so as to dynamically adapt according to the users’ needs, is becoming increasingly significant. This characteristic, in particular, allows the Conversational Agents to aim for long-term sustainability, maintaining a high level of effectiveness of the interaction and user engagement. This adaptive and dynamic behavior should be exhibited in different contexts that range from simple question answering, to the execution of cognitive exercises or to support the management of daily activities. In addition, the interaction should also take into consideration any preferences or deficiencies associated to personal habits or cognitive/physical limits due to age.

With the aim of contributing in this direction, this paper proposes an integration of different AI techniques proposing a Forward-looking Conversational Agent called Savant (from SAnbot Vocal AssistaNT). In addition to dynamically adapting to the various aspects related to the characteristics of people such as personality, preferences and deficiencies, this Conversational Agent is able to take advantage of different layers of information, customizing the interaction according to the current context while tailoring it towards the achievement of particular objectives set by the healthcare professionals. To this purpose, Savant is part of a two-layered approach (proposed in [8]) that uses: (a) a pipeline of Knowledge Representation and Reasoning approaches to exploit human knowledge and generate high-level speech strategies, encapsulating a general vision about the specific needs of the assisted person; and (b) a Policy-based approach in the more interactive layer to actually execute a step-by-step interaction strategy by synthesizing and combining speech acts toward the assisted human. The latter layer, in particular,
Tailoring a Forward Looking Vocal Assistant to Older Adults

necessarily has a more limited vision with respect to general assistive objectives but, at the same time, it is endowed with a significantly more responsive conduct that can ensure robustness toward dynamic changes, by supporting the required adaptivity in the produced dialogue. Since interaction with real users demands to be as natural and engaging as possible, a part of the work, in the development of the system, has been concentrated in taking into account the human aspects on which the personalisation and adaptability of the system rely on.

2 Vocal Assistants for Frail People

Conversational agents are human-machine interaction approaches designed to give the impression to humans that they are conversing with other humans, instead of machines [2]. The first studies on this discipline date back to the “Imitation Game” proposed by Turing in his 1950 seminal paper [22], proceeding for the first chatbot ELIZA [27], and the Artificial Linguistic Internet Computer Entity (ALICE), which is relevant for the introduction of the Artificial Intelligent Markup Language (AIML) [25] allowing the developers to define the building blocks of the agent’s knowledge. What these systems have in common is the ability to reach a large number of users in a widespread manner, interfacing with them through natural language, while relieving human operators from performing often tedious and repetitive tasks.

Within the AAL research area, in particular, a growing body of work suggests natural language interaction as the best means of interaction for users with cognitive disabilities or in general for frail people. Conversational Agents, in particular, have the potential to play an increasingly important role in health and medical care, assisting clinicians during the consultation, supporting consumers with behavior change challenges, or assisting patients and older individuals in their living environments [14].

Numerous conversational assistants have been developed for assistive tasks like social companionship for older people living alone [18], or for supporting multilingual assistance [26]. In [13] the objective of the Kompass project was to develop a virtual assistant to accompany and guide the older user throughout the day. In this project the authors have developed a conversational agent that provides a style of dialogue that allows robustness and reliability, referring to this approach as “socially cooperative dialogue”.

To address the problem of low adherence to drugs, and the increase in the cost of treatment, among patients with chronic diseases, the authors of [3] have developed a new interactive technology for self-management of drugs for patients. The system uses an automatic translation process to translate highly technical information about drugs and provide patient-friendly instructions through a CA. The results of a system evaluation show how older people responded positively to the system, also remembering messages more accurately than younger adults. These results confirm the idea that conversational agents can support the learning of older adults by also giving rise to social responses. The agent used non-verbal and verbal cues to convey the affective and cognitive meaning of the drug information. Ultimately, improving cognitive accessibility of health information through
CA-based systems should increase the self-care of older adults by increasing their acceptance of the technology.

However, creating and applying conversational agents for older users raises specific challenges. This category of users, indeed, often have selectively impaired skills, e.g. auditory perception, articulation, imposing the need to adapt the style of interaction in a personalized way, and adopting an appropriate and intelligent style of turn-taking in the conversation [28,29]. Users with motor, linguistic, and cognitive impairments, can effectively interact with voice assistants, given specific levels of residual cognitive and linguistic skills. Practical indicators can be used to predict the level of accessibility of speech-based interactive systems and designs guidelines based on the performance results observed in users with disabilities [15].

Other work has focused on real-time dialogue systems suggesting the need to consider the context of the speech, the partial and overlapping expressions or the information coming from several correlated modalities to socio-emotional aspects such as attention and engagement [16].

Overall, this brief introduction to vocal assistants for older adults shows how the characteristics to be pursued are the need to customise, to make the interaction continuous over time, and to take into account the context and dynamism of the dialogue. As a result of these considerations this article describes our work towards the realisation of a forward-looking vocal assistant which, in addition to taking the current context into consideration, allows the latter to be influenced by the execution of personalised plans, customizing the interaction on multiple dimensions. In the next section we situate our work within a simplified categorisation of current approaches to the development of conversational agents and we provide some definitions of concepts underlying the development of SAVANT, our forward-looking vocal assistant.

3 Technical Approaches to Vocal Assistants

The crucial aspect that nowadays conversational agents focus on concerns the management of the context. Context is intended as the background of the situation the agent is talking about and plays a primary role in understanding the meaning of the sentences within a dialogue or to generate appropriate responses to the users.

Depending on how the users’ input is interpreted, how the context is handled and how the responses are generated, conversational agents can be divided, in a very schematic way, into two large families which we call Pure-ML-Based, entirely relying on machine learning techniques, and Hybrid, that rely on a combination of both machine learning and other forms of reasoning. Pure-ML-Based conversational agents, sketched in Fig. 1, use large quantities of unstructured data, usually
referred to as the corpus, to train a pipeline based on recurrent and/or convolutional neural networks, resulting in a system that, without further effort from programmers or domain experts, directly interacts with users [5,10].

These approaches have been proved to be particularly effective in their very recent incarnations. They not only understand the input coming from the users, but also offer the possibility of independently building the responses to users by generating summaries and/or interpreting the text contained in the training corpus. This type of techniques is evolving rapidly [1], leading to better and better results, however, by producing answers based solely on the content of the corpus, they still remain relatively uncontrollable, making it difficult to correct any wrong system behavior. Although they have features to manage the context, such capabilities are still limited and remain an open research topic. The resulting systems suffer when in need of establishing a reasonable dialogue with the users. Their behavior is typically triggered by the initiative of the user, being the initiative from the system limited to a few cases that go little beyond questioning and answering.

The Hybrid approach to conversational agents is sketched in Fig. 2. It consists in explicitly separating the Natural Language Understanding (NLU) aspects, mostly based on machine learning, from the language production aspects, that are mostly based on different kinds of rules-based reasoning. Assistants that follows this approach are for example Google Dialogflow2, IBM Watson Assistant3, and Rasa4.

They guarantee a good level of “expert tailoring” allowing the correction of wrong behaviors. Furthermore, by rather explicitly managing the context, there are no technical difficulties in producing complex dialogues that evolve over time. The inability to autonomously generate natural language, however, translates into the need to manually define, through a significant burden for the developers, a set of rules that establish how the system, in general, reacts to interactions with users. The result is, typically, a state-transition system [9] which, in a more or less explicit way, guides the interaction with the user.

The conversational agent proposed in this paper, Savant, follows the hybrid approach. The explicit management of the context, adopted by the integration of techniques, allows, as shown in more detail in the next sections, to integrate other forms of reasoning such as, for example, semantic and planning reasoning, hence enhancing the argumentation capabilities of the assistants by providing initiative capabilities with long-term goals in mind. Although we will focus mainly on this integration, our system interfaces with state-of-the-art NLU modules, hence it is

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2 https://cloud.google.com/dialogflow.
appropriate to introduce the basic terminology and summarizing few concepts to better understand the proposed architecture. The basic distinction is the one between the *utterance*, that is anything the user says, like, for example, “I’m looking for doctor Rossi”, and its *intent* that is a characterization of the intention the user was aiming at in issuing that utterance. As an example, the intention of a user saying something like “I’m looking for doctor Rossi” to a receptionist assistant is to seek for something (namely the doctor Rossi). Each intent has its name, such as `seekSomething`, which is used for identifying and reasoning upon it.

When a user says something, the NLU module matches the utterance with the best available intent. This process is referred to as *intent recognition* or *intent classification*. Finally, *entities* are modifications to the intent such as “doctor” and “Rossi”. Similarly to intents, entities have also a type such as `thing` for “doctor” or `person` for “Rossi”.

Training data for most of the NLU systems typically consists in a set of utterances, each characterized by an intent and, possibly, a set of entities. Once trained, the system receives new utterances, not necessarily among those in the training data (e.g., “Where is doctor Rossi?”), recognizing the users’ intents and, possibly, the presence of entities (e.g., “doctor” as `thing` and “Rossi” as `person`).

Once understood what the users say, a dialogue management module takes care of selecting their answers. By typically maintaining a state-transition system, indeed, this module manages the transitions from one state (i.e., the current context) to another (i.e., the resulting context). The answers are provided to the user on the basis of the intents and the entities extracted from the NLU module while selecting.

4 SAVANT: A Forward-Looking Conversational Agent

As introduced before, we are realizing the SAVANT system, a “forward-looking” Conversational Agent which adopts the hybrid approach. In particular, our goal is to enhance a standard architecture of state-transition systems with AI modules for both semantic and planning reasoning. By adopting an approach that clearly distinguishes natural language understanding from natural language generation, SAVANT introduces the possibility of updating the context not only, through the NLU module, as a response to user utterances, but also by means of the execution of customized plans, hence guaranteeing to enlarge the look-ahead perspective (from here the “forward-looking” adjective we are using). Such perspective regards both the content of the dialogues and also the possibility for the system to take its own initiatives. Additionally, the description of the state-transition system, by the domain expert, is facilitated thanks to the introduction of a set of rules, which we call *actions*, inspired by those used in classical planning [11]. As it will soon be clear, the definition of these actions allows to specify the state-transition system implicitly, simplifying to the domain expert the formulation of the system behavior.
The different components that characterize the SAVANT system are described in Fig. 3. In particular, (a) the user’s vocal expressions are translated into text by a speech-to-text module, (b) the recognized utterance is then processed by a NLU module which extracts the key information (namely, intents and entities) on the basis of which, together with other parameters, (c) the system carries out reasoning and produces text which is finally synthesized toward the user through a text-to-speech module.

Some of the modules are created using some of the IBM Watson cloud services (i.e., Speech to Text, the NLU module of Watson Assistant and Text to Speech). This section describes the new elements developed in order to obtain the needed capabilities.

![Fig. 3. The overall SAVANT architecture.](image)

The key element of the SAVANT system for managing dialogues with humans is the context. By context we refer to a set of variables, both symbols and numbers, which characterize the current state of the state-transition system. These variables are used to keep track of all the information that, more or less dynamically, change over time. Specifically, context variables include, beside the elements of the dialogue like the intents and the entities recognized by the NLU module, all those factors which are connected to the human aspects such as, for example, those related to the user’s personality and current mood, so as to personalize the interaction and obtain dialogues that are as fluent and engaging as possible.

Past interactions with each user, indeed, are memorized and analyzed through personality insight tools in order to collect information on the user model through aspects such as the Big Five personality traits (i.e., openness to experience, conscientiousness, extraversion, agreeableness and neuroticism), and on the current mood, such as a form of sentiment analysis. This information, in particular, enriches the context by updating the corresponding variables and hence fosters the system’s personalization.

Suppose, for example, the user says something like “I’m looking for doctor Rossi”. Starting from this utterance, SAVANT asks to the NLU module for the
user’s intent and for the presence of any entities, assigning to the \textit{intent} context variable the \#ask value, to the \textit{thing} context variable the “doctor” value and to the \textit{person} context variable the “Rossi” value, effectively making an uncontrollable, since it depends from what the user says, transition in the state machine. At this stage \textsc{Savant} should produce a contextualized answer for the user. The responses, in particular, are produced through the execution of specific actions which are defined for the current AAL domain. Each action, in particular, is characterized by three elements: (a) a logical combination (i.e., conjunctions and/or disjunctions) of constraints on the context variables representing the executability \textit{condition} of the action; (b) a set of sentences representing the system’s responses for the users (if the set contains more than one sentence, one is chosen randomly); and (c) a set of \textit{effects} on the context variables, representing the updates to apply on both symbolic and numeric context variables whenever the action is executed. Each action whose conditions are verified in the current context is said to be \textit{executable}. Whenever asked to the system, for example as a consequence of the interactions from a user, all executable actions are executed in the order they are defined by the domain author. The presence of such actions, indeed, is intended both to establish which responses to provide to the users and to make further transitions in the state space by means of their effects updating, for example, some context variables on the current discussion topic.

Through the combined management of context and actions, as an example, it is possible to administer dialogues, very common in daily conversations, in which, implicit subjects are present. The user, indeed, could ask about Dr. Rossi to a receptionist agent which, in turn, would respond giving indications on the location of his office. If, at this point, the user asks for information about his reception hours through an utterance like “when does he receive?”, the NLU module would perfectly recognizes the user’s intent to know the reception hours but would have no information relating to the subject to which the user refers. The introduction of a “topic” context variable, and its assignment with the value “Dr. Rossi” coming from the \textit{person} intent would resolve the ambiguity. Studying and predicting these possible anomalies within the daily speech, we design and build the dialogue as the system can understand the implied subject of the sentence, giving an appropriate response to the user. The prediction of these linguistic behaviors is crucial to achieve the most natural interaction between the robot and the user.

The system, as described so far, is only endowed with reactive capabilities, effectively implementing a \textit{policy} $\pi(\text{ctx}) = a$ that dynamically reacts to possible changes in context variables. By exploiting further some domain knowledge, however, the system is nonetheless able to use the predictive capabilities offered by the semantic and planning reasoner. This is done as depicted in Fig. 4, \textsc{Savant} realizes \textit{knowledge abstraction} and \textit{goal recognition} by adopting KOaLa (\textit{Knowledge-based cOntinuous Loop}), an ontology-based cognitive system also applied to domestic assistance \cite{23,24}. In particular, through the definition of a set of rules based on first order logic, a set of facts and a set of goals to achieve, KOaLa is able to generate plans over time which, if executed, lead to the
achievement of the set goals. Within Savant, specifically, starting from the actual user’s profile characterized, for our current purposes, by an ICF classification\(^5\), and by some rehabilitation goals specified by a healthcare professional, Koala produces a personalized timed path that leads the user to the achievement of the specified rehabilitation goals [8, 24]. The execution of the generated plan, however, does not directly translate into the execution of the planned stimuli but, through a sort of *intrinsic motivation* signals [19], results in the assignment, in due course, of additional values to particular context variables, triggering the execution of the executable actions and, ultimately, further influencing the behavior of the system.

One of the many possible uses we make of this integration, in particular, consists in planning personalized cognitive exercises. The execution of these plans, specifically, triggers at proper time, according to the users’ preferences and on the rehabilitation constraints, the policy, proposing rehabilitation exercises to the users which are customized to their needs. The integration of the reactive skills from the policy with the predictive capabilities from the semantic and planning reasoning, finally, endows the Savant system with a good adaptability to unpredictable events (as in the case of possible questions from users) while still pursuing the rehabilitation goals.

5 Generating Socially-Aware Dialogues

A preliminary dialogue configuration interface has been developed for continuously strengthening and testing the AI system’s capabilities, facilitating the process of building a context aware dialogue. Thanks to this application, indeed, it is possible to define the actions that characterize the pursuance of the dialogue, while testing and adapting the response to particular contexts or to specific users’ personalities and needs.

In order to categorize and recognize the users’ thoughts, words and speech choices, a set of training data for classifying intents and entities, covering a large part of our interest cases, has been collected and fed to the NLU module. Thanks to this ability, in particular, Savant is able to listen and understand the users’ requests and to analyze their behavior. Exploiting the generalization capabilities, indeed, the system is able to recognize synonymous and constructive sentences commonly used in the verbal conversation. Additionally, based on the context, characterized by a combination of different elements and variables, such as intents, entities, numeric or sentimental variables, the interface allows to construct and refine the actions that characterize the flow of the dialogue.

\(^5\) https://www.who.int/classifications/icf.
By combining these elements it is possible to tailor the appropriate responses to the specific users’ attitudes and needs.

Although the proposed approach is, in general, independent of the domain, we are situated in an AAL context and, in particular, in ensuring continuous assistance to elderly patients with specific needs as well as in providing general information in sanitary and health facilities, such as at reception or information points. Exploring a variety of possible scenarios and situations, Savant aims at producing a fluent and natural interaction between the CA and the user. The focus on the conversational elements, in particular, is key in the process of building dialogue systems that exhibit and evoke spontaneous behaviors for patients. The main aim, indeed, is not only to create a conversation between the CA and the user, but also to suggest a feeling of confidence for the patient to facilitate the exchange of personal and emotional information with the expectation of acknowledgement, empathy and sympathy in response.

The System at Work. To test the Savant’s responses, two different scenarios have been isolated. By adapting social strategies, in particular, we aim at enforcing a link between the user and the CA, improving the efficacy and the performance of their collaboration. Thus, we strive to delve into these social and semantic strategies and to enhance the automatic recognition of these conversational strategies. The research on the capability of a natural language module is crucial to capture user’s personal goals and input. The NLU module, in particular, is trained so as to categorize, by means of intents and entities, concepts, keywords, categories, feelings and semantic roles. Categorizing user’s needs and their questions allows us to build a natural and fluent dialogue, based on specific actions, predicting as many user’s behavior as possible in various contexts and situations.

The first scenario focuses on the reception and information point in a hospital setting. The receptionist CA, in particular, responds to people who ask for information about doctors and/or patients, customizing responses according to the users’ sentiment analysis. Stimulating a more fluent and natural communication, the aim is to apply a “sentiment analysis” to the CA. In addition to a response based on the personality, in particular, the CA seeks a personal adaptation responding to the emotional state of the person. For this purpose, sentiment analysis estimates and classifies sentences, opinions and emotions of the users, monitoring user’s attitudes and expressions. This aspect is crucial since it allows building a dialogue with a natural and fluent flow. In order to do so, we are mostly focusing on two opposite poles of the sentiment analysis: the
negative and positive dimensions. Whether positive or negative, the direction of the expression refers to a semantic orientation of what the user is saying and how is behaving. Analyzing inputs during the dialogue, the conversational agent is able to understand what is the orientation of the user and personal attitudes. Once the CA understands the orientation and the grade of the sentiment, it will reply with an adequate and fluent language, adapting the style of the response to the current detected sentiment of the user. Whenever the user asks information with rush and with an angry attitude, for example, the CA will reply using a language able to give the information and drive the response of the user to a positive way.

An example of interaction for this scenario is shown in Fig. 5. After an initial welcome message from the CA, the user asks for information about the restaurant. Suppose the user makes this request through a sentence with a positive attitude like, for example, “I am hungry and I have some spare time. Is there any restaurant inside the hospital by any chance?”, the NLU module recognizes the \#ask intent and an entity @thing assuming the value “restaurant”. Since the utterance has a positive sentiment (i.e., in the figure, the value of the Sentiment context variable assumes a value which is greater or equal then 0), SAVANT answers with the text contained within the balloon $n_2$. If, however, the user had made the same request in a more aggressive way, for example through the utterance “I am starving and I can’t find anything within this hospital! Is it possible there is no restaurant here?”, the NLU module would still recognize the same intent and entity but the sentiment analysis would assign a negative value to the Sentiment context variable diverting the speech towards the $n_1$ balloon. Furthermore, both actions would have assigned the “restaurant” value to the topic context variable, so as to allow the user to interact in a natural way without having to re-specify the topic of the discussion in subsequent interactions. The user could ask, for example, “Where is it?” and, on the basis of the current context variables, SAVANT would recognize the user is still referring to the restaurant and answer with the content of the $n_4$ balloon.

In the second scenario a set of personalized cognitive exercises, selected taking into account the disabilities of the users emerging from the ICF classification, is administered, at different times, to the user. Among other things, however, the system’s responses are customized according to the users’ extraversion. Within this scenario, indeed, the analysis of personality models is crucial and necessary to create a deeper connection between the robot and user. Especially exploring the Big Five personality model, it was possible to test and improve the interaction between the user and the robot stimulating the patient’s performance in the execution of the exercises. Although the Big Five includes five primary personality dimensions and, for this reason, the model is widely used to generally describe how a subject engages with the world, the scenario mainly focuses on the extraversion dimension, including the opposite introverted tendency, as the most suitable for the role of the coach during the “game”. Thus, based on this psycholinguistic analysis, different interactions and linguistic styles are associated to different personality characteristics. With the use of this extraversion
variable, SAVANT aims at a more effective and suitable interaction based on the user’s habits, seeking for a different style and interaction responses for the patients. For example, the extraverted linguistic style requires a more engaging and fast response, with a wider use of vocabulary and inclusive words. Whilst, the introverted style demands a more concrete and precise language with more articles and quantifications compere to the extroverted style. This second robot style contains more exclusive words and negations (such as but, excepts, not or no) and less inclusive words (e.g. and, with) suggesting the attention to their discretion in assimilating information.

An example of cognitive exercise initiated by the system is shown in Fig. 6. This type of dialogue, specifically, is initiated by the planner who, through the execution of a personalized plan, establishes at a certain point that it is proper time for the user to carry out a specific cognitive exercise. The “Find the word” exercise, in particular, consists in sending a series of words while asking to pay attention to one specific word. At the end of the list, SAVANT asks to the user how many times the target word has been said. When planned by KOaLa, the robot starts a conversation by introducing the exercise. The user answers, for example, with a sentence like “OK, let’s start!” which is recognized by the intent recognition module as an #ok intent. At this point, the dialogue engine assigns the value $n_2$ to the node context variable and provides the user with a description of the exercise. It is worth noting that the planner could not predict the user’s response and, therefore, could not include it in the initial plan. In the absence of the dialogue-based assistance module, in particular, the reaction to the user’s response would have required a potentially expensive adaptation of the plan. At this point, the user answers affirmatively and the exercise continues with the robot listing a set of words to the user and asking him how many occurrences there are of a specific word (in the example, “ball”).

The interesting aspect is that the responses that the dialogue-based assistance module provides to the user might depend on various factors that characterize the context. In particular, in the case of an incorrect answer, the system can respond more reassuringly, in case of an introverted person (i.e., the value of the Extroversion context variable assumes a value which is less than 0.5), or in a
more challenging way, in case of a more extroverted person (i.e., the Extroversion context variable value is greater than 0.5). Note that the cognitive exercises, synthesized by the planner, are already tailored to the characteristics of the users. In case of excessive inconsistencies and discontinuity of the logical flow by the elders, however, the control can return to KOaLa which, taking into account the new information emerging from the interaction, either adapts the current plan or generates a new plan from scratch.

Through this example, it has been demonstrated the capability of the developed system to administer customized training programs which can change adapting to occurring situations. Basically, starting from a tailored configuration of the training plans, through the verbal interaction with the user, the robot has been able to change the plans execution in order to adapt to the user’s contingent needs with the ultimate goal of completing the exercise by maintaining the user engaged.

Finally, it is worth noticing that the handling of understanding problems on the user’s need or language choices represents a crucial aspect. The cooperation between the user and Savant is required in order to avoid any misunderstanding or mistakes. Indeed, in case the system does not recognize the linguistic behavior or the speech choices, it will ask to the user to rephrase the question, replying with something like “Sorry, could you repeat with other words what you need?” or “Sorry I don’t understand what you are looking for, could you please rephrase it for me?”. On this way, the system is able to handle and manage the misunderstandings without the user noticing it or the conversation being interrupted.

6 Conclusions

This paper addresses the problem of synthesizing a conversational assistant to support an older person during is daily life. The system is currently being integrated on a robotic platform as an additional feature for the robotic capabilities, indeed the Savant service is designed so as to be used also on a stand-alone software application or on a mobile app.

We have described here how Savant follows a hybrid strategy for CAs and in particular for the NL generation phase we have used our own pipeline composed by a semantic reasoner and two different planning reasoners plus the Watson NLU, speech-to-text and text-to-speech functionalities. We have exemplified the system at work on two scenarios that are relevant use cases in one of our current projects.

Although further work is underway, the paper represent well the work performed to realize a forward-looking vocal assistant, endowed with flexible and adaptive dialogue-based interactions, while taking advantage of predictive planning skills. Our current general aim is to support cognitive rehabilitation in elderly users. When the NL coverage will be consistent enough we plan to realize an experimentation with actual users.
References

Design and Development of a Telepresence and Monitoring Service to Empower the Older Adults

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Abstract. Older people would like to live independently for as long as possible. However, seniors may experience cognitive and physical problems which could have a great impact on their autonomy and their quality of life. Over the last years, several national and European projects were founded to design, develop, and test reliable solutions to support the life of the older population. In this context, Information and Communication Technologies (ICTs), such as robots, could represent a valid solution to empower older people. Inspired by the current trends, this paper presents the design and the development of a telepresence and monitoring service to foster active aging. The proposed approach is based on a human-centered design which leads to the definitions of the services through the focus groups and the survey conducted within social cooperatives. Based on these results, a cloud system composed of environmental sensors and a telepresence robot was developed and tested in private homes and residential facilities without the presence of any external support. The results underline a positive attitude of the senior citizens such as the caregivers involved in the services. The telepresence robot demonstrates high reliability and it was used for more than 100 calls during the experimentation phase. During this experience, we collected and grouped multidisciplinary guidelines and feedbacks which we report in this paper as guidelines for future researchers.

Keywords: Telepresence service · Environmental monitoring · Human center design · Active aging

1 Introduction

With age, the seniors are more prone to illness and disability, in fact around 51% of the older people in Tuscany declare to suffer from a chronic or long-term illness \cite{1}. One of

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the major problems of aging is the decline of cognitive abilities and physical capabilities that entails the need to receive assistance, temporary or continuous, from a caregiver, represented by a family member or by a health and social worker. As highlighted in [2–4], the physical environment is a main determinant for the individual, becoming of particular and fundamental importance for those who are aging. However, the presence of older people at home greatly increases the risk of injuries such as falls or other domestic accidents [5–7]. Furthermore, it increases the likelihood of incurring problems with isolation or depression and loneliness [8].

This condition often requires that the older persons should move from their home to the nursing home, radically changing their everyday life, both from a practical-organizational point of view and from a psychological-relational point of view. Moving from home to the nursing home allows older persons to improve their health care and socialization. However, the biggest problems occurring in the nursing home care due to nightfalls in the absence of the operators [9], to the older persons moving away from the nursing home or losing themselves within the building [10, 11]. This context sets up new challenges for the design of environments, products, and services to support the older population [12], whether independent or in need of assistance by the family members or health and social workers.

The product-service system has the function of helping social and health operators in providing the main services, such as management of therapies, both cognitive and physical rehabilitation activities, recreational activities, health status monitoring, walking inside the residences. Recent trends in smart environment research for Ambient Assisted Living (AAL) [4, 13] include the possibility of integrating wireless sensor networks, robots, and wearable technologies in the domestic environment, to facilitate procedures for monitoring the state of health of the elderly, management of drugs and control of environmental conditions by social health professionals.

The challenge and the main purpose of our current research concern the development and the testing of robotic and social services in the cloud for the support of fragile and non-self-sufficient people within the nursing home and at home. The objective of our project is the development, integration, and evaluation of innovative solutions using a Service Cloud Solution model aimed to improve the quality of life and independence of the older persons and to support the activities of coordinators, managers, and social health professionals (i.e. social health workers, caregivers, nurses, and therapists) in three different contexts: nursing home, healthcare assistance residence for people with disabilities, and home care.

In this context, the paper presents the design and the development of a telepresence and monitoring service to empower older adults. The proposed solution applies the methodological approach of Human-Centred Design (HCD) and Ergonomics in Design for the home care sector and it is divided into four main phases:

- **Needs Study**: it aims at identifying the service to be implemented together with the end-users. In this paper, two different approaches were used, namely, focus groups and questionnaires. These data were analyzed and the final scenarios were identified. In this paper, the outcome of this phase focused on the telepresence and monitoring scenario.
• **Development phase:** based on the scenario and the requirements, the system components and architecture were designed and implemented.

• **Feasibility study:** the solutions were then tested in a real environment. Specifically, the telepresence service and the environmental monitoring presented in this paper have experimented in real houses and residential facilities. Additionally, the main findings were summarized.

• **Lesson learned:** the results and feedback acquired during the previous phases of the work were clustered into groups and presented as guidelines for future projects in this field.

The paper aims at detailing each phase and at reporting the main finding achieved to provide a complete case study of design a solution in the AAL field with a bottom-up approach. Indeed, it presents the solution from the conceptualization to the experimentation phase highlighting the barriers and the limitations found out during the field test. The remaining of the paper is structured as follows: Sect. 2 summarizes the needs study; Sect. 3 details the architecture and the system components; Sect. 4 presents the feasibility study and Sect. 5 concludes the work highlighting the lesson learned.

### 2 Needs Study

The international standard ISO 9241-210:2010 [14] defines Human-Centred Design as an approach addressed for the design and development of systems aimed to ensure interactive systems to be more useable by applying Human Factors/Ergonomics (HF/E) and the usability knowledge and techniques.

The methodological approach of Ergonomics in Design is a holistic approach for the design and evaluation of the interaction between the person (meant as operator or user) and the elements of the system in which he/she works. According to the definition established by IEA (International Ergonomics Association), Ergonomics is “the scientific branch of knowledge that studies the interaction between humans and other elements of a system throughout the execution of a specific activity” [15].

Ergonomics in Design pays close attention to humans, to their needs and expectations (Human-Centred Design), and the ways through which they relate – or interact – with objects, spaces, systems or services with and into which they conduct working or daily activities, evaluating different dimensions of this relation (physical, perceptual, cognitive, emotional) and considering their variability depending on various contexts and their mutual influence (Usability Evaluation, User Experience). As stated by Wilson (1995), participatory ergonomics involves people in planning and control because they have enough knowledge and power to influence both processes and outcomes to achieve desirable goals [16].

At present, surveys have been carried out to collect and assess the needs and expectations of older adults and social health professionals. Moreover, the assessments of the activities performed by the users of the new product-service and by the social health professionals have been carried out. The following methods were used: focus group and questionnaire.
2.1 Focus Group with Social Cooperative

The focus group is an investigative method, used in participatory ergonomics [17], which is useful to collect opinions and experiences from the participants, based on a discussion among a group of people, with the presence of moderators and focused on a specific topic [18, 19]. Five semi-structured focus groups [19, 20] were carried out at different times (one for social cooperative). They allowed participants to add more comments to other participants’ opinions. The semi-structured nature of the open questions, typical of exploratory research, allowed researchers/moderators to investigate the perspectives of the social health professional interviewed.

During the one-hour meetings, the attendees (managers and social health professionals) were asked questions about their work activities at the nursing home and elderly’s home, about the tools commonly used for work management, and about the improvements needed to make health care more efficient. At the end of the focus groups, the data were collected and processed in a summary document, common to all social cooperatives, named “Desiderata” (see Table 1).

<table>
<thead>
<tr>
<th>Needs</th>
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<tbody>
<tr>
<td>1. Monitoring, management, and environmental safety 24/7</td>
</tr>
<tr>
<td>2. Psycho-physical state monitoring and management</td>
</tr>
<tr>
<td>3. Socializing</td>
</tr>
<tr>
<td>4. Management and monitoring drugs intake</td>
</tr>
</tbody>
</table>

Subsequently, the collected data were analyzed and the 3 intervention scenarios were defined as follows:

- Scenario 1: environmental monitoring and telepresence by using commercial solutions, with the aim of night and daytime 24/7 surveillance, socialization, and remote presence of the older person;
- Scenario 2: design and development of a new robotic platform aimed to promote the socialization among users, to assess and monitor the emotional and cognitive state of the seniors, and finally to promote and improve the hydration and drugs intake;
- Scenario 3: design and development of wearable devices aimed to monitor the older person’s sleep and finally to support social health professionals in controlling operations.

2.2 Questionnaires

To corroborate the previous analysis, an online questionnaire was administered to collect feedback on services also including other relevant actors (i.e. technicians, managers, social operators) from other cooperatives of the Tuscany Region. Particularly, they were asked to answer the following questions:
1. *Do you think that technology could be useful for your work?* They had to rate the answer on a 5-point-Likert scale (Strongly disagree – Strongly Agree).

2. *Select the services that could be useful for the social cooperative you are working in (max 3 votes).* The listed services were: cognitive stimulation, social inclusion, remote monitoring, monitoring of physiological parameters, management of drugs, monitoring of chronic diseases, environmental cleaning and disinfection, food delivery, open/close door monitoring, communication with family, fall prevention, support during rehabilitation, communication with other actors of the care-chain, identification and management of the emergency, and nighttime monitoring.

A total of 32 respondents participated in this questionnaire and agreed to share the results for scientific research. Eighteen subjects were between 30 and 45 years old, 9 subjects between 46 and 55 years old, and 5 between 56 and 65 years old.

As regards question number 1, the average response was equal to 4.44, so the respondents agree and strongly agree that technology could support their work. Results from the second question were aggregated to identify the domains in which technology could play a fundamental role. Particularly, by clustering the services based on the application context, five domains were identified: communication, environmental monitoring, health monitoring, therapy support, and daily task support. Communication group included the following services: social inclusion, communication with family, communication with other actors of the care-chain. While the environmental monitoring included the services related to open/close door monitoring, fall prevention, remote monitoring, identification of risks, and nighttime monitoring; the health monitoring services were monitoring of physiological parameters, and monitoring of chronic diseases. The services belonging to daily task support were environmental cleaning and disinfection, and food delivery. The rest of the services was included in the therapy support group (i.e. management of drugs, support during rehabilitation, and identification and management of emergency). Figure 1 reports the results.

These results underline a positive attitude of the social operators toward technology which is important to promote and use technology in a real environment. It is also to mention that two out of the three most voted domains (i.e. environmental monitoring, health monitoring, and therapy support) confirmed the services highlighted in the previous section. Indeed, these are the domains where social cooperatives see a future for technology in their work. In this article, we focused on the implementation of scenario 1.

### 2.3 Service Definition

According to the results achieved with the HCD approach, the proposed scenarios were implemented. Table 2 and Table 3 present two possible examples of applicative scenarios (environmental monitoring and telepresence service), showing the service scheduling and the role of the agents of the implemented system.

In a future implementation, these two scenarios could be combined. As an example, if the caregiver receives an alert, he/she could activate the telepresence robot to check the alert and to talk to the end-user.
Fig. 1. Aggregate results for the question “Select the service that could be useful for the social cooperative you are working in”.

Table 2. Environmental Monitoring Scenario

<table>
<thead>
<tr>
<th>Actor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental sensor network</td>
<td>The environmental sensors continually send raw data to the database</td>
</tr>
<tr>
<td>Caregiver</td>
<td>The authorized caregivers, after authentication, access the webpage of the users to monitor the event occurrence</td>
</tr>
<tr>
<td>Alert &amp; Monitoring Module</td>
<td>This module autonomously analyses the environmental data to check for abnormal situations. In the case of a critical situation, the information on environmental status will be updated and alert service is triggered</td>
</tr>
<tr>
<td>Caregiver</td>
<td>The caregiver is informed of the critical situation through a pop-up on the interface or e-mail</td>
</tr>
</tbody>
</table>

Table 3. Telepresence scenario

<table>
<thead>
<tr>
<th>Actor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caregiver</td>
<td>After authentication on the portal, the caregiver will connect to the robot</td>
</tr>
<tr>
<td>Robot</td>
<td>The robot will be activated for the telepresence service</td>
</tr>
<tr>
<td>End-user</td>
<td>If the end-user agrees, the end-user will accept the incoming call and starts to talk to the caregiver</td>
</tr>
<tr>
<td>Caregiver</td>
<td>If necessary, the caregiver could move into the environment by using a joystick</td>
</tr>
</tbody>
</table>
3 System Description

The results of the evaluation phase allowed to define the objectives of scenario 1, namely (1) definition of the system architecture; (2) selection of sensors and telepresence robot; and (3) the design and implementation of a new digital interface for tablets.

3.1 System Architecture

The proposed system architecture was designed to be scalable and adaptable either in a private home or in a nursing home. As for the hardware components, the developed system is composed of a wide range of heterogeneous technologies. Namely, the system includes one commercial robotic platform and a ZigBee network of environmental sensors. The hardware was selected to accomplish the needs analysis described in the previous paragraph.

In this work, the software agents are developed based on the Cloud paradigm. As shown in Fig. 2, the Cloud solution guarantees an efficient communication between the heterogeneous hardware’s agents as well as a greater computational ability to analyze the data in real-time. In detail, the proposed system includes the following cloud resources: (1) a Database and the Database Management Service, (2) the alarm module, and (3) the user interface. While the first Cloud element is essential to collect sensory data, the alarm module is responsible to detect abnormal events occurring in the house, and to ensure the continuous monitoring of the older person. The user interface stored on the Cloud Platform is designed to facilitate and optimize the workflow of social health professionals. It provides for the visualization of the data. Thanks to several alarms and pop-ups, ad hoc designed and developed, it will be possible for operators to monitor the activities of the older persons (See Sect. 3.3). The following paragraphs detail the system components and the related design choices.

3.2 Agents

**Double Robot.** This work exploits the usage of a commercial robotics platform in real houses. The Double robot is a telepresence robot produced by Double Robotics (Burlingame, California). It is a two-wheeled robot that can be teleoperated in the environment. On top of its structure, it mounts an iPad (Apple, California), which the face of the remote user is displayed during the telepresence service. The robot and the iPad are connected through Bluetooth technology. By using the robot, the caregiver could remotely visit the user’s home, interacting and navigating in the environment, almost as if she/he was there in person.

**Environmental Sensors.** The proposed system provides for the installation of environmental sensors produced by Cleode (Lannion, France). They have been chosen after market research, as they met the usability and cost requirements of end-users. The environmental sensors are integrated within a ZigBee network. Namely, they send data to a USB dongle connected to the PC. On the PC, proprietary software (i.e. CleoBee) was installed to manage the sensor connection and the data transmission. The hardware components of the sensors’ network were grouped into a kit. According to the need study,
Fig. 2. System Architecture which includes the hardware agents (environmental sensor network and Double robot) and the software agents (the database, the alerts and monitoring module, and the user interface).

The following sensors were included in the kit: switch sensors, PIR sensor for motion detector, and temperature sensors. The complete list of installed sensors is reported in Table 4. Thanks to its ease of installation, the kit can be used in nursing homes, healthcare assistance residences for people with disabilities, and at home.

Table 4. List of environmental sensors included in the network.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinator</td>
<td>It’s the coordinator of ZigBee Network with an amplified signal up to +20 dBm</td>
</tr>
<tr>
<td>Switch Sensor</td>
<td>Detects intrusion with a magnet and reed-switch mechanism that reports an alarm during unauthorized entry by door or window</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>It’s a temperature sensor. It measures the temperature of the room where it is installed</td>
</tr>
<tr>
<td>PIR Sensor</td>
<td>It’s a wireless PIR motion detector. It measures the movement detected in the operative zone</td>
</tr>
<tr>
<td>Smart Plug</td>
<td>ZPlug Boost is a wireless Power Outlet that can be switched On/Off by Zigbee protocol. It measures the instantaneous power and cumulated consumption of the connected device. Additionally, it amplifies the signal and connects the other sensor with the coordinator</td>
</tr>
</tbody>
</table>
3.3 Cloud Platform

**Database and Database Management Service.** The cloud service stores all the environmental information and manages the accesses to its resources. It consists of a MySQL relational database (DB) and a database Management Service (DBMS). The DBMS manages all the DB entries and queries ensuring privacy and data security. A relational database is a collection of data items among where exist predefined relationships. In the proposed system, the DB is composed of several tables (see Fig. 3): one for each observation of the sensor outputs (Reportslog), one containing the list of installed sensors (Devices), one containing the list of users (Users) and another table contains the sensors associated to the users (Sensors_Associated). Each row can be marked with a unique identifier called the primary key; the rows of different tables are correlated using foreign keys. These data can be accessed in many ways without reorganizing the database tables.

![Fig. 3. Relationships between tables of the environmental monitoring service.](image)

**Alert Management and Monitoring.** The software module monitors the home status during all-day recording and saving data in the DB. From the alert page, the last 10 alerts for each installed sensor can be visualized to monitoring the users.

The web interface alerts caregivers in the case of critical situations, thanks to blinking led (red = alert; green = no alert). The blinking led is activated by the DBMS queries on the Reportslog table from DB every 5 s to read the possible changes of the status of the environmental sensors and monitoring the user’s activities. As an example, the social operators can monitor the movement of the user over the night, the temperature in the room, and the opening status of the door and windows over the times of the days (Table 5). Thus, the implemented alarms are:

- **Open/Close windows and doors management:** this alarm occurs when the user opens or closes the door of the room or the doors of the bathroom during the night (23:00 - 06:00)
- **Movements detected by the specific PIR sensors:** this alarm occurs when the user moves into the rooms during the night (23:00 - 06:00)
Table 5. Segmentation of day-time (24 h) into time segments (Times of the Day) according to [21].

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time of the Day (ToD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Time</td>
<td>23:00–5:59</td>
</tr>
<tr>
<td>Early Morning</td>
<td>6:00–9:59</td>
</tr>
<tr>
<td>Late Morning</td>
<td>10:00–11:59</td>
</tr>
<tr>
<td>Early Afternoon</td>
<td>12:00–13:59</td>
</tr>
<tr>
<td>Afternoon</td>
<td>14:00–16:59</td>
</tr>
<tr>
<td>Evening</td>
<td>17:00–19:59</td>
</tr>
<tr>
<td>Late Evening</td>
<td>20:00–22:59</td>
</tr>
</tbody>
</table>

– Temperature management: this alarm occurs when the temperature exceeds 27 °C during the day.

**Double Robot Interface.** Double robotics provides a dedicated web interface to tele-operate the Double robot. On the remote side, the caregiver first needs to authenticate (with username and password) on the Double website. When the authentication is verified, the list of available Doubles accessible by the caregiver is shown. By selecting the robot in the house of interest, the caregiver can start interacting with the user in his home. Thanks to the Ipad cameras, the caregiver can see the environment and move around. To improve the interaction, from the web interface, the caregiver can adjust the height of the robot. Furthermore, by clicking on the iPad screen, the user can end the calls by pressing the corresponding button.

**User Interface.** The graphic user interface (GUI) project involved the design and development of system architecture and wireframe based on the 10 usability heuristics for user interface design developed by Nielsen [22] and the principles of Interaction Design [23].

The interface includes a login home page, dedicated to the social health professionals of the cooperative. Once logged in, the complete list of guests of the nursing home is accessible. For each of them, it is possible to effectively identify any alarms or emergencies, indicated, depending on the urgency, in a color ranging from green to red (Fig. 4a). It is also possible to view the older person’s photo, guest’s number, room, and any information or notes. By selecting the individual user, it is possible to access personal information and specific health data.

The menu on the left directs the user to the three specific macro-areas: environment, health, and drug management (Fig. 4b). Each area allows the visualization and management of guests’ data. The information shown on the interface is directly derived from the data stored on the database. Namely, the web application is connected directly to the DB on the same remote server with a public static IP, and the access is restricted to authorized people only. In this paper, we only report the environment section (Fig. 4b).
The environment section has the main function of monitoring the safety of the nursing home. It provides the monitoring of the room of the single guest (e.g. by mean of recorded temperature values), through the detection of the opening/closing of doors and windows, extrapolated by the installed PIR status. Also, in the home page section, near the users’ photo, there is an indicator light (Fig. 4a). The light blinks red in case of an alarm situation, otherwise it remains green. If there is no indicator light, it means that there are no sensors in that user’s room. By clicking on the indicator light, a web page is shown to the caregiver. This page represents a summary page showing tables (Fig. 4c) with the latest events detected by all the environmental sensors related to the room occupied by the selected guest. The Web digital interface has been developed with HTML and Javascript languages and the PHP language is used to manage DB entries and queries.

4 Feasibility Study

This section introduced two studies that we conducted in private homes to test the environmental monitoring (Sect. 4.1) and the telepresence service (Sect. 4.2). At the end of the trials, we had an informal discussion with the managers of the involved social cooperative to highlights the strength and weaknesses of the proposed study from their point of view (Sect. 4.3).

4.1 Environmental Monitoring Service

Description. The domiciliary assistance based on the environmental monitoring service was performed in two real houses. To achieve it, a technician installed a dedicated kit, composed of environmental sensors described in Sect. 3.2. The kit’s set up in the 2 houses is described in Table 6. A PC with a Wi-Fi module was installed in each experimental site to gather the sensor outputs. In this implementation, this PC runs a WAMP server [24] where the DB, DBMS, and the interfaces were installed. In the experimental setting, the cloud solution could not be used for privacy reasons (Fig. 5).

During 30 days, the user was free to live in his home with the installed system. Remotely, the caregivers could monitor the users’ activities through the interface installed on the local server (by using TeamViewer), receiving the information on movements during the day, and, in case, the alerts during the night. While testing the service, the caregivers were requested to write a diary, annotating their own experience with the web interface and the environmental sensors. Particularly, they were requested to rate: i) the usability of the service, ii) the potential usability of the service in their work, iii) the system errors, and any anomalies detected in the user’s behavior (e.g. wake-up during the night).

Caregivers’ feedbacks are used in this work to evaluate the robustness and easiness of the service, whereas the data collected from the sensors were used to estimate the activity of the end-users over the weeks.

Results. In this study, we considered different ways of segmenting the data to explore the users’ behavior over time, without focusing on a specific activity. Particularly, the
Fig. 4. The graphic user interface: (a) Home Page with the list of the people involved in experimentation; (b) The environmental management page; (c) The alarm page.
Fig. 5. Environmental monitoring service architecture used in the feasibility study.

Table 6. Description of the 2 kit configurations.

<table>
<thead>
<tr>
<th></th>
<th>Environment #1</th>
<th>Environment #2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N° of Sensors</td>
<td>Location</td>
</tr>
<tr>
<td>PC (Server)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Coordinator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Switch Sensor</td>
<td>2</td>
<td>Door Entrance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Window living</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>1</td>
<td>Bedroom</td>
</tr>
<tr>
<td>PIR Sensor</td>
<td>5</td>
<td>Entrance –</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bedroom - Living</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Room – Bathroom-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kitchen</td>
</tr>
<tr>
<td>Smart Plug</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

busyness metric [25] was used. This metric evaluates the users’ behavior by counting the sensor’s events that occurred at different times of the day, namely “Times of the Day” (ToD), reported in Table 5. The PIR motion sensors were used to capture the busyness in a specific room during a ToD period. In this work, we considered only the PIRs installed in the bedroom, bathroom, entrance, kitchen, and living room. As concern the results, Fig. 6 reports the average busyness computed over 1 week for each ToD and the selected rooms. As shown, during the morning the user spent a lot of time in the bathroom (red line), and during the night there is no movement in the house, in fact from 11 pm to 6 am the user used to sleep.

As for the qualitative data collected from the caregiver feedback, he/she highlights the easy installation of the sensors, but they also pointed out more sensor adaptability to all types of internal or external windows and doors. Since they have not a soft surface, in some types of old doors they can easily fall.

Future studies will analyze the collected busyness data to analyze the behavior of the users to identify anomalies since they could be symptoms of mental disorders or
cognitive declines [26, 27]. However, that data analytics required a large dataset full of real data. One week of monitoring is not enough to achieve such a goal, more data was requested to train the algorithms.

Fig. 6. Average PIR sensors busyness over the ToD computed for a week.

4.2 Telepresence Service

Description. As for the evaluation of the telepresence service, the Double robot was used as part of the domiciliary assistance provided by the social cooperatives in 12 real houses. Over 10 days, the user was free to interact with the Double robot as he/she wanted. As part of the experimentation, the caregiver video-called the participant by using the robot every day in a fixed time-slot (i.e. before lunch, early morning, after lunch). This design choice was introduced in order not to interfere with the daily life of elderly users.

During this trial, both the caregiver and the primary used wrote a diary, annotating their own experience with the robot. Particularly, their feedbacks are used in this work to evaluate the robustness of the service. The metrics used in the evaluation are the total number and the duration of the performed calls, the communication clarity (CCCL) perceived by the caregiver, the quality of communication perceived by the user (ECCL), and the perceived psychological distance of the caregiver during the communication (DPSY). All scores were rated on a scale of 5 points where 1 means absence, 4 means high, and 5 means (“I don’t know”). Indeed, at the beginning and the end of the trial, the users had to rate the expectation, usability, and acceptability domains using two ad-hoc questionnaires [28, 29].

Results. In total, 119 video calls have been performed by using the robot. The total duration of the telepresence’s services has been equal to 3201 min, with an average
duration of 28.94 min for each video call. Figure 7 shows the total duration of service for each user.

The feedbacks analysis is performed on 11 users, due to missing reports about PR10’s trial. From the caregiver’s reports, the CCCL was rated as “High” by 8 caregivers, “Good” by 2 caregivers, and “Low” by 1 caregiver. Related to the primary users’ feedback, 7 users rated as “High” the ECCL and 4 users rated it as “Medium”. As concern the DPSY, 3 subjects rated the experience as “High”, 3 as “Medium”, 2 subjects rated it as “Low/Absence”, whereas 3 subjects did not have a clear opinion. The positive trends underlined by the caregivers’ reports are mostly confirmed by the users’ comments. This result shows that the proposed system is characterized by a high level of technical reliability and robustness.

As for the evaluation of the expectation, the acceptability, and the usability, the results underline that the positive expectation had an impact on the real use of the robot. Indeed, after the use of the robot, older participants significantly changed their minds showing a generally positive trend regarding usability and acceptability. The full results are reported in [30].

![Fig. 7. The total duration of videocalls for each user.](image)

4.3 Remarks from Informal Interviews

Telepresence service is a useful service that could support older adults and their families. Nevertheless, they need to be educated about technology since most of them were skeptical, and sometimes was hard to find people that would like to join the field trial. Curiosity for technology is a key aspect to promote an efficient recruitment process. In this trial, a participant (aged 98) contacted the caregivers asking to be included in the field test because he/she saw the robot to his/her neighbour, and he/she was just curious to try. Moreover, interviewed caregivers state that the web interface for environmental
monitoring was useful and easy to use for a safe monitoring service and he/she would like to test the full Cloud service in the future.

5 Conclusion and Lessons Learned

The experience described in this chapter demonstrated that mature AAL technologies can actively be used in assisting older citizens directly in their homes. Both telepresence and monitoring services aim at improving the sociality and the safety of older persons. A total of 14 older people tested the two proposed services: 2 older adults tested the environmental monitoring system whereas 12 older adults tested the telepresence service. Analyzing the feedbacks collected from the end-users and stakeholders, here we summarize some lessons learned that future usable robotics and ICT solutions should deal with:

- **Privacy and security issues**: Monitoring is a pervasive solution in a private environment. The recorded data should be protected by external cyber attacks as well as by the formal stakeholder. Ethical norms should not be violated, especially when technology is tested in the real world. To overcome this limitation, for this feasibility study, the architecture of the system was adapted before the test. Indeed, the server was installed on a local machine to avoid the transmission of sensitive data over the cloud, as detailed in Fig. 5. For future studies, ethical advisors should cooperate with technical developers and experimentation managers to define the right path to enter the technology in the real world. Additionally, privacy by design approaches should be also included in exploited cloud architecture.

- **Training activity**: Within the presented study, the telepresence services were rated at the beginning and the end of the study. The results [30] underlines how the expectation toward the technology could have an impact on the adoption. As a consequence, to better exploit the proposed technology in the real world, end-users and stakeholders should be gently introduced to it. Also, the informal interview with the caregiver remarked the necessity to train and educate the users. For instance, dedicated training activities should be organized as well as detailed leaflets describing important warnings and information should be provided. Despite the training activity, a positive attitude towards the use of technology is fundamental.

- **Attitude of the caregiver**: To foster the promotion and the adoption of technology in the real world, the attitude of caregivers is an important issue that should be considered (as remarked in Sect. 4.3). Indeed, if they show a positive attitude towards technology and its use in daily life, they can positively influence also older users. In this project, caregivers were involved since the early design phases of the project and they were the first actors who conducted the experimental phase. They showed a positive attitude for the entire duration of the Double robot experimentation and we collected more than 100 days of experimentation. Therefore, future studies must assign a key role to these important stakeholders because if they feel part of the development process, they could reduce the time-to-market.

- **Adaptability and customization of the solution**: Future services based on assistive technology should rely on adaptable and customizable software and hardware configurations. What we practically learned from this study is that each house has each
own configuration (see Sect. 4.1). For instance, assuming that in each room there are at least a door and a window, the exact position of these two elements can deeply affect the environmental sensors’ network performances. If the older person lived in old houses with thick walls, the network went down dramatically. Similarly, the tele-operated robot could not be introduced in a house characterized by multiple floors, since it cannot moves along the stairs.

- **The readiness of the technology:** For long experimentations in real environments a high level of readiness of technology is requested to not negatively influence the impression on the technology. In the proposed experimentation, the user was requested to share the home (or the room) with the technology and to use it without any external intervention to mimic real-life conditions. Indeed, our results underline that the system relies on robust technology. Indeed in the diary the caregiver did not report any fatal errors. So, the system must be extensively tested in a lab environment before a real experimentation.

- **Large dataset to train the system:** To develop a monitoring module system based on environmental sensors, a large dataset of environmental data is requested for improving data analytics (see Sect. 4.1). As for the proposed environmental monitoring system, it should be trained on the data of the subjects thus to identify the proper “normal” busyness and to detect anomalies in the data that could be correlated with mental and/or physical declines. Additionally, it is worth noticing that acquiring this kind of data with a label assigned from the user/caregiver is time-consuming and too often not applicable in real-world situations. Therefore, future systems should rely on machine learning techniques (i.e. unsupervised, semisupervised techniques, or deep learning) which do not require a complete set of labeled data and can learn from the users. It is also worth mentioning that such datasets are not so easy to find in literature since the majority of the available datasets were built-in laboratory settings (e.g. CASAS Washington State University⁠¹). Such functionality could represent the real innovation of such systems that could make the difference concerning a traditional remote monitoring system.

- **Design:** The challenge of design is therefore to consider, within the project brief, the declared and/or tacit needs and expectations of users, but also to foresee their interaction with the proposed system/service. The aim is to communicate and re-elaborate not only the information but also the personal stories and experiences that generate the complex human-product interaction (e.g. robots and wearable devices). As a consequence, the solutions can be designed according to universally shared patterns and characteristics, although influenced by extremely subjective factors and the personal experience of every single user. Moreover, design can generate experiences that adapt and evolve based on the context of reference and the user. Indeed, these new technologies can provide a significant contribution to the creation of ever-richer experiences, through dynamic and customized tangible interfaces (TUI – Tangible User Interface) and/or intangible interfaces (GUI – Graphical User Interface). The priority design challenge, for the present and the future, is therefore to make the knowledge and use

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of technological systems accessible, immediate and universal, leading, through innovation, the integration in everyday contexts in the function of a hoped-for extension of human activity support.  

This paper presented the experience gained, from the service definition with end-users to the experimentation in real environments and analysis of the results. This work would present a case study and report to the scientific community the lessons learned from the different phases of the project, pointing out useful considerations and inputs for the next development of improvement of the proposed services.

References

Assistive Technology for Active Ageing: The NATIFLife Project

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Abstract. This paper provides an overview of the research activities developed within the NATIFLife project, aimed at developing an Integrated Platform of Assistive Technology solutions supporting elderly and people with impairments in their domestic environment, in order to improve their life quality, autonomy and health, also through remote forms of monitoring and assistance.

The NATIFLife project has been funded by INTERREG V-A Italy-Malta Cooperation Programme, and its main outcomes include: the development of innovative research on assistive technology; the improvement of the quality of life of elderly and people with minor mobility impairments and the contamination between stakeholders of active ageing and wellbeing.

The above challenges have been addressed within the Project framework by tackling the following objectives: the development of an integrated platform of assistive technology, the realization of two Pilot Demo Sites, the reinforcement of two research centers on assistive technology and the implementation of effective communication and networking actions.

Activities and results for each project’s objective have been presented throughout the paper.

Keywords: Assistive technology · Activities of Daily Living (ADL) · User-environment interaction · Wireless sensor networks · Inkjet printing technology

1 Introduction

The population of industrialized countries is undergoing progressive aging, as demonstrated by numerous demographic studies. With reference to the European Union, for example, studies conducted by Eurostat [1] confirm that, due to the reduction in births and the increase in life expectancy, the ratio between the number of adults of working age...
and pensioners is progressively reducing. This will translate, over the next few decades, into an increase in social expenditure due to the provision of pensions, health care and long-term care, which will affect an increasingly narrow portion of people of working age [2]. The aging of the population, therefore, will have an economic impact on the whole society, not only on the elderly.

The World Health Organization has analyzed the phenomenon of demographic aging from the point of view of the quality of life, introducing the concept of active aging, which has as fundamental values the protection of autonomy, independence and quality of life of older people [3].

The quality of life of an elder can be assessed by monitoring his ability to perform a variety of self-care actions daily, what has been called Activities of Daily Living [4, 5]. In other words, the ability to carry out the common activities of everyday life independently and to take care of oneself are essential requirements.

In this context, the availability of technological solutions capable of contributing to the improvement of the safety, health and quality of life of the elderly, by decentralizing part of the social-assistance activities from healthcare facilities to the users’ residences, represents an enabling step towards implementation of new social assistance models [6].

Many research efforts by the authors have been focused, in recent years, on the development of reliable solutions for ADL monitoring [7–12].

In this paper research activities developed within the NATIFLife project – “A Network of Assistive Technology for an Independent and Functional Life” are presented [13].

The project is funded by the INTERREG V-A Italy Malta Cooperation Programme [14], under Priority Axis 1: Innovation and Research, aimed at strengthening the innovative capacity of the actors in the cross-border area in the areas of cultural heritage and quality of life and health of citizens, matching the innovation offer and demand through the activation of projects and collaboration networks between the world of research and production areas in the territory, promoting business investment in research and innovation, developing links and synergies between enterprises, research and development centers and the higher education sector.

The NATIFLife project aims at providing effective technological solutions to the growing needs of independency and autonomy of elderly and people with impairments, by developing assistive technology solutions to improve the life quality, autonomy, and health of elderly living alone, also through remote forms of monitoring and assistance.

This kind of technologies could be really effective, strategic, and strongly compliant with actions required to confine dangerous epidemics phenomenon (such as the COVID-19). Such emergencies require people to remain at home, with particular regards to elders. The use of an advanced systems of assistive technology, such as the NATIFLife platform, would allow for the remote monitoring of habits and physical status of elderlies, thus guaranteeing the required degree of assistance.

The NATIFLife framework, schematized in Fig. 1, addresses the identified societal challenge by tackling the following objectives:

1. The development of an integrated platform of assistive technology, compliant with traditional and innovative solutions, including both home sensors and wearable devices.
2. The realization of two Pilot Demo Sites, where the integrated architecture of assistive technology will be validated and demonstrated to end-users and stakeholders.
3. The reinforcement of two research centers (one per region) equipped with advanced facilities to develop innovative research and support to enterprises in the field of assistive technology.
4. The implementation of effective communication and networking actions, aimed at disseminating information on project’s objectives and activities, promoting the transfer of knowledge, and reinforcing relationships between stakeholders.

Expected project’s outcomes are the following:

- The development of innovative research on assistive technology and innovative services (transfer of knowledge and technological facilities) in favor of enterprises, by the realization of two advanced research centers and pilot demo sites.
- Improvement of the quality of life of elderly and people with minor mobility impairments, by the development of an innovative integrated platform of assistive technology.
- Actuating contamination between stakeholders of active ageing and wellbeing (end-users, enterprises, research centers, institutions), to exchange information on user needs, offers and competences.

![Fig. 1. The NATIFLife project framework and objectives.](image)

According to what was previously introduced, the assistive technology platform developed within the NATIFLife project would allow to monitor the physical state and habits of users, allowing the collection of useful information to support the user in critical situations, but also to identify early deviations from habitual behaviors and identifying
any uncomfortable situations in time. The platform also allows to convey information, in particular alarms, to the caregivers and allows them to make a continuous analysis over time on the state and habits of the user, allowing them to intervene quickly, helping to improve the user’s quality of life.

In this paper an overview of the activities carried out within the NATIFLife project and related achieved results is provided. In particular, research activity results on assistive technology solutions, including seat-posture detection, flexible user-system interfaces, user habits monitoring through RFID technology, robotic locomotion aids and artificial vision applied to user localization and fall detection are reported.

In the next section, the state of the art in the above-mentioned assistive technology solution is analyzed; Sect. 3 focuses on research activities; the Living Labs are discussed in Sect. 4; Sect. 5 is dedicated to the integrated platform of assistive technology, while communication and networking activities are discussed in Sect. 6; conclusions and future developments are presented in Sect. 7.

2 Related Works

With reference to recognition and monitoring of sitting posture, several studies have been reported in literature concerning applications in professional fields, like office job and automotive [15–17]. The application of seat posture detection techniques in the home environment, as an assistive technology solution, has been discussed in [18].

Most of applications reported in literature make use of commercially available pressure mapping systems, which exploit resistive [19, 20] or capacitive [21] readout strategies.

Compared to above-mentioned solutions, the main novelty introduced in this research activity is related to the exploitation of low-cost, rapid prototyping technologies, like inkjet printing and micro-patterning, allowing the fabrication of customized devices on flexible substrates [22].

Assistive technology solutions exploiting radio-frequency identification (RFID) technology have attracted great attention and shown increased applicability in the fields of Ambient Assisted Living (AAL). Examples of applications range from assisted navigation and indoor navigation systems [23–25], to rehabilitation devices [26, 27].

RFID technology applied to human activity tracking in retail, healthcare, work-place safety, and manufacturing fields, has been presented in [28].

The application of RFID technology to monitor user’s habits, such as the use of food, beverages, and/or drugs, including monitoring of home appliances usage, environment exploitation, and activity rate, has been described in [29]. The presented approach has many advantages compared to other solutions, e.g., those based on cameras, which are related to the low level of invasiveness and flexibility of the adopted technology.

The RFID system presented in this work integrates facilities to monitor food and beverage intake, combined with a unique identification of the user within the living environment.

Concerning artificial vision systems, in recent years, the research area concerning tracking of multiple entities and monitoring has grown significantly, also thanks to the increased popularity of low-cost RGB-D cameras, allowing for the development of
various techniques that utilize both color and depth information to improve the overall performance of current systems [30].

Most of the work done on human detection and tracking consists of the exploitation of both color and depth data, but depending on the nature of certain environments, only depth data can be used [31–33] since the use of RGB imaging information may lead to privacy infringement risks.

The research reported here deals with a framework based on RGB-D cameras to localize and monitor elderly people during their daily activities, that relies on the depth data captured from the cameras which is used to determine the location of the elderly person(s). Moreover, the data is used to identify abnormal behavior, such as falls, lack of movement for long timespans, and in turn raises alarms to the elderly person, family members and caregivers. The proposed system exploits low-cost hardware and is targeted for the field of ambient assistive living where few solutions exist and are most of the time proprietary [34].

3 Research Activities

Activities carried on by the researcher team of the NATIFLife project have been focused to the development of the following assistive technology solutions: a seat-posture detection system, a flexible touchpad, RFID technology for user habits monitoring, a robotic locomotion aid and a vision system for user localization.

3.1 Seat-Posture Detection System

The focus of this research activity is on the development of a sensing system aimed to provide information on a person’s seat posture, which is useful to both get awareness on the pressure distribution on the sitting area, as well as on the user activity rate. The main novelty introduced by this research is intrinsic in the use of rapid prototyping fabrications technologies that allow realizing customizable devices on flexible substrates, which can be properly designed with different shapes to address specific needs, at relative low cost.

The basic idea of the application exploits a sensing matrix, realized over a thin, flexible polymer substrate, which can be easily integrated inside the padding of a chair’s pillow, generally consisting of layers of foam rubber and wadding.

The device has been designed by considering typical seat pressure distribution maps reported in literature, and by defining a flexible mechanical structure capable of intercepting the areas where pressure is higher, and by translating the mechanical deformation of the structure into electrical signals by means of deformation sensors.

A dedicated conditioning electronic has been developed to properly process signals provided by the strain gauges. Sensors lines are multiplexed to a single signal conditioning circuit consisting of a resistive measurement bridge connected to an instrumentation amplifier. An Arduino Uno board is exploited to control the multiplexer and acquire the analog signal provided by the amplifier. Digital data are the suitably formatted and transmitted to the server via an integrated Wi-Fi module. The electronics is hosted in an external box, placed on the chair in a way that does not interfere with the normal usage.

In Fig. 2a the layout of the sensing matrix is shown, superimposed to a typical pressure distribution map, while in Fig. 2b a partially assembled prototype is reported.
3.2 Flexible Touchpad

The device is aimed to provide a hardware User Interface to be integrated, for example, in the arm of an armchair, providing the user a mean to send commands and requests to the Platform of Assistive Technology through a wireless radio interface. It has been designed as a matrix of interdigitated capacitive cells, fabricated by inkjet printing of conductive ink over a thin, flexible, pet substrate [35, 36]. The sensing principle exploits the change in the dielectric permittivity of the medium around the interdigitated electrodes which, in turns, produce a change in the capacitance of the sensing cell. Suitably designed electronics allows detecting this capacitance variations. The prototype of a $4 \times 2$ inkjet printed touchpad is shown in Fig. 2c.

3.3 RFID Technology for User Habits Monitoring

RFID-based solutions have attracted a lot of attention and increasing applicability in the field of Ambient Assisted Living. Application examples include assisted and indoor navigation systems, rehabilitation devices, human activity tracking [29].

Within the NATIFLife project, this technology has been exploited for the development of an RFID based system designed to monitor user’s habits, such as the use of food/beverage/drugs. In addition, the same solution has been effectively applied to monitor the use of home appliances, exploitation of the indoor environment and the monitoring of the activity rate. The main idea is to monitor the interaction between the user and generic targets (food, beverage, appliances, doors, etc.). To such aim, the user has to wear the RFID reader, while each target of interest is labelled by a passive tag. The realized device is made up of a commercial RFID reader, a power management system, a rechargeable battery, and a Serial to Bluetooth converter for the sake of enabling a communication between the device and a smartphone. A prototype of the wearable RFID reader is shown in Fig. 2d, while an example of the commercial flexible passive tags applied to a typical item/furniture to be monitored is shown in Fig. 2e.

Moreover, the adoption of RFID technology enables implementing the users’ activity tracking on the system, providing a mean to pair the actions performed on a monitored item with the user who performed it. For example, by making reference to the fridge installed in the living lab, which is shown in Fig. 4a, it has been equipped with a switch that monitors the opening of its door, and a passive tag that can be read by the RFID reader worn by the user. In such a way the server is able to pair the information related to the fridge usage to the identity of the user. The same principles apply to other furniture/items monitored in the living lab. Caregivers can visualize reports on users’ activities on the web interface of the platform.

RFID tags applied to door jambs, as shown in Fig. 4d, allow to keep track of the user’s movements between the various environments of the living lab, as when passing through the doors the tags are read by the RFID reader worn by the user and the information is recorded on the platform database.

As an example, in Fig. 3, the fridge utilization on a daily basis for a given user is displayed.
3.4 Robotic Locomotion Aid

The ability to walk is one of the most important and fundamental functions for humans to live high-quality lives. However, such a locomotion capability can be partially or entirely compromised, especially in the case of the elderly or in the case of the mobility impaired.

Research efforts have been devoted to the development of a Smart Walker: a robotic locomotion aid, which is basically a conventional walker equipped with sensing, actuation, and control systems to ease its usage by the user and, more importantly, to avoid collisions or hindrances while walking, which may result in dangerous falls.

In particular, the developed device consists of a differential-drive-like active smart walker of avoiding obstacles within the environment, thanks to the data coming from a 2D laser scanner [37]. A simulation and a real view of the device are shown in Fig. 2f and Fig. 2g, respectively.

3.5 A Vision System for User Localization

An artificial vision system aimed at monitoring elderly activities, based on an RGB-D system, has been developed [34] within the NATIFLife project framework. The solution uses depth information to determine the location of the elderly and report it to the cloud. Moreover, the system provides real-time alerts to the caregivers if abnormal behavior, such as a fall, is detected (see Fig. 2h) or no movement is registered for a long-time span.

The proposed framework uses low-cost hardware and is targeted for the field of ambient assistive living where few solutions exist and are most of the time proprietary.

In Fig. 2i an example of position tracking performed by the vision system on a user with the smart walker.

4 Living Labs

One of the main outcomes of the NATIFLife project is the realization of two living labs, or Pilot Demo Sites (PDS), one in Malta and one in Catania (Italy), where innovative and traditional solutions of assistive technology can be validated and demonstrated to end-users and stakeholders. The PDS are the places where R&D, enterprises and users’ needs can meet, enabling a user-centered design approach.

The structure of the PDS resumes that of a common home, equipped with the typical living environments and furnishings, where the devices and equipment necessary for the implementation of the integrated platform of assistance technology have been installed.

Some examples of sensors and devices installed at the PDS are shown in Fig. 4: a) RFID tag and magnetic switch for monitoring the use of the refrigerator; b) magnetic switch for pantry monitoring; c) smart switches for control and monitoring of lights; d) RFID tags applied to door jambs to monitor the use of the environments.

The Pilot Demo Sites will be kept active even after the closure of the project in order to continue with the demonstration and experimentation activities.
Fig. 2. Overview of the NATIFLife project research activities outcomes on innovative assistive technology: Seat-posture monitoring system (a, b); Flexible inkjet-printed touchpad (c); RFID system for user habits monitoring (d, e); Robotic locomotion aid (f, g); Depth cameras-based user localization and tracking system fall detection alert (h) and user’s position tracking (i).

Fig. 3. An example of user activity report generated by the web interface: fridge utilization on daily basis for a user of the integrated platform of assistive technology.
5 The Integrated Platform

The architecture of the integrated platform of assistive technology is schematized in Fig. 5. The following macro-blocks can be identified [6]:

– A user *Body Area Sensor* network made up of several devices worn, or carried on, by the user, including a *smartwatch* to monitor user status and activity, the *RFID reader* to implement user habits monitoring and, eventually, a dedicated sensor system to perform electrocardiogram on users with specific needs. A *smartphone* with a suitably developed App acts as a gateway for the Body Area Sensor Network and as Graphical User Interface.

– An environment level sensor network, consisting of all the devices installed in the environment, aimed at user state and habits monitoring, environment monitoring and control devices (see Sect. 2).

– Caregivers are also equipped with a *smartphone* with a dedicated interface in which they receive notifications and information on the status of users and with which they can access the data on the platform.

– The overall system and data management is implemented by means of:

  • A remote server, resident on the Cloud, that manages the operation of the whole system, archives the data provided by the sensors, performs advanced data processing (data mining), provides feedback to end-users and alerts to caregivers.
  • A *local server*, which manages the operation of the sensor network and acts as a gateway to the remote server. It is aimed at monitoring data exchanged over the network, filtering and collecting information, synchronizing the local database tables with the remote ones stored on the cloud platform.
6 Communication and Networking

Communication towards the target groups (enterprises, end-Users, citizens, research centers, institutions) to make them aware of the developed innovative assistive technologies, to advertise the pilot demo sites and their activities, to bring people to visit them and validate the proposed technologies, plays a fundamental role to reach specific objectives of the Project.

In order to achieve this result, different communication activities are foreseen during the project by the project website, the informative portal, newsletters, different social media, outreach activities towards the citizen, organizing communication events, scientific publications.

With reference to Networking Activity, one of the results of the project consists of the realization of an informative portal aimed at creating a network of Stakeholders potentially interested in the development of innovative assistive technology. Those Stakeholders can join the NATIFLife Network, by registering to the informative portal. A screenshot of the informative portal is shown in Fig. 6.

Following is a summary of the main advantages that may result from the Networking activities:

- Visibility, exchange of Best Practice between Stakeholders, meeting between demand and supply of technologies.
- Opportunities to participate in research projects for the development of Innovative assistive technologies.
- Participation in training sessions and Hands-On activities on assistive technologies.
- Participation in dissemination events and communication on the activities of the project.
- Access to technologies for the joint development of activities of industrial interest.
7 Conclusions

This paper presents main activities developed within the NATIFLife project. The main objective of the project has been the development of a framework of Assistive Technology to support elderly and people in their everyday life at home. Main outcomes of the project can be summarized as follows:

1. The development of an integrated platform of assistive technology.
2. The realization of two Pilot Demo Sites.
3. The reinforcement of two research centers working on Assistive Technology.
4. The implementation of communication and networking actions.

As presented through this paper, several research activities have been performed with particular regards to the monitoring of the user-environment interaction, the user status, and the user activity rate. Such activities have been developed through a joint effort of research centers, companies and other stakeholders involved in the field of Assistive Technology, such as care centers.

Results achieved through this project, including the two valuable Living Labs, will be sustained in the future years with the aim of exploiting the project results, proposing even more effective developments, and fostering new synergies among strategic stakeholders, with the mandatory involvement of end-users.
References

Personalized Integrated Care for Frail Seniors
Within the Pharaon Project: The Italian Pilot Site

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6 Hewlett Packard Enterprise, Milan, Italy
7 Co-Robotics S.r.L., Capannoli, Pisa, Italy
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Abstract. Technology plays an important role into the life of older people. With the increase of age, they are experiencing physical and cognitive frailties and they require assistance for the management of their daily activities. In this sense, digital technologies could offer a holistic ecosystem which could empower their daily life 24 h decreasing the caregiver burden. Multi-domains researchers are joining their efforts to propose a selection of services. In this context, this paper introduces the large scale pilot Pharaon project, pointing out the attention on the Italian pilot site. Within the Italian pilot, a personalized and integrated care service was and will be investigated in the forthcoming years to meet the challenge of older population. Particularly, the paper introduces the methodology and the actions performed to face the covid-19 pandemic which affect the first stage of the process, the service domains, and the methodology applied. Additionally, the paper presents and discusses the key performance indicators related to impact, business, social and clinical domains and how the technology is used within the Italian pilot to support the population during the pandemic emergency.

Keywords: Personalized care · Pharaon project · Integrated IoT system · Older persons · Need study

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1 Introduction

1.1 Background

Fast ageing of the population, along with concurrent healthcare and social trends, has in the latest years raised a generalized issue across the whole European Union, to preserve and protect the quality of life (QoL) for a population segment quickly become highly frail and vulnerable [1]. Most of the countries lack the technical, organizational, and legal instruments to effectively cope with this growing problem. Frailty is the main determinant cause of death, and it is strictly related to the ageing process [2]. Timely action during the process that progressively makes a subject disabled could significantly impact the entire social and health system. Life expectancy in Italy is the second in all of Europe, and in Tuscany the average life is 85.4 years for women and 81.3 years for men, whereas in Apulia is 84.8 years for women and 80.6 years for men [3]. As a result, the number of seniors is growing and leading to a change in the traditional family model.

This evolution was raising challenges for the Italian health-care and welfare system, even before the COVID-19 outbreak, especially relating to seniors with reduced capabilities of independent living, not relying upon a nearby family and/or a habitual relationship network. These people are at potential risk of isolation and protection loss by public institutions. According to a 2017 report from the Italian Statistic Institute [4], 18% of elderly people perceived around them a weak social support network, and about half of them didn’t consider their social protection as “strong”. Adding up to this, are the challenges linked to socio-demographic changes (falling ratio between birthrate and average age), limited autonomy (30% of elderly declaring “severe trouble in running household activities”), and the resource cut suffered by the Italian public welfare system in the last decade. Hence, innovative and sustainable solutions for improving the lives of elderly citizens can by all means be paramount for improving their day-by-day status and quality of life.

Digital technologies play a key role in winning this challenge since they can support the extended caregivers’ ecosystem in multiple ways. Indeed, on the healthcare side, they allow 24 × 7, real-time monitoring of older people vital parameters, and promptly detect situations where a direct care intervention must occur. On the assistive side, they can allow an easier contact of older people with their caregivers and keep them in constant connection with their families as well as their friends and the outside world [5].

This scenario has become further accelerated by the ongoing COVID-19 crisis, severely when not fully crippling the physical connections, and making digital inclusion a must even for a social segment like the older adults who have at large extent been left out of this societal transformation [6].

The medical, social, and technological research are joining their efforts to find innovative, effective, and widely applicable solutions to overcome seniors frailty and exclusion. The European institutions are making important investments to support these efforts, fostering a tight collaboration of the different professional and scientific actors into large multidisciplinary projects, encompassing pilots with real users on a significant scale, prepared by methodologies enabling joint requirement elicitation and co-design. Pharaon is part of this effort within the Horizon 2020 frame-programme, along with
other large-scale pilot (LSP) projects tackling the topic from complementary viewpoints, like ACTIVAGE\textsuperscript{1}, SMART BEAR\textsuperscript{2}, GATEKEEPER\textsuperscript{3}, SHAPES\textsuperscript{4}, ADLIFE\textsuperscript{5}, InteropEHRate\textsuperscript{6}, Smart4Health\textsuperscript{7}. These projects compose the Large Scale Pilots Health and Care Cluster, defined within the “EU OPEN-DEI” project (GA No. 857065)\textsuperscript{8}, which is a coordination and support action (CSA) aiming at the creation of common data platforms based on a unified architecture and established standards.

1.2 The Pharaon Project: The Italian Pilot Site

Pharaon (Pilots for Healthy and Active Ageing) is an Innovation Action funded by the European Union’s Horizon 2020 programme under the Grant Agreement n°857188 (www.pharaon.eu). This large-scale pilot project involves partners from 12 European countries and aims to achieve smart and active living for Europe’s ageing population. Pharaon is creating a set of highly customizable interoperable open platforms to integrate advanced services, devices and tools including IoT, artificial intelligence, robotics, cloud computing, smart wearables, big data, and intelligent analytics. These solutions are going to be widely tested and validated, to respond to the needs of older adults and aim at enhancing the independence, safety, and capabilities of people as they age. The project is a collaboration of 41 organisations, led by the Department of Industrial Engineering of University of Florence (UNIFI), based in Pisa, Italy, and will last 48 months (from December 2019 to November 2023). Pharaon adopts a user-centric approach and is going to test several digital solutions in 6 different pilots over 5 countries: Italy (Tuscany-Apulia), Spain (Murcia and Andalusia), the Netherlands (Twente), Slovenia (Isola) and Portugal (Coimbra-Amadora).

The Italian pilot is coordinated by UNIFI; it includes two pilot sites: Umana Persone Social Enterprise R&D Network (UP) which operates in Tuscany Region, and Ospedale Casa Sollievo della Sofferenza (CSS) located in Apulia Region. Umana Persone is a network contract with legal subjectivity that currently involves ten social cooperatives operating in Tuscany and active in the social welfare services sector. Its mission is to carry out research and development activities for the innovation of the Third Sector\textsuperscript{9}. Ospedale Casa Sollievo della Sofferenza\textsuperscript{10} is one of the historic and largest hospitals and research centres in Southern Italy. Its mission is represented by hospital care activities, scientific research, education, and professional training of healthcare personnel. Additionally,
the Italian pilot involves three industrial partners: Hewlett Packard Enterprise (HPE)\textsuperscript{11}, Co-Robotics s.r.l. (CORO)\textsuperscript{12}, and Orthokey Italia s.r.l. (OKEY)\textsuperscript{13}.

HPE is a technical partner contributing its expertise and competencies in ICT infrastructure specification, design, and deployment. HPE offers its know-how to make, along with other technical partners, the best choices for what will be the foundational platform developed by the project, on top of which advanced technological components will be integrated and deployed to enable the whole span of innovative care services delivered by Pharaon. CORO is a spin-off company of Scuola Superiore Sant’Anna and its role in the Italian pilot sites such as in Pharaon project is to provide and to develop technological solutions based on robotic platforms and wearable sensors. Finally, Orthokey core business is the development of innovative solutions for the healthcare sector. OKEY also avails itself of the expertise of Medea, its third party connected to the Pharaon project, which deals with the evaluation of the socio-economic impact of innovation processes and solutions.

2 Challenges of the Italian Pilot

Pharaon is developing open platforms for smart living at home to allow intelligent integration of advanced ICTs from fields such as robotics, IoT, Big Data, or smart wearables. This will effectively enable the European ageing population to face the negative consequences limiting their independence and QoL by cognitive impairment, frailty, and multiple chronic health conditions. Currently, most digital technologies in healthcare are fragmented and utilized only on a small scale. Pharaon wants to contribute to the sustainability and scale-up of existing and future business models, thus reduce the risk of their obsolescence by supporting technological and market scalability and thereby enhancing the competitive supply of good quality services. Through the 6 planned pilots and the activities addressing ecosystem expansion, the Pharaon project wants to demonstrate the suitability of the platforms to integrate digital technologies and the capacity of these technologies to keep people at their homes longer, while using institutional healthcare facilities only when intensive care is needed.

Within the Pharaon project, 10 challenges (PCH) have been identified and are going to be addressed within the 6 pilots. Each pilot has its own challenges. Table 1 summarizes the challenges of the Italian pilot site. In Italy, Pharaon is focusing on setting up and merging Health and Care at home for older vulnerable subjects or moderately frail individuals. In doing so, the pilot wants to emphasize correct lifestyles (e.g. characterized by personalized diets and physical exercise programs, social connectivity) and health status monitoring at home.

3 The Pharaon Methodology Within the Italian Pilot

Pharaon methodology applied to the Italian pilot is composed of five main steps (Fig. 1). The first step aims at refining, translating, and adapting the Pharaon challenges (Sect. 2)

\textsuperscript{11} HPE official website: https://www.hpe.com/it/it/home.html.
\textsuperscript{12} Co-Robotics s.r.l. official website: http://www.corobotics.eu/.
\textsuperscript{13} Orthokey Italia official website: http://www.orthokey.com/.
### Table 1. Pharaon Challenges (PCHs) of the Italian pilot site.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>PCH1: The behaviour and the approach of elderly to friendly technological devices</td>
<td>Through co-creation meetings and interviews with users, experts and consortium members, ideas for useful functions of the system must be collected in a creative atmosphere, visualized in terms of user scenarios, and evaluated for their fit with social and technical requirements</td>
</tr>
<tr>
<td>PCH2: Health status definition and its progress over time</td>
<td>With the Pharaon project, we intend to demonstrate that it is possible to improve the health and wellbeing of patients through 1) their proper categorization, 2) establishing a consensus concerning planned clinical actions among all levels of care for each situation that is supported by a tool noting the entire patient history, 3) transparency that facilitates tracking between all healthcare and social areas, allowing to apply the recommended clinical actions</td>
</tr>
<tr>
<td>PCH4: Promote Social Cohesion</td>
<td>Mobility is a vital factor of social inclusion within society and an important precondition for a satisfying QoL in the old age. Reduced mobility leads to isolation and dependence can have a devastating effect on seniors’ self-esteem. Within the Pharaon project, the need to provide alternatives to foster social connectivity is highlighted</td>
</tr>
<tr>
<td>PCH5: Define specific personalized care plan on the basis of user´s needs</td>
<td>Different personalized care plan based on objective evaluations made autonomously by the system would be defined, evaluating its results through a large and comprehensive data collection and analysis</td>
</tr>
<tr>
<td>PCH10 - Support to caregivers towards more efficient and personalized care services</td>
<td>Caregivers are at an increased risk to experience burnout and often eagerly need support. Fortunately, their burden can be reduced considerably by implementing ICT solutions. Pharaon project aims at proposing solutions to reduce the caregiver workload</td>
</tr>
</tbody>
</table>

into the needs of the two Italian pilot sites. The second step aims to refine these scenarios with end-users (i.e. older persons, formal and informal caregivers) to define the goal models such as the final Pharaon scenarios [7]. Then, within the third step, these scenarios will be developed following agile co-creation approaches where the end-users will be requested to evaluate the solutions providing advice and feedback at different
developmental stages [8]. Finally, the solution will be pre-validated and tested in real scenarios (respectively 4th and 5th steps of the scenario). The following paragraphs detail the first and the second step of this methodology.

![Fig. 1. Overview of the pharaon methodology applied at Italian Pilot level](image)

### 4 Target Stakeholders

The Italian Pharaon Pilot Site has planned to recruit and involve a large number of participants, which is currently estimated to be around 700 users, distributed as follows: 300 older adults in fragile condition, mainly with mild dementia, 300 relatives and informal caregivers, 100 healthcare professionals. These participants are going to directly use the Pharaon platforms and technologies, and they will provide enough differences to be a great test field for trials and improvement. Older adults and informal caregivers are involved according to the following processes:

- Active participation in the identification of their needs and suggestions.
- Self-Empowerment in making an informed choice about their health status.
- Use of the digitized Comprehensive Geriatric Assessment (CGA).
- Improve communication with the other actors of the care process.
- Decrease in social isolation.

Furthermore, healthcare professionals are involved in considering the following processes and role:

i) Psychologists and Physicians:

- Coordinate, training, guidance.
- Monitor testing.
- Support the design, development, and refinement of the digitized CGA.
ii) Professional caregivers:

• Use data and tools to improve the quality and effectiveness of their work, decreasing the risk of burnout.

In addition to the main stakeholders described above, other actors can play an important role in achieving the objectives defined for the Italian Pilot. Indeed, volunteering could improve the social connection of older people and can increase communication among the network of stakeholders. Moreover, strict collaboration with Public (local and regional) administration is needed, and local social services should work with the services providers in the recruitment of end-users.

5 1st Step: Scenario Refinement at Italian Pilot Level

5.1 Scenarios Definition

According to the methodology previously described, the Italian pilot’s challenges have been discussed within the consortium to fit the challenges to the two realities (i.e. domiciliary assistance and residential/hospital environment). The following paragraphs summarize the scenario refinement domains such as a preliminary identification of the system requirements.

Health Status Definition. Within this scenario, the Pharaon system aims at measuring and monitoring the CGA domains [9]. Here, the Pharaon system will be activated by the caregiver/physician (e.g. one possibility could be to trigger the “initialization” phase through a specific vocal command given by the caregiver); then it starts to ask questions to the frail senior about social support network data (e.g. where the patient lives, etc.) and about the clinical data of CGA that clinicians would like to monitor. It is expected that the user is seated and that the care staff have entered basic data into the system such as the patient’s name and age that are loaded in the platform at the patient admission in Geriatric Unit. Additionally, the Pharaon system should identify the carers and patient (e.g. using RFID sensors) and it should be able to correctly manage and store the acquired data.

Remote Monitoring. In our vision, the Pharaon system will run a dedicated interface that mainly consists of three modules: the first one includes variables acquired through questionnaires. The second one will collect data regarding vital signs and other domains such as cognitive, functional, social and emotional outcomes of CGA. The third module will collect the data related to the personalized care scenario concerning the monitoring of the level of social inclusion, movements, emotional and mental states. Key aspects of this interface include flexibility and modularity because the active modules depend on the scenario the users are involved in.

Support for Caregiver’s Work. Caregivers, physicians, and psychologists could access the interface for monitoring patient’s health status, providing feedback to personalize the care. Informal caregivers will receive in their own devices (smartphone, tablet, etc.)
Promote Social Inclusion. Social cohesion is related to the action of territorial policies and personal mobility of older persons. Through the Pharaon interfaces, the frail senior could be in contact with the other actors of the care process. Indeed, within Tuscany Region, little groups of 3–4 older people, who live not too far one from each other, will be formed to foster social cooperation and inclusion. A platform could be installed on their TV and through the Pharaon app, they could chat, organize visits, virtually meet and play cards.

Personalized Care. Through this service, the older person could access the Pharaon system from home which, for instance, suggests him/her physical and cognitive stimulation exercises tailored on the person’s profile. The Pharaon system will analyse part of this data using smart algorithms to automatize the care process planning. Additionally, sensors could be installed in the domestic environment. In case of problems, an alert should be sent to formal and informal caregivers. Every person will have “special connections”, according to the needs and interests: doctor, friends, relatives, associations, etc. Additionally, as detailed in the previous scenario, seniors could use the Pharaon system to stay in contact with other seniors and play together.

5.2 Description of the System Components

According to the scenario refinement previously described, an initial list of system components were outlined within the pilot as reported in Table 2.

These system components should be refined within Step 2 and then, they should be integrated within the Pharaon architecture.

The Pharaon architecture is under development starting from an initial baseline, represented by a restricted number of existing, potentially suitable platforms best fitting the project’s objectives and requirements. By performing a proper analysis and matching of the project’s requirements, a Pharaon architectural blueprint will be developed, aimed at creating a superset of the different platforms’ capabilities, through proper interoperability mechanisms as well as tighter integrations, according to the results of the design investigation phase. Then, the platform blueprint will be adapted and specialized for each of the project pilots, and the tailored design will be deployed on the pilots’ physical infrastructures. For the Italian pilot, this platform will be developed on HPE resources, who, along with the other pilot technical partners, will mainly take care of:

- ensuring that the platform components support the requested data flow, moving information and controls from/to the periphery (IoT devices, wearable devices on patients, robots) into the system intelligent core (e.g., modules executing machine learning algorithms to process data and detect actions);
- setting up the platform components in charge of elaborating heterogeneous, multi-source data processing, extracting added value information by the combination of data
Table 2. Overview of system components.

<table>
<thead>
<tr>
<th>Service</th>
<th>System Components</th>
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<tbody>
<tr>
<td>Managing and storing health data</td>
<td>• Integrated Care platforms for managing the connection between the devices and the management of data.</td>
</tr>
<tr>
<td>Remote monitoring</td>
<td>• Smart AI algorithms for analysing aggregated data.</td>
</tr>
<tr>
<td></td>
<td>• Robots for automatizing the CGA monitoring service.</td>
</tr>
<tr>
<td></td>
<td>• Wearable devices and sensors – to monitor the health status of the patients and the parameters of the CGA.</td>
</tr>
<tr>
<td></td>
<td>• Interfaces to manage data acquisition, test administration, and data visualization.</td>
</tr>
<tr>
<td>Facilitating interactions</td>
<td>• Smart TV and Pharaon application to manage the social meetings among peoples of the same community.</td>
</tr>
<tr>
<td></td>
<td>• Telepresence robot at home to promote the interaction proposing telco with relatives but also with clinicians and psychologists to reduce the social isolation.</td>
</tr>
<tr>
<td>Personalized service at seniors’ home and in the domestic environment</td>
<td>• A personalized interface where people can access and visualize important data (i.e. include a Smart TV).</td>
</tr>
<tr>
<td></td>
<td>• Smart solutions to promote personalized care plan including physical and cognitive stimulation (i.e. through games) and teleassistance;</td>
</tr>
<tr>
<td></td>
<td>• Smart algorithms for decision supporting.</td>
</tr>
</tbody>
</table>

from the person’s monitoring, existing care records, and manually input information (by patients as well as caregivers);
• granting data storage in the defined repositories, and data accessibility from the presentation layer making the information available and usable for physicians and caregivers;
• configuring the platform to best meet the non-functional attributes set out by the pilot requirements, in terms of Key Performance Indicators (KPIs) like scalability, elasticity, resilience, reconfigurability;
• developing the platform to be intrinsically secure, resilient to external attacks and safeguarding the privacy of sensitive/PII (Personally Identifiable Information) data moving across the Pharaon system.

6 2nd Step: Scenario Refinement with End-Users

According to the Pharaon methodology, the Italian’s scenarios should be refined within co-creative sessions. However, the world has suddenly faced a pandemic emergency caused by the COVID-19 virus. Thus, from the beginning of March 2020 several restrictions, including social distances and lockdown, have been applied by the governments in Italy as well as in all the countries involved in the Pharaon project. Consequently, face-to-face meetings have not been allowed and planned workshops have been cancelled. Therefore, Italian co-creators organized a plan to react to the emergency collecting the
requested feedback. The contingency methodology proposed to face the COVID-19 situation included a structured interview (through videoconference systems or phone calls) with older people, informal and formal stakeholders such as clinicians, nurses and social operators. Additionally, a virtual workshop has been organized involving Social/Technical workers from the social cooperatives of the Umana Persone’s network. Interviews and workshops covered the same topics to easily compared and shared the results.

6.1 Participants

According to the proposed methodology, older persons, informal and formal caregivers have been contacted by phone calls or videoconference systems to refine the scenarios. Moreover, a dedicated virtual workshop has been organized within the Tuscany pilot site to collect additional feedback from the Social/Technical workers, who are in charge to design, manage and coordinate assistive services within the social cooperatives linked to UP.

Users are recruited voluntarily. Inclusion criteria for older people are:

- presence of physical frailty;
- absence or presence of cognitive frailty with a Mini-Mental State Examination (MMSE) \( \geq 24/30 \);
- absence of sensorial issues (hearing and/or vision).

The professional and informal caregivers have been involved based on their experience with seniors with cognitive and/or physical frailty. Table 3 summarizes the recruited subjects in the two pilot sites for the scenarios refinement phase.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>Older Adults</th>
<th>Informal caregivers</th>
<th>Professionals</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Social Workers</td>
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<td>Clinicians</td>
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<td>Technician/Engineers</td>
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<td>Public Social Services</td>
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<tr>
<td>Apulia</td>
<td>10</td>
<td>10</td>
<td>-</td>
<td>3</td>
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<tr>
<td>Tuscany</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>-</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td><strong>22</strong></td>
<td><strong>8</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

6.2 Interview Guidelines

According to the participants’ preferences, the interviews have been conducted by videoconference system (e.g. skype, zoom) or by phone. The videoconference system was the
preferred and suggested way because the interviewers could make evidence and observe also non-verbal cues. The proposed interview has been divided into three main parts:

**Informed Consent Acquisition** – this part was devoted to the oral acquisition of informed consent. If the participant agreed, the interviewer turned on the video recording and reconfirmed the informed consent orally with the video recorder on (see Sect. 6.4 for more details).

**Attitude Towards Technologies** – within this part, the interviewer asked questions related to socio-demographic information (i.e. age, sex, level of education). Then, he/she asked for the attitude toward technologies and to what extent the assistive devices (e.g. robots, IoT) could be useful to support daily life. All the technological components listed in Table 2 were included in the analysis to collect complete feedback. In the end, the Pharaon project and services (see previous sections) have been introduced. If the interview was conducted by phone, the interviewer read a story, whereas if the interview was conducted by a videoconference system, a slide presentation was used.

**Interview on Pharaon Services** – at the end of the presentation, the patient was asked to what extent Pharaon can be useful underlying his/her needs and priorities. The objective was to identify the respondent’s needs in terms of physical, cognitive and social assistance, and the acceptance level of technology. Then, the participants were asked to identify the emotional, quality and functional goals [7] of the relevant services identified during the discussion.

The interviews have been fully transcribed to support data analysis.

### 6.3 The Virtual Workshop

The virtual workshop has been proposed on the Zoom® video communication platform and divided into 5 main parts:

**Pharaon Introduction** – a general introduction of the project as well as the proposed Italian scenarios was delivered at the beginning of the workshop. It is worth noticing that the same slides used in the interview have been used in this workshop to be aligned with the content.

**Attitude Towards Technologies** – Each participant was asked to anonymously answer an online questionnaire. The proposed questionnaire followed the domains proposed also in the interview, i.e. the attitude toward the technology, and the preferences of Pharaon services and domains.

**Plenary Discussion and Service** – the results of the questionnaires have been briefly discussed during the plenary session. The three most voted services were identified such as the best three domains. Then, the workshop facilitators asked participants to discuss the service domains proposing some concrete services for their social cooperatives. For instance, if one of the selected domains was the home monitoring, they had to details how they wish to implement that service in their realities. The brainstorming idea has been collected on a virtual shared poster created with Google Presentation®.
NOW, WOW, HOW Prioritization – by using a shared virtual poster and virtual post-it created on Google Presentation®, the facilitators asked the participants to rate the ideas according to two parameters: feasibility/implementation and originality following the guidelines presented in [10]. According to these two parameters, three categories of ideas have been identified into three quadrants as follows:

- **Now** – Normal ideas, easy to implement. These ideas normally result in incremental benefits.
- **How** – Original ideas, impossible to implement. These are breakthrough ideas in terms of impact, but practically impossible to implement right now because of current technology/budget constraints.
- **Wow** – Original ideas, easy to implement. ‘Wow’ ideas are those with potential for orbit-shifting change and possible to implement within current reality.

The participants had to write the number of the services previously identified on the post-it and move the post-it into one of the three quadrants according to the level of priority assigned. In the end, the three most voted services within the NOW and WOW quadrants were identified (Fig. 2).

**Scenario Description** – The participants have been divided into three groups to write down the scenarios. Each group had to develop one of the three scenarios previously identified. A scenario template (using Google Docs) was provided to the group to guide the discussion; the participants were requested to describe the steps of the scenario, such as to identify the goals of the model (i.e. emotional, functional and quality goals) [7].

### 6.4 Legal and Ethical Guidelines for the Interviews

The Italian pilot site aims to build a user centered scenario, and it can’t be approached without seriously taking into consideration legal and ethical indicators among others. For this reason, the co-creation methodology represents the best way to consider all the
domains (i.e. physical, psychological, emotional, environmental, social) – most of them related to legal and ethical risks that tend to increase for aging adults – and ensure that legal and ethical requirements will be effectively respected, adapting solutions case by case.

Another important aspect to point out is that the legal and ethical indicators that have to be considered relevant, are not only those coming from the older adults, but also those from their families – when they do exist -, especially in Mediterranean cultures where the family is the most important social institution. Some useful indications came from the other partners of the Pharaon Consortium who gathered informations about the most relevant risks and threats for elderly in using technologies. At the end, some framework templates (i.e. Informed Consent, Factsheet, Revocation Sheet) were elaborated at project level according to these data and distributed at pilot levels.

Due to the contingency period caused by the Covid-19, pilots had to go ahead modifying the original program from face-to-face interviews/focus groups to phone or video interviews. Strategies were also modified and documents adapted. The interview framework was structured to ensure a balanced relationship between interviewer and interviewed. It was necessary to consider that the role of the interviewer was not only to facilitate dialogue in focus groups, but also to stimulate every single person to express their opinions and needs, ensuring in the meantime people didn’t feel influenced or embarrassed. For these reasons, we ensured people felt comfortable with the interviewer, adopting also simple measures such as choosing professionals with specific skills, who would follow the same person until the end.

A very big effort has been also dedicated to the training of professionals in managing interviews, selecting how/when to stress some topics, and leading conversations to collect the most relevant information.

As we weren’t able to stimulate in person the senses of the people interviewed (with pictures, or seeing, touching, trying technological devices), we focused on stimulating their imagination -whenever possible- through images, videos or storytelling (real examples of what a person can do at home with the devices).

Comparing information collected from the questionnaires submitted by other partners, we noticed that privacy and safety were the main concerns of the elderly and their families, so we focused primarily on them.

The main goal since the first contact with the elderly has been the accessibility of information. This meant that some efforts were dedicated to elaborate privacy policy, informed consent documents and some other tools to clearly and easily explain to people (not only the elderly, but also formal and informal caregivers and professionals) the characteristics of the project: what they are asked to do, which kind of data will be elaborated and how-where-until when it will be stored.

We wanted not only to be compliant with the GDPR, but also ensure effective comprehension of the contents. The main measures that were adopted are as follows:

- Simplifying the contents;
- Removal of complicated words, substituting them – whenever possible - with more simple ones;
- Underlining or writing in bold the most important aspects of each part of the content, to focus people’s attention on them;
• Providing all these documents and information with plenty of time for the recipient to read them several times.

We also elaborated a sort of “Road Map” for interviewers to guide them through the first part of the interviews. Following the steps of the Road Map, the interviewers ask specific questions in order to verify if the person interviewed fully understands the context. At this stage, people are invited to ask for clarification if needed, and in this case the interviewer should offer the explanation before collecting the consent and proceeding with the interview.

In order to approach ethical problems related to the fundamental human rights (i.e. dignity, freedom, independence, etc…), the interviewers deeply researched the domains of DOING, BEING and FEELING, in order to understand how technologies should operate, and in which way they should make people feel and develop the goal models.

People’s perceptions represent the first criteria used to filter technologies in order to be considered ethical. This doesn’t rule out refining these technologies and considering different ones in the future, but it means that the implementation of the scenario is based on a cyclic process that starts and finishes with the end-users follow up.

6.5 Data Analysis

The analysis of the data has been conducted in both the pilot sites (UP and CSS). To assure that the data analysis would follow the same procedure both in Tuscany and Apulia, we used the same template to report on the analysis. The proposed data analysis is adapted from [11, 12].

The interviews have been fully transcribed in both the pilot sites. After transcription, each interview has been analyzed using the method of Thematic Content Analysis (TCA). The first level of coding was meant to identify themes and units of meaning. In this, we stayed close to the wording used by the respondent. In the second level of coding, we used more theoretical words. Finally, the third level of coding was the actual analysis: looking for recurring themes, coherence and unique cases. In particular, the TCA is divided into two fundamental analyses: 1) Analysis of Vertical content [coding and categorizing by an intra-interview reading (progress of an interview on all codified themes)], and 2) Analysis of Horizontal content [second coding and categorizing on reading inter-interviews (illustration of a theme by all the interviews)]. In particular, the analysis was meant to highlight the similarities and differences between the two pilot sites.

Then, these results have been discussed among the multidisciplinary research team of the Italian pilot, which consists of geriatricians, psychologists, social operators, health service researchers, robotics engineers and biomedical engineers. The objective of this analysis is to bring the data from the two pilot sites (i.e., UP and CSS) together and perform a cross-site synthesis at the Italian pilot level. We aimed at identifying the commonalities and differences between the two sites regarding the goal models and the goal scenarios, related priority services and attitudes towards the technology and the Pharaon services. For this, we looked at both quantitative differences (e.g. the type of support needed, the number of older people positive about the technology) and qualitative differences (e.g. the type of arguments in favour of Pharaon services). Finally, the results have been aggregated to obtain the selected goal models as described in [7].
7 Key Performance Indicators

This section explains the multidimensional framework Key Performance Indicators (KPIs) that we are going to use within the Italian pilot to evaluate the proposed services. Indeed, the proposed KPI domains included: quality goal and performance indicators, social, clinical and emotional indicators, impact and business indicators, and legal and ethical indicators.

7.1 Quality Goals and Performance Indicators

The overall pilot evaluation will be driven by a set of indicators relating to the improvement in the delivery of care services, and the achieved leap forward in the life quality of participating older people. Nonetheless, these leading quality goals will have to be achieved also through several technical quality goals, instrumental and enabling to reach the sought outcomes of impact and effectiveness for the end-users. These technical quality goals will involve all the technology layers in the Pharaon system, peripheral/edge components, service platform, vertical applications and technology components. Numerical targets will be set out by Pharaon at a more advanced development state. Nevertheless, we can already envisage some qualitative targets that the pilot will have to carefully observe.

For the service platform, the quality goals are expected to include:

- **Technical parameters:** affecting the perceived user experience: data availability latency, connection setup latency, system stability; such parameters should be kept under control, to prevent negative reactions from the users, and not spark inefficiencies in the caregivers’ operation.
- **System accuracy:** e.g. data leaks along with the acquisition, processing and storage pipes, especially in the flows demanding levels of synchronicity.
- **Scalability and elasticity:** the system must provide, besides the physical capacity, also the functional capability of responding to sudden demand peaks, in line with the specific targets set out for the pilot, by prompt provisioning of additional resources to keep the service fulfillment level.
- **Security and privacy:** the system should be able to avoid unauthorized access to users’ data and/or to the own components; data integrity and consistency must be guaranteed; attacks and incidents must be handled and their impact must be kept at the minimum level.

7.2 Social, Clinical and Emotional Indicators

The pilot evaluation will be lead by a indicators set finalized to the improvement of social, clinical and emotional goals as shown below:

- **Clinical Indicators** will consist of the reduction of hospitalization, increasing of pharmacy adherence, increased level of physical activity (monitoring of movements), frailty risk reduction evaluated by the Comprehensive Geriatric Assessment (CGA), cognitive improvement assessed by the Mini-Mental State Examination (MMSE) [13],
decrement of the depression symptoms assessed by Cornell Scale for Depression in Dementia (CSDD) [14], improvement of the QoL measured by Quality of Life AD (QOL-AD) [15], and decreased levels of burnout of caregivers measured by Caregiver Burden Inventory (CBI) [16].

- **Social Indicators** will be obtained through the improving level of social connection and perceived social support measured by the Multidimensional Scale of Perceived Social Support (MSPSS) [17].

- **Emotional Indicators** will be modelled with the equal hierarchy to functional and quality goals because the consideration of emotion is fundamental to the development of sociotechnical systems. Different roles may have conflicting emotional goals in response to the same goal. So it is important to distinguish different emotional indicators for each stakeholder category.

  For older frail adults, the main emotional indicators are expected to be:

  - Improved Self-Empowerment and confidence: the system should increase people’s ability to take care of themselves, giving feedback about their lifestyle.
  - Reduced feelings of loneliness: through the Pharaon system seniors should have the sensation of being connected to other people and reaching them easily.
  - Improved sense of inclusion in the healthcare chain process due to improved communication.
  - Feeling part of something and still “useful” to society: being integrated into a network of positive relationships allow people to find meaning in their existence.
  - Easy access to Pharaon service: the system must be perceived as friendly and easy to use.
  - Easy access to healthcare data: older people must feel that information about their health status is always available to them.

  For professional and informal caregivers the main emotional indicators will include:

  - Reduced burden: the system must be a real help in carrying out daily tasks and make them easier.
  - Reduced sense of loneliness: the platforms used in the project should allow operators to continuously share information and emotions with colleagues.
  - Easy access to important data regarding the health status of the beloved care person.
  - Empowerment the management of the diseases: caregivers should increase their confidence in the ability to take care of their family member, increasing their awareness and competence about their disease and care plan.

7.3 **Impact Indicators**

The impact of digitalisation of health and social services has been profound and is expected to be even more thoughtful in the future. Like for other services, it is important to evaluate the impact of such digital health services. Decisions to adopt, use or reimburse new digital health services, at different levels of the health and social care system, are ideally based on evidence regarding their performance in the light of health system goals.
In order to evaluate this, a broad perspective should be taken. Attainment of the broad health system goals, including quality, accessibility, efficiency and equity, are objectives against which to judge new digital health services. Accordingly, evaluations should be designed and tailored in such a way as to capture all relevant changes in an adequate manner. According to such assumptions, within the “Personalized Integrated care for frail elderly”, the Italian Pharaon pilot aims at generating impact evidence on different dimensions and different stakeholders. In particular, the goal is to generate benefits for:

- End-users;
- Social and healthcare system;
- Public and private health/social care entities

In this regard, a study outcome has been identified. In particular, we foresee that ICT/IoT technologies improve the efficiency of health and care systems with demonstrated added value according to different elements:

- Users QoL;
- Sustainability of the service from an economic point of view and from human resources perspective;
- Efficiency of provided treatments.

In particular, the deployment in the Italian scenario of integrated care platforms able to manage the connection between various devices (wearables, sensors etc.) bound up to the high-quality management of data get the goal to generate noteworthy improvements.

Furthermore, the deployed technologies will be able to generate and analyse a higher volume of data thus allowing the definition of better treatments from caregivers to patients/elderly. Such highly refined and personalized treatments get several cascading goals:

- Seniors/patients improvement of related QoL due to personalised care.
- Health/Social care system’s equity improvement through the reduction of out-of-pocket-payments due to personalized treatments thus reducing the users’ money waste and improve their access to effective health and social care pathways also thanks to technologies that allow the caregivers and GPs remote monitoring.
- Improvements in health and social care system’s capacity to properly allocate human and financial resources according to the real needs of people.

Additionally, the implementation of Pharaon approaches has the goal to improve access to health and social care pathways to a larger population portion by promoting personalized care services. In fact, through technological devices, the goal is to collect and evaluate a large and comprehensive amount of data to define different and personalized care plan suitable to reduce in a short-medium run the use of health services by patients.

According to Italian pilot scenarios, through the help of digital devices, this approach aims at empowering the users to implement healthier behaviours and lifestyles and to improve users’ health literacy. According to WHO, “Health Literacy” refers to
“the achievement of a level of knowledge, personal skills and confidence to take action to improve personal and community health by changing personal lifestyles and living conditions. Thus, health literacy means more than being able to read pamphlets and make appointments. By improving people’s access to health information, and their capacity to use it effectively, health literacy is critical to empowerment” [18].

By the improvement of users’ “Health Literacy”, Pharaon gets the unique opportunity to promote a deep change, able to alleviate the ever-increasing pressure on the public system, relieve the caregivers from overstating stress and to reduce the waiting list by fostering teleassistance services, stimulate remote control and implementing continuous psychological support to caregivers using chat, telco, and information by the devices.

To analyze data and to generate Italian scenarios outcomes’ evidence, statistical approaches will be implemented to ensure outcomes accuracy and reduce bias elements typically included in such type of analysis. In particular, variables statistical description, statistical significance and multivariate statistical analysis will be implemented to generate the best possible evaluation and ensuring the achievements of the aforementioned expected evaluation goals.

7.4 Business Indicators

One of the main declared objectives of the Italian Pharaon pilot is to be sustainable in the medium/long run regardless of the project expiring date. According to European market observers, the IoT market is expected to surpass $241 billion in 2022. The true leader for IoT spending in the forthcoming years will be the consumer segment, with revenues exceeding $32 billion. The largest consumer use cases will be related to the smart home, personal wellness, and connected vehicles. Within smart homes, home automation and smart appliances will both experience strong spending growth over the forecast period and will help make consumer the fastest-growing industry segment overall with a five-year CAGR of 20.0% [19].

The Italian IoT market is growing at CAGR rate of 35% with an overall value of 5 billion (2018) [20]. The smart home segment shows the highest annual growth rate (+52%). In this competition, Artificial Intelligence can play a fundamental role in the IoT market, opening up new opportunities for enhancing the data collected to anticipate the needs of companies and consumers. The understanding of the main type of market is fundamental due to the fragmentation and the barriers to entry typical of the IoT market in order to define the proper business model.

According to a preliminary analysis, the business model that will be adopted in Italian Pharaon pilot will be a B2B2C, because services will be never sold directly to the citizens, but they will be always reached through public/private institutions in charge of delivering socio-healthcare services. Therefore, Italian Pharaon pilot target customers are:

- Public healthcare institutions.
- Public insurances.
- Private insurances.
The identified customers will necessarily make the Italian pilot exploitation to be adaptable to the different customers approaches, both from an engagement and selling policy point of views. If the customers are public institutions, it will be necessary to answer specific public tenders and adapt the offering to the specific tender needs, even including other kinds of supporting/integration services; in case of private customers, Italian Pharaon pilot will be tailored to very specific needs collected visiting the customers more than once and then the most suitable package and, consequently, the most appropriate selling policy will be jointly created.

On top of this, the aforementioned market represents a huge opportunity to be intercepted. As such, the implemented strategy foresees the setting-up of an interested and key stakeholders ecosystem able to promptly updates needs and translate them into Pharaon local actions. Through this ecosystem, it would be possible to make the best use of the assets generated through constant monitoring of external communities.

To set-up this ecosystem, specific webinars are going to be scheduled and key local stakeholders will be invited. Such webinars would have the goal to:

- Present the Italian Pharaon pilot to a wider community.
- Concretely understand stakeholders’ needs.
- Involve different stakeholders to create a local network that can be recognizable also at EU level as representative of them.

On top of this, the Italian partners are involved in international EU and extra-EU networks such as the “EU OPEN-DEI” project (GA No. 857065) and the related “Large Scale Pilots Health and Care Cluster” as well as in other relevant international networks such as the “International Collaboration Digital Transformation Healthy Ageing (IDIH)”14.

These initiatives represent a unique opportunity to leverage the Italian study outcomes and to get visibility in international fora. At this regard, several actions are already on stage (as workshops, webinars and newsletters) and will be further defined with key stakeholders during the project lifespan.

All the initiatives presented will contribute to the definition of the sustainability and replication analysis of the Italian case study according to national and international key players highlighting those elements suitable for Pharaon pilot site replication and scaling-up in different ecosystems than the pilot one. In order to accomplish with such strategy, at the end of the project, specific Italian guidelines will be released containing the analysis about the potential adaptations and enhancements proposed on top of Italian Pharaon case’s experimental framework to be considered for future adopters.

8 How the Proposed Solutions Could Support During COVID-19 Related Situation

The current spread of Covid-19 is the latest testimony to the threats to public health that have recently been addressed: 2002: SARS epidemic in China; 2012: MERS outbreak.

14 IDIH, https://idih-global.eu/.

The disease outbreak affects all segments of the population and is particularly detrimental to members of those social groups in the most vulnerable situations, such as frail people.

Indeed, according to a study released by Istituto Superiore di Sanità (ISS) and Italian Istituto Nazionale di Statistica (ISTAT), those with high risk of dying because of Covid-19 are those belonging to the 60+ age group [21]. Indeed, the mortality rate for male seniors aged over 60 is higher than 30%. Additionally, there seems to be a deadly trend toward mortality with Covid-19 in older patients with specific comorbidities, thus identifying a new “Covid Spiraling Frailty Syndrome” [22]. According to a recent case-control study conducted by the Agenzia Regionale di Sanità (ARS) Toscana [23], a chronically ill patient has a more than doubled risk of developing symptomatic Covid-19 compared to a healthy subject. Dementia is one of the major risk factors. A chronically ill or oncological patient, with the same gender and age group, has a 56% higher risk of developing symptomatic Covid-19.

Fostering remote care is of paramount importance to limit access to healthcare structures and contain the risk of contagion. In case of emergency, this would allow patients to be monitored by doctors, without any risk to them and without interrupting the service, as, unfortunately, chronic patients following a traditional care pathway are experiencing. Today, indeed, anyone who needs outpatient rehabilitation cannot be guaranteed the service; however, anyone who is an in-patient in a healthcare facility, cannot be visited by his or her relatives, and, as a result, may suffer a negative psychological impact. Older persons are not just struggling with greater health risks but are also likely to be less capable of supporting themselves in isolation (a condition that is dramatically worsened in such a health crisis). Although social distancing is necessary to reduce the spread of the disease, if not implemented correctly, such measures can also lead to the increased social isolation of older persons at a time when they may be at the most need of support.

Therefore, robotics and ICTs in the service of public health could represent a new consolidated model of clinical practice in the management of Covid-19 [24]. The cooperation between autonomous robotic systems and clinical staff could give rise to new prevention protocols that effectively and promptly counteract the spread, in the future, of infectious diseases capable of putting at risk the public health of our country and the globalized system in which we live.

In this context, the Italian pilot is planning concrete actions aimed at developing a modular robotic and ICT solution that can support and assist healthcare personnel during the Covid-19 emergency, helping to reduce the risk of infection and transmission of the virus. The realization of the described scenario can drastically reduce the contact between health/social workers and patients, proposing teleoperated robotic systems able to support in tasks such as visiting relatives, surveillance, and monitoring the status of the patients. The proposed solutions would be able to significantly mitigate the risks related to epidemic emergencies, promoting new styles of coexistence of humanity with very
virulent epidemics. Particularly, the following scenarios have planned to be implemented to meet the Covid-19 challenge:

- **Telepresence service (@Home, @Residential Facility):** a telepresence robot will be used in a semi-automated mode to establish a relationship between the socio-medical operator and patients, particularly for increasing the remote assistance and monitoring of the health status multiple times during the day.

- **Video-consultation (@Home):** the service will allow performing a remote patient examination, i.e. video-consultation session between doctors and patients.

- **Patient remote monitoring (@Home):** discharged patients after a hospital stay due to Covid-19 infection should be carefully monitored for a while. Thus, they are asked to daily fill a web-based checklist complete with all the relevant Covid-19 related symptom. Additionally, the system could ask them to insert some physiological measurements such as the body temperature and the oxygen saturation level. This data represents a mix of quality and quantity indicators for the monitoring process, to timely intervene in case of recurrence of the infection symptoms. Gathering such data from the discharged patients can be useful both for monitoring the health of these people, as well as for collecting data to be used for scientific purposes to improve the knowledge about the development of the disease over the time.

For what concerns the experimentation, the telepresence service will be tested within the Tuscany pilot and the other two services will be tested within the Apulia pilot.

## 9 Conclusion

The proposed paper introduces the personalized integrated care system for frail seniors within the Italian pilot of the Pharaon project. An overview of the Italian pilot is presented such as the used methodology and the identified KPIs. A summary of the results obtained during the first step of the methodology was presented, as well as the methodology proposed for the second step. A total of 73 users (older persons, informal caregivers, and professionals) were involved to refine the scenarios.

The technology could have a great impact on the lives of older persons as much as on the people that support them. However, sometimes research to market barriers are experienced that could be stem from a variety of causes. Indeed, Pharaon project aims to evaluate the services based on multidisciplinary KPIs which aim to give suggestions and improve the services considering issues which could promote and favour the exploitation of these technologies in the real world.

It is worth noticing that technology is playing an important role within the pandemic emergency. This is the reason why the Italian pilot would aim to make the difference proposing three services to face the challenge and supporting the frail older adults in managing social distances. These solutions are under test within the UP and CSS pilots.

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References

4. ISTAT: Elderly people: Health conditions in Italy and Europe Union (2017)
Preliminary Studies of a Model for a Robot that Creates an Interactive Communication with Elderly People to Satisfy Their Clothing Item Requests

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Abstract. Robotic technology has become more and more sophisticated in the last epoch and a consequence of this revolution is the huge diffusion of robots. Currently, robots are no more relegated only to the industrial field, indeed they can be employed in houses, as assistants for several tasks, or in hospitals. In this paper, in particular, we are going to describe a possible implementation of an innovative model for an assistive robot that creates an interactive communication with elderly people to satisfy their clothing item requests. In detail, assistive robots need several skills during this kind of task, such as cloth classification, manipulation of clothes, and human-robot interaction. Concerning manipulation, the use of machine learning is increasing in this field, which develops fast and powerful grasping models and this is the reason why we would like to use one of them in the grasping phase. The reasons described before brought us to propose an innovative model for an assistive robot that satisfies clothing item requests of elderly people.

Keywords: Assistive robot · Manipulation of clothes · Convolutional neural network

1 Introduction

The interaction and collaboration between robots and humans are becoming more and more important in our society because of the increasing aging of the population. People prefer to live in their own homes for as long as possible, instead of being institutionalized in sheltered homes, or nursery homes when problems related to aging appear [2]. This is the reason why there is a growing necessity for new technologies that can assist the elderly in their daily living. Assistive robots can be used with elderly people in different scenarios: for prevention of early degeneration of cognitive abilities, the management of chronic
diseases, fall prevention, maintaining social contacts, and the management of daily activities [6,8].

The reasons described above brought us to present this proposal whose aim is to implement an innovative model for an assistive robot that satisfies clothing item requests of elderly people. In particular, this model could be applied to a robot that helps elderly people in their own houses or in retirement homes.

In details, the main contributions of the proposal are the following:

- Creating a new large dataset of clothes useful for elderly people.
- Proposing from scratch a model for an assistive robot that does clothes classification using augmented features, grasps clothes using a specific neural network, and that can collect users’ feedback.
- Testing the model using a real robot.

In detail, the paper is organized as follows: in Sect. 2, the state of the art is presented; in Sect. 3 methods and tools and in Sect. 4 discussions regarding the article are shown. In Sect. 5, the conclusions of the article are summarized.

2 State of the Art

The Assistive Robotics field is an area of growing interest [23] in which robots are used as tools to better assist human users with special needs [3], allowing them to perform some Activities of Daily Living (ADLs) by themselves. An interesting area of Assistive Robotics is the Robot-Assisted Dressing branch. This area is becoming extremely challenging because of the complex tasks, together with the difficulty to control the contact-rich interactions between a garment and the body part to be dressed [21]. Finally, other issues that have been not yet solved regarding the dataset of clothes that contains few items, and the communication with elderly people to satisfy their clothing item requests.

2.1 Clothes Classification

One of the fields in Robot-Assisted Dressing is the classification of clothes and it is a sub-field that remains still to be developed from many points of view, comparing to the field of grasping clothes. In [19], the work of the authors deals with the classification of garment categories including pants, shorts, shirts, T-shirts, and towels. The knowledge of the garment category is crucial for its robotic manipulation and their work focuses particularly on garments being held in a hanging state by a robotic arm and the input of their method is a set of depth maps taken from different viewpoints around the garment which are fused into a single 3D point cloud. In [5], a Baxter robot, a two-armed robot with an animated face, was used to dress a jacket onto a mannequin and human participants considering several combinations of user pose and clothing type (base layers), while recording dynamic data from the robot, a load cell, and an Inertial Measurement Unit (IMU). The authors also expand the analysis to include classification
techniques such as decision trees and support vector machines using k-fold cross-validation. In [22], the authors presented a system for automatically extracting and classifying items in a pile of laundry. In detail, using only visual sensors, the robot identifies and extracts items sequentially from the pile. Finally, in [18] the authors proposed an attention-driven technique for tackling visual fashion clothes analysis in images, aiming to achieve clothing category classification and attribute prediction by producing regularised landmark layouts.

### 2.2 Grasping of Clothes

In this section, the selection of grasping points by the robot is shown. In [25], the authors described grasp points selection on an item of clothing randomly placed on a table, and in [14], the authors proposed a novel vision-based grasp points detection algorithm that can reliably detect the corners of a piece of cloth, using only geometric cues that are robust to variation in texture. In literature, several works also used Convolutional Neural Networks (CNNs) to train their dataset to find grasping points of clothes. In [17], the authors created a new dataset to train a CNN to improve the dressing assistance behaviour of a Pepper, a humanoid robot able to recognize faces and basic human emotions. In [16], the authors described a CNN that predicts the quality and pose of grasps at every pixel. This one-to-one mapping from a depth image overcomes the limitations of current deep-learning grasping techniques by avoiding discrete sampling of grasp candidates and long computation times. Finally, in [4] the problem of identifying optimal grasping poses for cloth-like deformable objects is addressed by means of a four-steps algorithm performing the processing of the data coming from a 3D camera.

### 3 Methods and Tools

In the following section, methods and tools for the implementation of the new model for an assistive robot, that helps elderly people in dressing tasks, are shown. The following block diagram describes the process before going into details (Fig. 1 and Fig. 2):

![Block diagram](image)

**Fig. 1.** Block diagram of the proposed model: it is composed of the command block followed by the clothes classification and grasping modules. After them, there is the user selection block that finishes the process which can be repeated.
Fig. 2. Block diagram of the new network. In the first phase, the user demands for a specific cloth, then, clothes classification is done with or without augmented features. After classification, the robot grasps the cloth and gives it to the patient that gives a feedback based on what he/she receives.

3.1 Command

The command block represents what elderly people usually dress and one main goal of the model is to let the robot understanding the dressing needs of elderly people to dress them. To achieve this goal, first four types of clothes are put on a table: one pair of jeans, one leader trousers, one pajama, and one dressing gown of which the second two are usually worn by elderly people while the other two are worn by younger people. The novelty of the network consists of having a model of grasping clothes that has the goal to satisfy the dressing needs of elderly people.

3.2 Clothes Classification

This module is used to acquire images of clothes using an RGB-D camera. Both colours and depth of the camera are important in the grasping of clothes for having a better performance of the network. The images are acquired from the camera sensor that takes the RGB-D images of the clothes. The dataset is the split into 80% (training and dev set) and the remaining 20% part is the test set. The actual classification is done by concatenating the neural network to an MLP
(Multy-Layer Perceptron). In this module, the network is augmented concatenating some extra features to achieve a better clothes classification performance.

### 3.3 Clothes Grasping

In this module, the methodology of grasping clothes is chosen. We will use the Generative Grasping Convolutional Neural Network (GG-CNN) [16], modifying a little the internal part of it, to grasp clothes. This network predicts the quality and pose of grasps at every pixel. This one-to-one mapping from a depth image overcomes limitations of current deep-learning grasping techniques by avoiding discrete sampling of grasp candidates and long computation times. Additionally, GG-CNN is orders of magnitude smaller while detecting stable grasps with equivalent performance to current state-of-the-art techniques. The light-weight and single-pass generative nature of GG-CNN allows for closed-loop control at up 50 Hz, enabling accurate grasping in non-static environments where objects move and in the presence of robot control inaccuracies. The challenge of using this network is the fact that GG-CNN has problems with thin objects (like clothes), and so solving this issue could be a great contribution in the improvement of this network.

### 3.4 User Feedback

In this module, the elderly person takes the item that the robot has brought him and presses two buttons on the tablet that the robot has to answer the following questions using yes/no answers:

- Do you like the item that the robot brings you?
- Do you want another item?

Then according to which answers the elderly person gives on the tablet, the robot takes another cloth or stops its process.

The choice of using pressing buttons to answer specific questions is due to the low motor skills that elderly people have. In the tablet, the robot stores the information provided by elderly people to remember elderly people’ satisfaction regarding the items that it gave them.

### 3.5 Hardware and Experimental Scenario

An important element is the choice of the robot: an idea is to test the grasping model using the assistive robot called Doro (Fig. 3) created by the Assistive Robotic Lab of Sant’Anna School of Advanced Studies [1]. This robot has an Xtion camera mounted on its head and has a Kinova 6-DoF arm with a hand as end-effector. In Fig. 4, a hypothetical experimental set-up scenario is shown.
4 Preliminary Classification Methods

In this section, the preliminary results related to the classification method are presented. We used the Fashion-MNIST dataset as a preliminary dataset and we trained it on two different networks: a Convolutional Neural Network that we called FashionCNN, and a LeNet.

4.1 Proposed Networks Framework

For what concerns the clothes classification task, we took inspiration from [12] where the authors concatenated Histogram of Oriented Gradient (HOG) and color features to their network features to increase the performance of the network clothes classification. In our work, we decided to evaluate the performance of two different networks that use the Fashion-MNIST dataset with or without two features that are Canny and Sobel filters. We chose these two features since they can extract the shape of each cloth, providing an easier classification of the item.

FashionCNN. The first CNN used takes inspiration from the AlexNet network [10] and it has the following layers:

- Two Sequential layers each consisting of the following layers:
  - Convolution layer that has kernel size of 3 * 3, padding = 1 in 1st layer and padding = 0 in second one. Stride of 1 in both layers.
  - Batch Normalization layer.
  - Activation function
  - Max Pooling layer with kernel size of 2 * 2 and stride 2.
  - Flatten out the output for dense layer (a.k.a. fully connected layer).
  - 3 Fully connected layers with different in/out features.
  - 1 Dropout layer that has class probability p = 0.25.

The input image is changing in a following way:
- First Convolution layer: input: 28 * 28 * 3, output: 28 * 28 * 32
- First Max Pooling layer: input: 28 * 28 * 32, output: 14 * 14 * 32
LeNet. LeNet possesses the basic units of a CNN, such as convolutional layer, pooling layer and full connection layer. LeNet-5 consists of seven layers. The layer composition consists of 3 convolutional layers, 2 subsampling layers and 2 fully connected layers.

4.2 Features Extraction

The main goal of the experimental part is to obtain better clothes classification concatenating some features to the principal network features, as can be seen, in Fig. 5. In detail, we decided to concatenate to the network features, two other features that are the Canny edge detector and Sobel filter.

The augmented features that we used are the Canny edge detector and the Sobel Filter.

Canny Edge Detector. This is an operator that uses an algorithm to detect edges in images and it was developed by Canny in 1986. The Canny edge detection is a technique to extract useful structural information from different objects and reduce the amount of data to be processed. Among the edge detection methods developed so far, Canny edge detection algorithm is one of the most strictly defined methods that provide good and reliable detection.

Sobel Filter. The Sobel filter is used for edge detection and was developed by Sobel and Feldman. When we apply this mask to the image, it simply works like as first order derivate and calculates the difference of pixel intensities in an edge region.
Fig. 5. Proposed model with the augmented features. The clothes image is processed by the neural network. Then, the features extracted from the network are concatenated to other features (Canny and Sobel) and fed into an MLP for classification.

4.3 Experiments

In the following paragraph, we compared the networks’ performance with or without the Canny and Sobel features on the Fashion-MNIST Dataset.

The Fashion-MNIST Dataset. The Fashion-MNIST dataset is proposed as a more challenging replacement dataset for the MNIST dataset [11], it is based on the assortment on Zalando’s website [24], and it is composed of pictures having a light-gray background. The original picture is resampled with multiple resolutions, e.g., large, medium, small, thumbnail, and tiny. The authors used the front look thumbnail images of 70,000 unique products to build Fashion-MNIST. In particular, white-color products are not included in the dataset as they have low contrast to the background. For the class labels, the authors used the silhouette code of the product.

Methods and Settings. In our work, we used the Adam optimizer together with the cross-entropy function as the loss function for training. The following equation describes the cross-entropy function:

$$\text{Loss} = - \sum_{i=1}^{n} y_i \log \hat{y}_i$$

where $\hat{y}_i$ is the i-th scalar value in the model output, $y_i$ is the corresponding target value, and $n$ is the number of scalar values in the model output. Experimentally, we set the learning rate as 0.01, the batch size as 128. We applied a 5-fold cross validation which divided the dataset into 80 % (training) and 20 % (test) set.
Results and Analysis. We first compared the loss and the accuracy of FashionCNN with and without Canny and Sobel features. From Table 1 can be seen that the average accuracy (86.8 %) without Canny and Sobel features is higher than the one with those filters (84.6 %). As a consequence the average loss (0.37) without features is less than the one with Canny and Sobel features (0.39).

Table 1. Losses and accuracies of FashionCNN with and without Canny and Sobel features

<table>
<thead>
<tr>
<th>FashionCNN</th>
<th>F0</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss without Canny and Sobel</td>
<td>0.37</td>
<td>0.35</td>
<td>0.35</td>
<td>0.44</td>
<td>0.36</td>
<td>0.37</td>
</tr>
<tr>
<td>Loss with Canny and Sobel</td>
<td>0.40</td>
<td>0.40</td>
<td>0.37</td>
<td>0.41</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Accuracy without Canny and Sobel</td>
<td>87%</td>
<td>86%</td>
<td>88%</td>
<td>86%</td>
<td>87%</td>
<td>86.8%</td>
</tr>
<tr>
<td>Accuracy with Canny and Sobel</td>
<td>85%</td>
<td>84%</td>
<td>85%</td>
<td>86%</td>
<td>83%</td>
<td>84.6%</td>
</tr>
</tbody>
</table>

Secondly, we evaluated the loss and the accuracy of Lenet with and without Canny and Sobel features (Table 2). Concerning the accuracy average, we obtained in this case that the one with features is higher compared to the one without Canny and Sobel filters. (81.6% against 69.4 %). The losses were 0.51 and 0.81 with and without features respectively.

Table 2. Losses and accuracies of Lenet with and without Canny and Sobel features

<table>
<thead>
<tr>
<th>Lenet</th>
<th>F0</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss without Canny and Sobel</td>
<td>0.73</td>
<td>0.78</td>
<td>0.75</td>
<td>0.96</td>
<td>0.80</td>
<td>0.81</td>
</tr>
<tr>
<td>Loss with Canny and Sobel</td>
<td>0.52</td>
<td>0.50</td>
<td>0.51</td>
<td>0.50</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>Accuracy without Canny and Sobel</td>
<td>71%</td>
<td>69%</td>
<td>72%</td>
<td>67%</td>
<td>68%</td>
<td>69.4%</td>
</tr>
<tr>
<td>Accuracy with Canny and Sobel</td>
<td>81%</td>
<td>82%</td>
<td>81%</td>
<td>82%</td>
<td>82%</td>
<td>81.6%</td>
</tr>
</tbody>
</table>

From the results shown before, we achieved that the Canny and Sobel filters work and increase the performance of the Lenet, while there is no benefit using these features with the FashionCNN network. From our analysis, features from Lenet are not fully extracted so that sub-features, such as Canny and Sobel help to increase the performance. However, features from Fashion CNN are already sufficiently extracted. As a result, Canny and Sobel features are a factor of decreasing performance.

5 Future Work

In this paper, an innovative model for an assistive robot that satisfies clothing item requests of elderly people is presented. Although substantial advances in
machine learning perception were made in the last decade, especially in object recognition [13] and action recognition [7], there’s still a lack of systems that operate under diverse natural conditions and real-world time constraints that social interaction demands [26]. Moreover, most of the current social robots have been designed for interaction that lasts on the order of several minutes or hours but, on the contrary, human-human social interactions span months, and even years and this issue should be overcome in the future [26]. Going into details in the area of Assisted Dressing, even if this branch is increasing in importance, there are still some limitations in this area. Most of the studies on safety in robot-assisted dressing don’t include tests with users and are limited to experiments on a mannequin. In [21], the authors used a styrofoam head with a dual-arm robot with attached anthropomorphic hand learning to put a knit cap. In [9], a mannequin was used to estimate Human-Cloth topological relationship using a depth sensor. Also in [20], the authors used a mannequin to test Reinforcement Learning for clothing assistance with a dual arm robot. Another issue for the future is that the majority of state of the art that works in robotic manipulation focuses on working with rigid objects, that either do not deform when they are grasped or have negligible deformation even if, deformable object manipulation has many important real-world applications (cloth folding, bed making, getting dressed) [15].

Finally, most of the papers on Robot-Assisted Dressing field do not take into consideration the clothing item requests and the feedback of people that they are dressing so this research project comes intending to solve the issues described before.

6 Conclusion

In this article, an innovative model for an assistive robot that satisfies clothing item requests of elderly people is presented.

Firstly, the state of the art is shown; then, methods and tools and preliminary classification methods with discussions elaborated from the state of the art are presented. This article came with the aim of solving issues presented in the discussions and tries to answer challenging problems of clothes manipulation in the Robot-Assisted Dressing field.

References


Comparing Middle-Aged and Seniors’ Preferences Toward Virtual Agents and Android Robots: Is There a Generational Shift in Assistive Technologies’ Preferences?

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Abstract. The present research aims at investigating effects of participants’ age (middle-aged and seniors) and type of assistive device (female virtual agents vs female android robots) on users’ acceptance. The study involved 4 groups of two middle-aged and two seniors (for a total of 181) participants asked to express their potential acceptance to be assisted in their daily routines by two female android robots/virtual agents. Acceptance was assessed in terms of scores assigned by participants to their willingness to interact with the female agents/robots and pragmatic (PQ), hedonic - identity (HQI), hedonic - feeling (HQF) and attractiveness (ATT) qualities. Video clips of the proposed agents or robots were randomly presented, and after each presentation, participants scored the proposed assistive device by filling either the VAAQ (Virtual Agent Acceptance) or the RAQ (Robot Acceptance) questionnaire. Repeated measures ANOVA were utilized to statistically assess participants’ preferences. Seniors were significantly more open to interact with virtual agents rather than robots, while middle-aged participants were showed slightly more open to interact with robots rather than agents. Participants’ gender significantly affected the evaluation of robots rather than agents’ one, and the appearance of the proposed devices (younger toward mature agents, or haired toward hairless robots), strongly affected users’ acceptance.

Keywords: Seniors · Middle-aged · Assistive technologies · Virtual agents · Android robots · Users’ acceptance
1 Introduction

Ambient Assisted Living (AAL) technologies aim at supporting seniors, promoting active aging, their independence, and healthy living [1]. Virtual agents and social assistive robots (SARs) represent two typologies of technological devices which could be exploited within the field of AAL, to support elderly users in their daily activities, providing assistance and companionship [2, 3]. Hence the need to focus on elders’ acceptance and perceptions toward these potential assistants, identifying features which may favor and facilitate seniors’ usage of the above-mentioned devices. Concerning elders’ perception of virtual agents, which are defined as “…computer-generated animated characters that combine facial expression, body stance, hand gestures, and speech to provide a more human-like and more engaging interaction” [4], studies highlighted that elders prefer to interact with humanoid agents (rather than with robotic or animal appearing agents), displaying positive personalities (i.e. joyful and practical) and consider female agents able to interact using voices more useful and pleasant than their male counterparts [5–8].

On the other hand, studies exploring elders’ acceptance of social robots produced conflicting findings. Some studies had shown that seniors prefer to interact with humanoid (with human-like appearance) rather than android (mimicking realistically human appearance) robots [9–12]. Others had shown that elders felt more positively engaged by female android rather than female humanoid robots [13, 14]. These studies differed among them for the type of robots used (from animal-like to human-like appearing robots), methods of investigations (showing pictures or movies of the robots and/or exploiting only questionnaires from different sources) and robots’ appearances (varying degree of human like appearance). In addition, some current studies [13, 14] reported that seniors largely preferred androids vs. humanoid robots. Since the main aim of this paper was to investigate seniors’ differences in preferences toward virtual agents and robots, only android robots were chosen since their appearance was very human-like and close to the appearance of the selected virtual agents. In addition since it was reported that female virtual agents [5–8] were largely preferred to male ones, we selected only female agents and robots. The current investigation aims to compare users’ preferences toward virtual agents and android robots in order to:

1. Investigate which technological device (virtual agents vs android robots) is more accepted by the proposed users (seniors and middle-aged adults).
2. Investigate differences in preferences according to differences in participants’ gender and age.
3. Investigate whether there can be specific agents or robotics’ features (such as boldness or long hairs) affecting users’ preferences.

2 Material and Method

To achieve the abovementioned goals an experiment assessing users’ degree of acceptance toward female either virtual or robotics agents was carried out. Acceptance was investigated in terms of participants’ willingness to interact with the agents/robots and scores attributed to their pragmatic, hedonic, and attractive qualities (details are on Sect. 2.3).
2.1 Participants

A total of 181 participants joined the experiment. Participants were partitioned into four groups. Group 1 composed of 45 middle-aged (21 males, mean age = 50.42, SD = ±4.12), and group 2 composed of 46 older adults (22 males, mean age = 71.59, SD = ±6.32) were administered video clips showing two female virtual agents. Group 3 composed of 45 middle-aged (23 males, mean age = 47.67, SD = ±4.72) and group 4 composed of 45 older adults (22 males, mean age = 73.04, SD = ±7.03) were administered video clips showing two female android robots. To be included in the study, participants had to declare that they were in a good health with no (or corrected) vision and/or hearing problems, and belong to the age groups of interest, i.e., middle-aged between 40–55 years and seniors 65+ years old. Participants were recruited in the Campania region (south of Italy). They joined the study on a voluntary basis and signed an informed consent formulated according to the current Italian and European laws about privacy and data protection (D. Lgs. 196/2003). The research was approved, with the protocol number 25/2017, by the ethical committee of the Università degli Studi della Campania “Luigi Vanvitelli”, Department of Psychology.

2.2 Stimuli

From the website BOTLIBRE (www.botlibre.com), which provides a wide set of agents with different visual semblances and enables users to create a customer version, two female virtual agents were selected. (See Fig. 1). The two agents were named Clara and Giulia (Victoria2 and Julie3 on BOTLIBRE).

The selected female android robots (see Fig. 2) were Sophia developed by the Hanson Robotics (https://www.hansonrobotics.com/) and Erica (developed by Ishiguro at the University of Osaka, Japan, http://www.geminoid.jp/en/robots.html). Four video clips were defined, showing the two female virtual and robotic agents, half torso, in a frontal position while uttering the Italian sentence “Ciao sono Clara/Giulia/Sophia/Erica. Se vuoi posso aiutarti nelle tue attività quotidiane” (Hi, my name is Clara/Giulia/Sophia/Erica. If you allow me, I can assist you in your daily activities).

The Italian female synthetic voices were generated through the Natural Reader synthesizer (www.naturalreaders.com), recorded with the free audio software Audacity (www.audacityteam.org), and inserted in the video clips by using the Windows 10 application “Videomomenti”. Each video clip lasted between 4 and 7 seconds, to avoid interferences in the assessment of both robots and virtual agents the quality of synthetic voices was kept the same both robots and virtual agents. Indeed, the appearance of the two virtual agents and robots was different to assess the weight of their appearances inside the same class of assistive devices.

2.3 Tools

Participants’ preferences toward the proposed agents/robots were assessed by administering the Virtual Agent Acceptance Questionnaire (VAAQ), and Robot Acceptance Questionnaire (RAQ) for the agents and robots, respectively. VAAQ and RAQ have been
developed by Esposito and colleagues [7, 8, 13, 14] at Università degli Studi della Campania, “Luigi Vanvitelli”, Department of Psychology. The two questionnaires are structured in sections of which Sect. 1 consists of 7 items investigating participants’ degree of experience and familiarity with technological devices such as smartphones, tablets, and laptops. Section 2 consists of a single item assessing participants’ willingness to be involved in a potential long-lasting interaction with the proposed agents/robots. Sections 3, 4, 5 and 6 (each composed of ten items) assessing the Pragmatic, Hedonic and Attractive qualities an interactive system should be endowed with in order to be widely accepted by their potential users. Specifically, the investigated qualities (inspired by Hassenzahl’s theoretical model [15, 16]) were:

- Pragmatic Qualities (PQ) associated to the usefulness, practical and easiness of use perception of the proposed agent/robot.
- Hedonic Qualities-Identity (HQI) associated to originality, creativity, and aesthetical pleasantness attributed by users to the proposed agents/robots.
- Hedonic Qualities- Feeling (HQF) devoted to assign to the proposed agents/robots the ability to arouse either positive or negative emotions.
- Attractiveness (ATT) devoted to check whether proposed agents/robots engage their users in an increasing usage.
Except for Sect. 1, questionnaires’ items are scored on a 5-point Likert scale (1 = strongly agree, 2 = agree, 3 = I do not know, 4 = disagree, 5 = strongly disagree), and involve both positive and negative statements. Negative statements were corrected in a reverse way, and therefore, low scores summon to more positive, and high scores to more negative evaluations of the proposed agents/robots. Middle-aged and seniors who saw the female agents, were administered the paper version of the VAAQ, while those who saw the female android robots, were administered respectively the paper and a digitalized version of the Robot Acceptance Questionnaire (RAQ). The RAQ digitalized version was developed by using a Java script enabling to automatically randomize the presentation order of the questionnaire’s sections for each participant.

2.4 Procedures

Participants were briefed on the aims of the study, subsequently signed an informed consent, and then they were randomly assigned to one of the experimental conditions (assessing virtual or robotic agents). Then, they completed the socio-demographic section (section 1 of the questionnaire). Subsequently, they watched either video clips depicting agents or robots presented to them in a random order, and after each presentation they filled the remaining sections of questionnaires.

3 Data Analysis

Separate ANOVA repeated measures analyses were carried out on the questionnaire’s scores to assess participants’ (middle-aged and seniors) preferences toward either virtual agents (A) or robots (B). The questionnaire’s scores obtained by virtual agents and robots were compared (C) as to investigate participants’ preferences toward these two different typologies of assistive devices. In a first analysis (A) preferences expressed by middle-aged and seniors toward the two proposed female virtual agents (Clara and Giulia) were investigated. Participants’ gender and their age group (middle-aged and seniors) were considered as between subjects’ factors and VAAQ scores obtained in terms of willingness to interact, pragmatic (PQ), hedonic-identity (HQI) and feeling (HQF)- and attractiveness (ATT) as within subjects’ factors. The significance was set at $\alpha < .05$ and differences among means were assessed through Bonferroni’s post hoc tests. Due to the reverse correction of negative items, low scores summon to more positive whereas high scores to more negative agents’ evaluations. In a further analysis (B) preference expressed by middle-aged and seniors toward the female android robots Sophia and Erica were considered. Participants’ gender and their age (middle-aged and seniors) were considered as between subjects’ factors and RAQ scores obtained in terms of willingness to interact, pragmatic (PQ), hedonic-identity (HQI), hedonic-feeling (HQF) and attractiveness (ATT) qualities as within subjects’ factors. The significance was set at $\alpha < .05$ and differences among means were assessed through Bonferroni’s post hoc tests. Due to the reverse correction of negative items, low scores summon to more positive and high scores to more negative robots’ evaluations. The third and last data analysis compares preferences expressed by middle-aged and senior participants toward female virtual agents and android robots. To this aim, PQ, HQI, HQF and ATT scores obtained
by the agents Clara and Giulia and the robots Erica and Sophia were respectively added together. Repeated measures ANOVA analyses were performed considering participants’ gender and age (middle-aged and seniors) and stimulus’ type (virtual agents and android robots) as between subjects’ variables. PQ, HQI, HQF, and ATT scores were considered as within subjects’ variables. The significance was set at $\alpha < .05$ and differences among means were assessed through Bonferroni’s post hoc tests. Due to the reverse correction of negative items, low scores summon to more positive and high scores to more negative evaluations of either the proposed agents or robots.

4 Descriptive Statistics

Before describing results obtained through the statistical analysis, in the present section will be portrayed some information concerning participants’ educational level and their degree of experience with technological devices. As shown in Figs. 3 and 4, seniors which were administered robot, reported lower educational levels and lower degree of technological expertise compared to the groups of middle-aged participants, both the ones who saw robots and virtual agents.

![Educational level](image.png)

Fig. 3. Descriptive statistics: educational level of the four group of participants

5 Results-Virtual Agents’ Assessment (A)

Separate ANOVA repeated measures analyses were carried out on the VAAQ questionnaire’s scores to assess participants’ preferences toward the two virtual agents. Participants’ gender and their age group (middle-aged = Group 1 and seniors = Groups 2) were considered as between subjects and VAAQ scores as within subjects’ factors. For sections 2 (willingness to interact), 3 (PQ), 4 (H奎), 5 (HQF) and 6 (ATT) due to the reverse correction of negative items, low scores summon to positive agents’ assessments whereas high scores to negative ones. In all the analyses, the significance level was set at $\alpha < .05$ and differences among means were assessed through Bonferroni’s post hoc tests.
Comparing Middle-Aged and Seniors’ Preferences Toward Virtual Agents

Fig. 4. Descriptive statistics: participants’ technological expertise

**Willingness to Interact**
Significant differences emerged between age’ groups (F (1,87) = 24.607, p << .01): seniors’ (mean = 1.634) were significantly more prone than middle-aged (mean = 2.333, p << .01) participants to interact with the agents. Significant differences emerged in participants’ willingness to interact (F (1,87) = 12.045, p = .001) with the proposed agents, both seniors and middle-aged participants were significantly more willing to interact with Giulia (mean = 1.789, p = .001) rather than with Clara (mean = 2.179).

**Pragmatic Qualities (PQ)**
Significant differences emerged between PQ scores attributed to the agents by seniors and middle-aged participants (F (1,87) = 26.948, p << .01): agents were considered significantly more useful by seniors (mean = 20.624) compared to middle-aged participants (mean = 26.948, p << .01). The two proposed agents differed significantly in the PQ scores attributed to them (F (1,87) = 6.751, p = .011), Giulia (mean = 22.638) was considered significantly more useful than Clara (mean = 24.934, p = .011) by both seniors and middle-aged participants.

**Hedonic Qualities-Identity (HQI)**
Significant differences emerged between HQI scores attributed to the agents by seniors and middle-aged participants (F (1,87) = 14.184, p << .01), agents were considered significantly more pleasant by seniors (mean = 22.252) compared to middle-aged participants (mean = 27.485, p << .01). The two female agents differed significantly in the HQI scores attributed to them (F (1,87) = 10.748, p = .002): Giulia (mean = 23.287) was considered significantly more pleasant than Clara (mean = 26.450, p = .002) by both seniors and middle-aged participants.

**Hedonic Qualities-Feeling (HQF)**
Significant differences emerged between HQF scores attributed to the agents by seniors and middle-aged participants (F (1,87) = 19.526, p << .01), agents were considered significantly more able to arouse positive feelings by seniors (mean = 21.616) compared to middle-aged participants (mean = 27.878, p << .01). The two proposed female agents significantly differed in the HQF scores attributed to them (F (1,87) = 5.124, p = .026),
Giulia (mean = 23.728) was considered more able to arouse positive feelings than Clara (mean = 25.767, p = .026) by both seniors and middle-aged participants. A significant interaction emerged between participants’ age group and HQF scores (F (1,87) = 5.335, p = .023). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and Clara and Giulia HQF scores). Tests revealed that: concerning participants’ age, Clara (mean = 23.676) and Giulia (mean = 19.557) were significantly more able to elicit positive feeling in seniors rather than middle-aged participants (Clara: mean = 27.857, p = .017; Giulia: mean = 27.899, p << .01). Concerning the HQF scores, seniors attributed to Giulia (mean = 19.557) HQF scores significantly more positive than those attributed to Clara (mean = 23.676, p = .002).

**Attractiveness (ATT)**

Significant differences emerged between age’ groups (F (1,87) = 20.311, p << .01). Seniors (mean = 20.939) considered the two proposed agents significantly more attractive than middle-aged participants (mean = 27.119, p << .01). Clara and Giulia scored slightly differently in terms of attractiveness (F (1,87) = 4.263, p = .042). Giulia (mean = 23.097) was considered slightly more attractive than Clara (mean = 24.962, p = .042).

Fig. 5 summarizes the above discussed results.

![Virtual Agents' assessment](image)

**Fig. 5.** Middle-aged and seniors’ assessment of the two proposed virtual agents Clara and Giulia on willingness to interact, PQ, HQI, HQF, and ATT scores

### 6 Results-Robots’ Assessment (B)

Separate ANOVA repeated measures analyses were carried out on the RAQ questionnaire’s scores to assess participants’ preferences toward the two android robots. Participants’ gender and their age group (middle-aged = Group 3 and seniors = Groups 4) were considered as between subjects and RAQ scores as within subjects’ factors. For sections 2 (willingness to interact), 3 (PQ), 4 (HQI), 5 (HQF) and 6 (ATT) due to the reverse correction of negative items, low scores summon to positive robots’ assessments whereas high scores to negative ones. In all the analyses, the significance level was set at $\alpha < .05$ and differences among means were assessed through Bonferroni’s post hoc tests.
Comparing Middle-Aged and Seniors’ Preferences Toward Virtual Agents

Willingness to Interact
Significant effects of participants’ gender (F(1,86) = 7.355, p = .008) were observed in terms of willingness to interact with the proposed female robots. Male participants (mean = 2.252) were significantly more willing to interact than female participants (mean = 2.869, p = .008) with the proposed robots. Significant differences emerged between age groups (F(1,86) = 11.644, p = .001), middle-aged (mean = 2.173) were significantly more prone than seniors (mean = 2.948, p = .001) to interact with the proposed robots. Willingness to interact scores differed significantly between the proposed female robots (F(1,86) = 15.226, p << .01): participants were significantly more willing to interact with Erica (mean = 2.323) rather than with Sophia (mean = 2.798, p << .01). A significant interaction emerged between age groups and willingness to interact scores (F(1,86) = 13.988, p << .01). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and Erica and Sophia willingness to interact scores). Tests revealed that concerning participants’ age, seniors (mean = 3.482) were significantly less willing than middle-aged participants (mean = 2.183, p << .01) to interact with Sophia. Concerning robots, seniors’ willingness to interact scores attributed to Sophia (mean = 3.482) were significantly worse than those attributed to Erica (mean = 2.482, p << .01).

Pragmatic Qualities (PQ)
Robots’ pragmatic qualities were significantly affected by participants’ gender (F(1,86) = 6.216, p = .015). Male participants (mean = 26.665) considered the proposed robots significantly more useful than female participants (mean = 29.718, p = .015). PQ scores differed significantly between the two robots (F(1,86) = 12.449, p = .001). Erica (mean = 27.366) was considered significantly more useful than Sophia (mean = 29.017, p = .001). A significant interaction emerged between participants’ age and PQ scores (F(1,86) = 7.698, p = .007). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and robots – Erica and Sophia PQ scores). Concerning participants’ age, seniors (mean = 30.715) considered Sophia significantly less useful than middle-aged participants (mean = 27.318, p = .012). Concerning the two robots, PQ scores attributed by seniors to Sophia (mean = 30.715) were significantly worse than those attributed to Erica (mean = 27.766, p << .01).

Hedonic Qualities-Identity (HQI)
HQI scores were significantly affected by participants’ gender (F(1,86) = 6.941, p = .010). Male participants (mean = 25.603) considered the robots significantly more pleasant than female participants (mean = 28.875, p = .010). Significant differences emerged between age groups (F(1,86) = 4.982, p = .028). Middle-aged participants (mean = 25.853) considered the robots significantly more pleasant than seniors (mean = 28.625, p = .028). HQI scores significantly differed between the two proposed robots (F(1,86) = 29.198, p << .01). Erica (mean = 25.555) was considered significantly more pleasant than Sophia (mean = 28.922, p << .01). A significant interaction emerged between participants’ age and HQI scores (F(1,86) = 11.256, p = .001). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and robots – Erica and Sophia HQI scores). Concerning participants’ age, seniors (mean = 31.354) considered Sophia significantly less pleasant than middle-aged participants (mean = 26.491, p = .002). Concerning the robots, seniors’ HQI scores attributed by seniors to
Sophia (mean = 31.354) were significantly worse than those attributed to Erica (mean = 25.895, p << .01).

**Hedonic Qualities-Feeling (HQF)**
HQF scores were significantly affected by participants’ gender (F (1,86) = 6.548, p = .012). Male participants (mean = 24.780) considered the proposed robots significantly more able to arouse positive feelings than female participants (mean = 28.203, p = .012). HQF scores significantly differed between the two robots (F (1,86) = 5.914, p = .017). Erica (mean = 25.799) was considered significantly more able to arouse positive feelings than Sophia (mean = 27.184, p = .017). A significant interaction emerged between participants’ age and HQF scores (F (1,86) = 13.196, p << .01). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and robots – Erica and Sophia HQF scores). Concerning participants’ age, HQF scores attributed to the proposed robots did not differ significantly among seniors and middle-aged participants. Concerning the robots, HQF scores attributed by seniors to Sophia (mean = 28.213) were significantly worse than those attributed to Erica (mean = 24.760, p << .01).

**Attractiveness (ATT)**
ATT scores were significantly affected by participants’ gender (F (1,86) = 9.303, p = .003). Male participants (mean = 24.978) considered the proposed robots significantly more attractive than female participants (mean = 28.490, p = .003). Participants’ age significantly affected ATT scores (F (1,86) = 9.063, p = .003). Middle-aged participants’ (mean = 25.001) considered the robots significantly more attractive than seniors (mean = 28.467, p = .003). ATT scores significantly differed between the two robots (F (1,86) = 5.147, p = .026). Erica (mean = 26.109) was considered significantly more attractive than Sophia (mean = 27.359, p = .026). A significant interaction emerged between participants’ age and ATT scores (F (1,86) = 17.989, p << .01). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and robots – Erica and Sophia ATT scores). Concerning participants’ age, seniors (mean = 30.261) considered Sophia significantly less attractive than middle-aged participants (mean = 24.458, p << .01). Concerning the robots, ATT scores attributed by seniors to Sophia (mean = 30.261) were significantly worse than those attributed to Erica (mean = 26.674, p << .01). Figure 6 summarized these results.

### 7 Results-Comparing Virtual Agents and Robots (C)

Scores at participants’ Willingness to Interact (second section of the VAAQ and RAQ questionnaires, respectively) composed of a single item were analyzed through arithmetical means. Conversely, PQ, HQI, HQF and ATT scores obtained by the agents Clara and Giulia and the robots Erica and Sophia were respectively added together. Repeated measures ANOVA analyses were carried out considering participants’ gender and age (middle-aged and seniors) and stimulus’ type (virtual agents and android robots) as between subjects’ variables. PQ, HQI, HQF, and ATT scores were considered as within subjects’ variables. The significance was set at $\alpha < .05$ and differences among means
Comparing Middle-Aged and Seniors’ Preferences Toward Virtual Agents

Fig. 6. Middle-aged and seniors’ assessment of the female android robots Sophia and Erica on willingness to interact, pragmatic (PQ), hedonic-identity (HQI), hedonic- feeling (HQF), and attractiveness (ATT) scores.

were assessed through Bonferroni’s post hoc tests. Please note, due to the reverse correction of negative items, low scores summon to more positive and high scores to more negative evaluations of either the proposed agents or robots.

Willingness to Interact
Participants’ willingness to be involved in a potential long-lasting interaction with the proposed agents or robots is reported in Table 1. The data suggest that seniors are more willing than middle-aged participants to interact with virtual agents rather than robots. This is not the case with middle-aged participants who did not show preferences towards either agents or robots.

Table 1. Virtual Agents and Robots’ scores in terms of participants’ willingness to interact with them.

<table>
<thead>
<tr>
<th></th>
<th>Virtual Agents</th>
<th></th>
<th></th>
<th>Robots</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>4.644</td>
<td>1.583</td>
<td></td>
<td>4.333</td>
<td>1.610</td>
</tr>
<tr>
<td>Seniors</td>
<td>3.261</td>
<td>1.084</td>
<td></td>
<td>5.911</td>
<td>2.695</td>
</tr>
</tbody>
</table>

Comparing Agents and Robots’ PQ, HQI, HQF, and ATT Scores
Significant effects of participants’ age emerged (F (1,173) = 4.968, p = .027). PQ, HQI, HQF, and ATT scores attributed by seniors (mean = 49.563) either to the robots or agents were significantly more positive than those attributed by middle-aged participants (mean = 53.480, p = .027). Significant differences emerged among agents and robots (F (1,173) = 10.195, p = .002). PQ, HQI, HQF, and ATT scores attributed to the agents (mean = 48.715) were significantly more positive than those attributed to robots (mean = 54.328,
A significant interaction (F (1,173) = 7.348, p = .007) emerged between participants’ gender and the type of assistive device (agents vs robots). Bonferroni’s post hoc tests were performed for each single factor (participants’ gender and type of assistive device). Concerning the gender, a significant preference of female participants toward virtual agents (mean = 47.266) rather than android robots (mean = 57.643, p << .01) was observed. Concerning the assistive devices, robots were evaluated significantly more positively by males (mean = 51.013) rather than female participants (mean = 57.643, p = .009), while virtual agents received similar scores by both male (mean = 50.165) and female (mean = 47.266, p = .244) participants. A significant interaction (F (1,173) = 21.139, p << .01) emerged between participants’ age and the type of assistive device (agents vs robots). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and type of assistive device). Concerning participants’ age, seniors scored the agents (mean = 42.716) significantly better than robots (mean = 56.410, p << .01). Concerning the type of assistive device, seniors (mean = 42.716) significantly differed from middle-aged participants (mean = 54.715, p << .01) in attributing significantly more positive scores to the agents rather than robots. Significant differences emerged among PQ, HQI, HQF, and ATT scores (F (3,519) = 3.831, p = .010); both agents and robots were evaluated significantly more positively on ATT scores (means = 50.763) rather than PQ (mean = 51.977, p = .028) and HQI (mean = 52.107, p = .044) scores.

A significant interaction emerged between participants’ age and PQ, HQI, HQF, and ATT scores (F (3,519) = 7.313, p << .01). Bonferroni’s post hoc tests were performed for each single factor (participants’ age and PQ, HQI, HQF, and ATT scores). Concerning participants’ age, middle-aged participants scored agents and robots as more attractive (ATT mean = 52.120) rather than useful (PQ mean = 54.090, p = .007) and able to arouse positive feelings (HQF mean = 54.374, p = .001). Instead, seniors scored agents and robots as more able to arouse positive feelings (HQF mean = 48.103) rather than being useful (PQ mean = 49.865, p = .036) and pleasant (HQI mean = 50.876, p << .01).

A significant interaction emerged between type of assistive device (agents vs robots) and PQ, HQI, HQF, and ATT scores (F (3,519) = 12.349, p << .01). Bonferroni’s post hoc tests, performed for each single factor (type of assistive device and PQ, HQI, HQF, and ATT scores) revealed that, concerning the type of assistive devices, agents’ usefulness (PQ mean = 47.572) was considered more valuable than agents’ pleasantness (HQI mean = 49.737, p = .016) and agents’ ability to arouse positive feelings (HQF mean = 49.494, p = .017). Indeed, robots’ ability to arouse positive feelings (HQF mean = 52.983, p << .01) and attractiveness (ATT mean = 53.468, p << .01) were considered more valuable than robots’ usefulness (PQ mean = 56.382). Concerning PQ, HQI, HQF, and ATT scores, PQ (mean = 47.572), HQI (mean = 49.737) and ATT (mean = 48.058) scores attributed to the agents were significantly more positive than PQ (mean = 56.382, p << .01), HQI (mean = 54.477, p = .012) and ATT (mean = 53.468, p = .003) scores attributed to robots.

A significant interaction emerged among the type of assistive device (agents vs robots), participants’ age and PQ, HQI, HQF, and ATT scores (F (3,519) = 4.702, p = .003). Bonferroni’s post hoc tests were performed only for type of assistive device,
and participants’ age, while PQ, HQI, HQF, and ATT scores were not compared among
them since already discussed at the beginning of this section. Concerning participants’
age seniors’ PQ (mean = 41.248), HQI (mean = 44.504), HQF (mean = 43.233), and
ATT (mean = 41.879) scores significantly differed from middle-aged PQ (mean = 53.896, p << .01), HQI (mean = 54.970, p << .01), HQF (mean = 55.756, p << .01)
and ATT (mean = 54.238, p << .01) scores. Concerning the assistive devices, HQI
(mean = 57.249) and ATT (mean = 56.935) scores attributed to robots by seniors were
significantly different from HQI (mean = 51.706, p = .037) and ATT (mean = 50.002,
p = .007) scores attributed to robots by middle-aged participants. Instead, seniors’ PQ
(mean = 41.248), HQI (mean = 44.504), HQF (mean = 43.233), and ATT (mean = 41.879) scores attributed to the agents differed significantly from seniors’ PQ (mean = 58.481, p << .01), HQI (mean = 57.249, p << .01), HQF (mean = 52.973, p = .001) and ATT (mean = 56.935, p << .01) scores attributed to robots. These results are
summarized in Fig. 7.

Fig. 7. Middle-aged and seniors’ assessment of virtual agents and android robots on willingness
to interact, pragmatic (PQ), hedonic-identity (HQI), hedonic-feeling (HQF) and attractiveness
(ATT) scores.

Figures 8 and 9 report separately the scores attributed by seniors (Fig. 6) and middle-aged
participants (Fig. 7) to the proposed agents and robots.

8 Discussion and Conclusions

The proposed study was devoted at investigating whether middle-aged and seniors’ users
may differ in their preferences to interact with virtual agents (Clara and Giulia) or android
robots (Sophia and Erica) or both. The agents and robots’ investigated qualities were
participants’ willingness to interact with them and scores attributed to their pragmatic
(PQ), hedonic-identity (HQI), hedonic-feeling (HQF) and attractive (ATT) qualities.

When only agents are considered, results show that seniors are significantly more
willing than middle-aged participants to interact with the agents, and judged them as
more useful, easy to use, more pleasant and attractive than middle-aged participants. In
addition, between the two proposed agents, both middle-aged and seniors ex-pressed a clear preference toward the female agent Giulia rather than Clara, suggesting that also agents’ appearance plays a role in users’ preferences. It is likely that this choice was motivated by the fact that Clara, was perceived younger than Giulia and therefore appeared more naïve and unprofessional and less capable than Giulia to arouse positive feelings (see details in [8, 14]).

On the other hand, when only robots are considered, it appears that middle-aged participants are significantly more willing than seniors to interact with robots rather than the agents, and judged them as more useful, easier to use, more pleasant and attractive than seniors. In addition, between the two proposed robots, both middle-aged and seniors expressed a clear preference toward the female robot Erica rather than Sophia, suggesting that also robots’ appearance plays a role in determining users’ preferences. It is likely that, the fact that Sophia is hairless may have elicited a sense of social discomfort, since
hairless females are socially unusual in everyday interactional ex- changes, and this feature may have guided participants’ preferences in favor of Erica. Moreover, the fact that we have chosen a hairless robot excluding hairless virtual agents could represent an element which could have affected results and also limited the research, in particular when comparing the two types of assistive devices. This effect was strongly biased by seniors’ rather than middle-aged participants’ scores, the latter did not show significant differences in the scores attributed to the two robots. Finally, when robots and agents were compared together, it clearly appears that seniors’ preferences are strongly toward virtual agents rather than android robots, while middle-aged participants preferences are slightly toward robots rather than virtual agents. This effect seems to suggest a generational change, with middle-aged participants less prejudiced and more used to accept the physical presence of such assistive devices. Other studies [17–19] highlighted younger participants’ more positive attitude toward robots compared to elders, which instead seem to be more engaged by humanoid agents with a less robotic appearance.

In general, when PQ, HQI, HQF, and ATT scores are compared together for robots and agents, it clearly appears that seniors scored agents significantly more reliable, practical, engaging, and attractive than robots, while middle-aged participants even less enthusiast than seniors seemed to prefer robots rather than agents. In addition, significant differences among participants’ gender were observed only for robots, and not for virtual agents, with male more favorable than female participants in initiating a long-lasting interaction with the robots. An element worth to be investigated is if this effect shows-up in a reverse form when android male robots are considered, as to test a possible cross-gender effect, or in other words male participants preference toward female robots and female participants better evaluation of male robots [20, 21]. Otherwise, it can be deducted that female are less available than male participants to be assisted by robots, as already showed by studies highlighting that females have more negative attitudes toward interaction with robots than males [22–24].

Conclusively, the present study highlighted that both types of assistive devices and the age of their users play a fundamental role in the design and implementation of ambient assisted living technologies. It also suggests that preferences may be generational, as for the datum that seniors showed a clear preference toward virtual agents rather than robots, while middle-aged preferences were in the opposite direction. In addition, this study showed that depending on the type of assistive device, the gender attributed to the device plays a role on its acceptance. Female robots are more accepted by male rather than female users. Finally, the appearance of the device plays a role on users’ acceptance. Mature virtual assistants are preferred to younger ones, haired robots are preferred to hairless.

These results may also be attributed to a cultural generational gap existing between seniors and middle-aged participants either in their educational level or their experience with the technology or both. It is evident that the two groups of seniors and particularly seniors which were administered the robots’ stimuli, reported lower educational levels and lower degrees of technological expertise with respect to the two groups of middle-aged participants. These differences may support the hypothesis of a generational gap. More investigations are however needed to assess these data and the proposed work posits the bases for future research.
Future works should also consider comparisons between male virtual agents and robots, and then male and female virtual agents and robots, as well as involve differently aged groups of participants, among those adolescents and young adults.

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References

Towards an Assessment Model of Governance for Active and Healthy Ageing: Results from the ASTAHG Project

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Abstract. Population ageing calls for an evidence based and efficient AHA governance through the involvement and shared commitment of different stakeholders according to the Quadruple Helix approach. Based on these premises, the Alpine Space Transnational Governance of Active and Healthy Ageing (ASTAHG) project collected information on AHA policies implemented in the AS and promoted the development of an assessment model of governance for AHA. Policy data, gathered through a survey defined ad hoc by the project partners, have been a functional source of information for the development of the assessment model. The latter procedure, starting from the six evaluation criteria defined by the Development Assistance Committee of the Organization for Economic Co-operation and Development, involved three further steps, including the selection of indicators, variables, and related targets. Textual analysis of the descriptive texts collected through the ASTAHG survey was used for the process of constructing indicators and variables. The methodology underlying the model suggests that indicators, variables, and targets can be adapted according to the specific characteristics and priorities of each territorial area as well as the evaluation object and objectives. Such a model aims to support governance for AHA in self-monitoring and self-evaluation processes by identifying challenges and rooms for improvement of analyzed policies as well as providing policy makers with a flexible operational tool adaptable to the needs of each context. Future reflections and interventions are however necessary to ensure further development of our assessment model as well as its practical applications in contexts other than the AS.

Keywords: Active and healthy ageing · Governance · Alpine space · Policy · Assessment

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1 Introduction

Demographic change is one of the main challenges faced by governments, economies, and societies of developed countries. This endeavor requires the joint commitment of different stakeholders to support Active and Healthy Ageing (AHA), defined as «the process of optimizing opportunities for health, participation, and security in order to enhance quality of life as people age» (WHO 1994, 2002, 2017).

To tackle the challenges of ageing, the Alpine Space Transnational Governance of Active and Healthy Ageing (ASTAHG) project aimed to develop and implement a transnational, multisectoral and multilevel approach and social innovation framework to promote AHA in the Alpine Space (AS). The AS is defined as a transnational heterogeneous geographic area composed of regions belonging to different countries and showing specific and distinctive territorial characteristics and priorities (Bausch 2014), which manifest somewhat common needs that require targeted and coordinated interventions. This being so, to promote AHA in the AS, the general objective of ASTAHG project was twofold: 1) improving the governance capacities of regional AHA policies and 2) easing the transferring of innovations and initiatives within the AS.

Governance has been defined as the formulation and implementation of public policies for the development of a territory based on coordinating actions of different actors, promoting stakeholder involvement and participation, integrating various policy sectors, being adaptive to changing contexts, and producing context-related specificities and impacts (Rivolin et al. 2014; WHO 2011). Consequently, the improvement of governance capacities has the objective of ameliorating policy performance, which results in the formulation and implementation of better policies (WHO 2016). Because policies represent the first level of implementation of governance, it follows that AHA policy analysis can be a pragmatic and useful starting point for the assessment of AHA governance models.

Within the ASTAHG project, a specific activity concerned the data gathering of AHA governance models in the AS and their assessment. The aim of this task was to evaluate the characteristics of existing policies (i.e., expression of governance models) in the AS - assessing their limits and institutional bottlenecks, as well as strengths and rooms for improvement. The ultimate purpose of these actions was to contribute to building up and enabling capacities for evidence based and efficient AHA decision making in the AS area. Within this framework, the present paper shows the development and implementation process of an assessment model of AHA governance, considering the AHA policies collected in the AS during the ASTAHG project.

The authors of this paper belong to a regional context—Friuli Venezia Giulia region, Italy—characterized by several experiences on AHA (WHO 2018) and by a strong legal framework supporting AHA initiatives, the Regional Law n.22/2014 «Combating loneliness and promoting active ageing». In this context the ASTAHG project found a fertile ground for testing innovative solutions and for developing further theoretical and operational steps on the topic of AHA.

1 This Law was one of the AHA policies collected during the ASTAHG project. It was amended by Regional Laws n.28/2015 and n.18/2020.
2 The Collection of AHA Policies in the AS

A collection of AHA policies implemented in the AS was carried out using a survey, developed ad hoc by the ASTAHG project partners, which was completed at four different times: May 2019 (Time 1), from July to November 2019 (Time 2), from January to May 2020 (Time 3), from June to July 2020 (Time 4). Policy information was collected through literature reviews and during Transnational Governance Board meetings, independent meetings, or local events. Pre-selection criteria had been applied during data collection to gather only policies that were 1) effective (i.e., achieved their objectives), 2) cost-effective compared to available alternatives, 3) transferable to different contexts (i.e., other AS regions participating in the ASTAHG project), and 4) multisectoral (i.e., covering at least two sectors among social care, health care, long term care, independent living, wellbeing, culture and tourism, mobility and transport). The stakeholders involved in the survey were identified by the project partners following the Quadruple Helix approach that recognizes the crucial role of four main actors in innovation processes, i.e., governance, academia, industry, and civil society. Overall, 7 AHA policies implemented in three countries of the AS were collected: three in Italy, two in France and two in Slovenia.

2.1 The ASTAHG Survey

The survey consisted of 57 questions grouped in the following dimensions: general characteristics and context, description of the AHA policy, innovation level, target population and time frame, stakeholders and governance, design, decision making and operational processes, evaluation and budget and respondents’ information. Referring to these dimensions, detailed information on policies was requested, such as their geographic context, maturity level, priority and other involved sectors, aims and objectives, drivers and opportunities as well as barriers to implementation, type of innovation, primary and secondary users, access restrictions, duration, responsible stakeholder and other engaged stakeholders, horizontal and vertical governance, effectiveness and impact evaluation and funding. Some questions were open-ended, while others were multiple choice, requesting to select one or more options in a drop-down menu. Completing the survey required about 40 min.

3 The Development of the Assessment Model of Governance for AHA

An assessment model of the governance for AHA in the AS—based on the theoretical and methodological framework developed in the ASTAHG project and other metrics

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2 ASTAHG project Output T2.1 “Framework for collaboration on AHA initiatives”; Responsible partners: European Centre for Social Welfare Policy and Research (Austria), Centre for Ethics and Poverty Research at University of Salzburg (Austria); Authors: Christian Ernst Heinrich Boehler, Rahel Kahlert, Leonard Geyer, Annemarie Müllauer, Elisabeth Kapferer, Andreas Koch 2020.
Towards an Assessment Model of Governance

provided by the literature—was then operationalized starting from the policy data collected through the ASTAHG survey. The goal of this in-depth study and information analysis was to gather as many elements as possible for the development of a transparent and evidence-based assessment model of AHA governance, targeted at the needs of the AS area.

3.1 The Methodology Underlying the Assessment Model

The reference methodological framework adopted for the development of the assessment model was Lazarsfeld’s procedural model (Lazarsfeld 1958, 1959; Lazarsfeld and Barton 1951), based on which a logical-methodological procedure for the construction of complex variables (operationalization) was applied (Lazarsfeld 1958). The first stage of Lazarsfeld’s model involves defining a concept measurable to a variable extent. This concept is then broken down into indicators, representing empirically detectable properties with a lower level of generality with respect to the concept to which they refer. The indicators are in turn broken down and operationalized into variables, defined as properties to which different values are assigned. Indicators, therefore, have the function of synthesizing into a single piece of information a wider set of more analytical information (variables). In a nutshell, Lazarsfeld’s model proceeds from the general concepts to the more specific variables.

Being rooted in this methodological framework, the development of the assessment model of the governance for AHA in the AS included four steps: 1) the identification of the main dimensions (the concepts in Lazarsfeld’s model) for the evaluation of AHA governance; 2) the selection of indicators; 3) the selection of variables; 4) the setting of targets (see Fig. 1).

Fig. 1. The four steps of the AHA governance assessment model.

The Identification of Dimensions. Starting from the framework developed in the ASTAHG project, we identified the evaluation criteria defined by the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD) as main dimensions for the evaluation of AHA governance. These dimensions, i.e., Relevance, Coherence, Effectiveness, Efficiency, Impact and Sustainability (OECD 2019, 2020), correspond to conceptual macro-areas allowing the identification of the crucial aspects for governance models assessment and represent a widely adopted reference framework for the evaluation of projects, programmes as well as public policies.
More specifically, 1) Relevance measures whether the policy is addressing and responding to needs and priorities of a target population in a specific context; 2) Coherence takes into account two main aspects: the compatibility of the policy with other interventions in the same context and the maturity (“readiness”) of the specific context in which the policy is embedded; 3) Effectiveness is related to outcomes, and accounts for the extent to which the policy is achieving its objectives and results; 4) Efficiency refers to both economic and temporal dimensions, and measures the extent to which the policy delivers results in an economic and timely way; 5) Impact accounts for the extent to which the policy has generated long-term effects (e.g., intended or unintended, positive or negative) related to different spheres (e.g., economic, social, environmental); 6) Sustainability prospectively measures to which extent the benefits of the policy will last over time. It is important to specify that both impact and sustainability refer to a broad time horizon. Figure 2 summarises the crucial aspects investigated by the dimensions derived from the OECD DAC evaluation criteria.

<table>
<thead>
<tr>
<th>1. Relevance</th>
<th>Is the policy doing the right things to respond to needs and priorities of a target population in a specific context?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Coherence</td>
<td>How well does the policy fit? (compatibility with other interventions and “readiness” of the context)</td>
</tr>
<tr>
<td>3. Effectiveness</td>
<td>To what extent is the policy achieving its objectives/results?</td>
</tr>
<tr>
<td>4. Efficiency</td>
<td>To what extent does the policy deliver results in an economic and timely way?</td>
</tr>
<tr>
<td>5. Impact</td>
<td>What difference does the policy make? Which are its effects? (social, environmental, economic, …)</td>
</tr>
<tr>
<td>6. Sustainability</td>
<td>To what extent will the benefits of the policy last?</td>
</tr>
</tbody>
</table>

**Fig. 2.** Questions underlying the OECD DAC evaluation criteria.

**The Selection of Indicators and Variables.** Indicators were selected for each of the six identified dimensions. While selecting the relevant indicators, the six identified dimensions were considered interlinked, in a process that aimed to assess policies starting with the relevance dimension and then moving on to coherence, effectiveness, efficiency, impact, and finally sustainability. For each of the defined indicators, the variables enabling its measurement were selected—resulting in the quantification of the indicators.

**Setting Targets.** For each of the selected variables the targets to be achieved were set according to the assessment objectives, the specific characteristics, the needs and preferences of each context as well as the characteristics of the object to be evaluated and those of the target population.

### 3.2 Identification of Indicators and Variables

Starting from the six dimensions borrowed from OECD DAC evaluation criteria, we identified a first set of indicators and variables. The sources used were an extensive list of theoretical macro-categories (related to specific AHA domains) provided in the literature and included in the framework developed within the ASTAHG project, the ASTAHG survey items and the stakeholder consultation (i.e., the textual analysis of the open-ended answers to the ASTAHG survey items).
Content Analysis. The textual analysis allowed us to examine the qualitative data gathered through the ASTAHG survey items (the stakeholder consultation) to define the indicators and variables to be considered in the development of the assessment model of AHA governance. More specifically, we conducted a content analysis, a specific type of textual analysis, described as “a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use” (Krippendorff 2004, p. 18).

Since the research design of this study involved the use of qualitative techniques to collect information and analyze data, non-probabilistic sampling was used. Specifically, reasoned-choice sampling was adopted in which the subjects are chosen for their characteristics, knowledge and relevance to the topic under investigation (Corbetta 2014; Di Franco 2010). In the case of the present study, the sample included the ASTAHG project partners who represented the privileged witnesses.

The overall goal of the textual analysis was to define indicators and variables that would allow to conduct evaluations through the application of the assessment model. More in detail, the aim of the content analysis was twofold: 1) to select the most appropriate indicators for our assessment model among those provided by the literature and included in the framework developed within the ASTAHG project; 2) to define new indicators, more pertinent and relevant with respect to the AS area, based on the most recurrent elements found in the AHA policies collected and analyzed through the ASTAHG survey.

The analytical procedure included methodologically structured steps. The first one was labeling: A label was assigned to each of the 7 collected AHA policies in order to uniquely identify them. Each label consisted of an alphanumeric code consisting of three elements: 1) the policy sequential number, 2) the first three letters relating to the priority sector of the analyzed policy (among social care, health care, long term care, independent living, wellbeing, culture and tourism, mobility and transport) and 3) the initials of the country of the policy. Table 1 shows the labels assigned to the 7 collected AHA policies.

Table 1. Labels assigned to the collected AHA policies.

<table>
<thead>
<tr>
<th>AHA policies</th>
<th>Labels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy 1 (Italy)</td>
<td>1_wel_it</td>
</tr>
<tr>
<td>Policy 2 (Slovenia)</td>
<td>2_hea_sl</td>
</tr>
<tr>
<td>Policy 3 (Italy)</td>
<td>3_soc_it</td>
</tr>
<tr>
<td>Policy 4 (France)</td>
<td>4_lon_fr</td>
</tr>
<tr>
<td>Policy 5 (France)</td>
<td>5_lon_fr</td>
</tr>
<tr>
<td>Policy 6 (Slovenia)</td>
<td>6_mob_sl</td>
</tr>
<tr>
<td>Policy 7 (France)</td>
<td>7_hea_fr</td>
</tr>
</tbody>
</table>
Regarding the coding of the collected data, we used selective coding. We started from some basic theoretical assumptions (i.e., theoretical macro-categories related to specific AHA domains provided in the literature and included in the framework developed within the ASTAHG project) and we used them as categories of analysis. Through the latter, we analyzed the descriptive texts of the policies collected through the survey (i.e., the open-ended answers to the ASTAHG survey items) and, for each category of analysis, we selected several text passages that allowed us to identify some potential indicators to be considered for the development of our assessment model (Cardano 2003; Vargiu 2007). Table 2 summarizes a part of the data coding procedure for the collected AHA policies, showing the starting theoretical macro-categories – related to specific AHA domains, the labels of the analyzed policies, the selected text passages, and finally the indicators emerged as a result of the content analysis. These identified indicators synthesize the key themes expressed in the corresponding analyzed text passages. The research group consisted of three coders (ASTAHG project team members) coordinated by a scientific supervisor providing external methodological support services.

Furthermore, through the analysis of text passages resulting from the compilation of the ASTAHG survey (i.e., the open-ended answers to the survey items), we identified some indicators that could not be associated with the macro-categories and related AHA domains included in the framework developed within the ASTAHG project—and were only used to test the application of our assessment model. Some of these indicators are adaptability level (i.e., degree of adaptability of the policy to different geographical contexts), maturity level (i.e., the extent of policy consolidation), Quadruple Helix approach (i.e., the extent to which actors belonging to the Quadruple Helix are involved in the design, decision-making, and operational processes), effectiveness evaluation (i.e., the presence of an effectiveness evaluation and the definition of related indicators) and impact evaluation (i.e., the presence of an impact evaluation and the definition of related indicators). Overall, the set of indicators we have developed represents, for each stakeholder, a starting point that could be adapted, expanded, and modified according to the specific characteristics, needs and priorities of each territorial area—as well as the evaluation object and objectives.

3.3 An Example of Application of the Assessment Model

Referring to the four steps of the assessment model outlined in Sect. 3.1, Table 3 gives examples of indicators, variables and related targets selected based on the available information collected through the ASTAHG survey. Specifically, the indicators maturity level and adaptability level are derived from the analysis of the ASTAHG survey items (these two policy characteristics were in fact investigated by two specific survey items) and both refer to the coherence dimension. As variables associated with these indicators, we selected the answer options of the two related items (i.e., multiple choice questions) from the ASTAHG survey: the first item referred to the maturity level of the policy while the second one to its geographic context. Regarding the targets, for the maturity level we selected 2. pilot stage or 3. routine use, as these two levels refer to policies with a higher level of maturity. Similarly, as targets for the adaptability level we selected all answers that included the presence of mountain areas, alone or together with other types of geographical contexts (i.e., 1. mountain areas, 4. mountain and rural areas, 5.
### Table 2. Coding of collected data: from theoretical macro-categories to indicators.

<table>
<thead>
<tr>
<th>AHA Domains</th>
<th>Macro-categories</th>
<th>Policy labels</th>
<th>Text passages</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic engagement &amp; Social Participation</td>
<td>Civic engagement</td>
<td>3_soc_it</td>
<td>“The Law enhances the role of citizens, older people and others, in determining a change in the old social policy models”</td>
<td>Active involvement and role in political and social life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3_soc_it</td>
<td>“interventions (...) in the areas of (...) volunteering”</td>
<td>Participation in volunteer activities</td>
</tr>
<tr>
<td>Community inclusion</td>
<td></td>
<td>3_soc_it</td>
<td>“Law 22/2014 contrasts all phenomena of prejudice and discrimination towards the third age”</td>
<td>Presence of interventions to combat prejudice and discrimination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7_hea_fr</td>
<td>“(...) the central themes of the (...) Plan, such as (...) reduction of social and territorial inequalities”</td>
<td>Presence of interventions to reduce social and territorial inequalities</td>
</tr>
<tr>
<td>Health &amp; care</td>
<td>Health promotion and prevention</td>
<td>4_lon_fr</td>
<td>“target actions of prevention of the loss of autonomy of elderly people”</td>
<td>Presence of interventions aimed at preventing loss of autonomy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7_hea_fr</td>
<td>“Adaptation of training courses for care staff in institutions”</td>
<td>Presence of training courses for care staff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2_hea_sl</td>
<td>“better integration of the health system in the social systems of local communities”</td>
<td>Social and health services accessibility</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>AHA Domains</th>
<th>Macro-categories</th>
<th>Policy labels</th>
<th>Text passages</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication, information &amp; education</td>
<td>Availability and usability of information</td>
<td>3_soc_it</td>
<td>“The associations have the possibilities to promote and give visibility to their activities on active ageing and share best practices with other stakeholders on the regional website for the active ageing”</td>
<td>Use of tools to share, disseminate, and promote activities conducted in support of AHA</td>
</tr>
<tr>
<td>Housing, outdoor spaces &amp; enabling environment</td>
<td>Living environment</td>
<td>7_hea_fr</td>
<td>“Offering innovative and alternative responses between home and institutional care (intergenerational housing; relay; temporary emergency accommodation, etc.)”</td>
<td>Presence of Ambient Assisted Living (AAL) solutions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3_soc_it</td>
<td>“a range of personal care services that guarantee (…) a response focused on the habitual living places”</td>
<td></td>
</tr>
</tbody>
</table>
mountain and urban areas or 7. mountain, rural and urban areas). The choice of this last target is closely linked to the peculiar nature of the AS area, highlighting how the application of the developed assessment model for AHA governance can be adapted according to the specificities of different territories, regions, or countries.

Table 3. Application example: dimension, indicator, variable, and target.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Indicator</th>
<th>Variable</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherence</td>
<td>Maturity level</td>
<td>Maturity level:</td>
<td>2 or 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. proof of concept</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. pilot stage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. routine use</td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td></td>
<td>Geographic context:</td>
<td>1, 4, 5 or 7</td>
</tr>
<tr>
<td>level</td>
<td></td>
<td>1. Mountain areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Rural areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Urban areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Mountain and rural areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Mountain and urban areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Rural and urban areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. Mountain, rural and urban areas</td>
<td></td>
</tr>
</tbody>
</table>

Depending on the assessment object and objectives—as well as the characteristics, needs and priorities of both specific context and target population—the choice of indicators, variables and targets may therefore vary to better define a model that is as consistent as possible with the geography and the specificities of different analyzed territorial settings.

4 Discussion and Implications

The present paper represents a first attempt to operationalize the framework developed within the ASTAHG project, as well as the theoretical and methodological guidelines provided by the literature, through the development of an assessment model of the governance for AHA in the AS. This model lends itself to a double reading: 1) among policies, allowing a comparative analysis of different AHA policies by identifying their common elements and differences; 2) within each policy, allowing the identification of its strengths, weaknesses, opportunities, threats and rooms for improvement.

It is necessary to emphasize that the main aim of the assessment was not to build a ranking of the analyzed policies but rather to concretely support governance for AHA with self-monitoring and self-evaluation processes. The assessment model aims to 1) identify rooms for improvement, challenges and future directions to be pursued to ensure continuous improvement of AHA policy making, 2) equip policy makers with a transversal and flexible tool, potentially applicable and adaptable to the profile of the most varied territorial, political and socio-cultural contexts and 3) provide a framework and a structured method for the development of further practical tools through the involvement of
specific expertise in the field of monitoring and evaluation. In a nutshell, the aim of the model is not to identify who is doing better but to provide useful indications so that everyone can do better, especially in a context, such as the AS area, where cooperation, both institutional and operational, is a crucial aspect.

Overall, the methodology for the assessment of AHA governance models described in the present work could form the basis for the development of further reflections as well as operational tools and interventions in support of AHA governance, concretely impacting the choices of policy makers. The model could also offer food for thought for the identification and potential development of specific solutions (e.g., technologies or services related, for example, to health and care, AAL, or communication, information and education) to be applied in the assessed territories in an effort to help strengthen their weaknesses and fill in their identified gaps. Overall, this paper enhances the formulation and implementation of increasingly evidence based AHA policies that are able to meet the needs of the elderly population in a targeted and effective way.

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WHO: Global strategy and action plan on ageing and health (2017)
WHO: Healthy settings for older people are healthy settings for all: the experience of Friuli-Venezia Giulia, Italy (2018)
Designing for Inclusion and Well-Being
DOMHO: Internet of Things for Ambient Assisted Co-housing

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Abstract. Technologies must be conceived as a valid support for every final user. The DOMHO project applies the Internet of Things (IoT) paradigm to Ambient Assisted Living. The present work describes the design and development, based on a participatory design approach, of a smart apartment for ambient assisted co-housing for people affected by motor and cognitive impairments. This smart environment featured intelligent lighting, environmental sensors, and automation, manageable through a user interface, for mobile devices, and voice commands. The intelligent apartment will allow testing of the fully integrated DOMHO system in a real-world context. The objective is to assess its ability in promoting independence, autonomy, social interaction, and therefore the overall well-being of people with disabilities.

Keywords: Co-housing · Internet of Things · Voice interfaces · Disabilities · Smart homes

1 Introduction

The term smart home (SH) has become part of our culture and imagination since the 90’, thanks to the iconic figure of Bill Gates [1]. He has been a pioneer in home automation, introducing technologies that automate lights, music, and temperature. Even today, he continues improving his smart home by integrating new cutting-edge devices [2]. However, a smart home includes various types of sensors or effectors connected through a network that permits them to communicate and interoperate with each other [3, 4].

Besides, in recent years, thanks to the market competition, some devices such as the Google Nest [5], Amazon Alexa [6], and Apple HomeKit [7] are now widespread all over the world. Currently, most IoT architecture solutions for home automation comprise a central element, a gateway, which monitors the entire system and responds to human
activities [8]. A smart home is related to the concept of Ambient Assisted Living [9]. Therefore, the IoT paradigm is fundamental in this field thanks to the possibility of favouring a scaling-up economy and opening the market to different players [10].

One of DOMHO’s objectives is to create an innovative and flexible system that can adapt to the needs of different users. Indeed, the IoT system has been designed and developed with a modular architecture and a basic structure capable of accommodating elementary units with specific functions (i.e., human interfacing, environment sensing, data computation, or decision actuation). The present work focuses on one of the projects’ real-world scenarios, i.e., an apartment for the co-housing of people with disabilities and their caregivers. The tests carried out in this environment will allow verifying a set of expected potential benefits for the inhabitants (e.g., increased autonomy, independence, quality of life).

This work is therefore structured as follows: Sects. 1.1 and 1.2, describe in detail the concept of smart homes and studies that involve people with disabilities, focusing on the usefulness of the co-housing experience from a social point of view; Sect. 2, details the project and the participatory design approach; Sect. 3, explains the expected outcomes linked to the experience with the fully integrated DOMHO system.

1.1 Smart Homes

The market of intelligent homes is constantly growing, also thanks to related benefits, such as reduction of energy consumption [11], high degree of innovation of the smart cities [12] and expected increment in well-being, quality of life, and sustainability [13]. A recent market analysis [14] estimates that in 2017 there were 22.5 million smart homes in Europe, which correspond to 9.9% of European households. Another study also quantifies the smart home market growth at ~30% annually or 84 million houses by 2022 [15]. A recent review on the topic [16] has identified 267 different commercialized technologies on the market, classifying them according to 13 application categories: household appliances, lighting, energy and utilities, entertainment, health and wellness, safety and security, baby and pet monitors, clothes and accessories, vehicles and drones, home robots, gardening, etc. This review also provides one of the most recent classifications of automated and intelligent homes. The authors identify five levels of intelligence (i.e., 1 = lowest, to 5 = highest) defined as follows:

1. The house presents some smart devices, i.e., a TV or a baby monitor, but users can decide if activate them, and the technologies do not communicate with each other.
2. At this level, the technologies begin to communicate with each other to support some basic or leisure services, such as heat (smart meter connected to a heat pump and advanced thermometer) or entertainment (smart TV connected to a smartphone).
3. At the third level, the home represents concrete support for the user, providing a basic level of automation and customization, such as turning on the lights at scheduled times (e.g., just before the user returns home).
4. This level introduces some degree of learning based on predicting the user’s need and adaptation to events thanks to environmental sensors and user feedback.
5. At the highest level, however, the system constantly monitors the home, anticipates, and learns from users thanks to the integration of multiple smart devices with the most disparate functions.

However, as reported in this review, the most recent and known studies on SH aim to assess this technology’s technic and economic aspects, showing little consideration for the human factors and potential benefits at the social level. In this regard, Aldrich [17] proposed one of the most authoritative classifications that focused on how SH could meet people with disabilities’ needs, proposing a five-class classification:

1. Homes in which intelligent objects, such as doors or window shades, can be opened via a remote-control switch. Also, motion-activated lighting could be an example of this level.
2. Homes that utilize wired or wireless networks for information exchange, such as a computer-controlled thermostat or lighting.
3. Homes that are connected with the external environment also called connected homes.
4. Homes that exploit the possibilities derived from cloud computing to analyze patterns of data and adapt their behavior accordingly.
5. Homes that learn and predict human needs, learning the inhabitants’ routines and acting accordingly.

The take-home message is more focused on the user and on how automation can support people with disabilities to accomplish daily tasks and routines that usually could represent insurmountable obstacles [1]. The automation of the response generates a reduced human involvement and increased accessibility of the environments [18]. Besides, a smart home improves other aspects such as comfort, protection, security, and management of energy resources [19].

1.2 Smart Homes for Disabilities

According to recent statistics, the percentage of Italian people with disabilities reaches 5.2% [20]. However, the world’s percentage is around 15%, according to an analysis carried out by the World Health Organization [21]. These data suggest the enormous importance of considering the disabilities in our society and the possible impact of IoT technologies and Ambient Assisted Living (e.g., people with severe motor disabilities and remote control of doors, shutters, lights). Indeed, the WHO strongly encourages using IoT technologies to improve the quality of life of individuals with disabilities, to allow the reduction of barriers that hinder their social and economic involvement [4]. The positive outcomes of IoT devices in this field are also emphasized by Domingo [22]: “We firmly believe that the IoT can offer people with disabilities the assistance and support they need, to achieve a good quality of life […]. Assistive IoT technologies are powerful tools to increase independence and improve participation”. This vision of the home automation system, with social support for individual independence and autonomy, has led to a slightly different definition of smart homes. In their study, Shin et al. [23] commented that an SH is an intelligent environment that can acquire and apply
knowledge about its inhabitants and surroundings to adapt and meet the goals of comfort and efficiency. A recent literature review reported that SH can improve socialization and even help users overcome the sense of isolation [19]. The authors underline the SH’s “enabling power” and how it can affect the self-efficacy perception [24]. Imagine, for example, a user with a motor disability able to become more autonomous and independent. This occurrence may significantly improve the quality of life of people who typically need frequent and daily assistance from professional or family caregivers.

Furthermore, there is a significant impact also on the caregivers. Recent papers describe the positive effects of assistive environments on workers’ lives by reducing the perceived burden derived from the constant commitment and effort in caring for individuals with disabilities [25, 26]. However, it is equally valid that not all research showed social benefits connected to SH. Some studies highlighted that users may fear the social stigma of using technology and that autonomy and independence could lead people with disabilities to isolate themselves and lose direct contact with others [19].

SH implementations considering the involvement of people with disabilities were detailed in a study conducted by Andrich and colleagues on the DAT project [27]. The project aimed to create an intelligent home environment to test and develop clinical protocols and innovative system-control solutions. The apartment exploited several technologies for promoting the independence, safety, and health of people with disabilities and reducing the workload of caregivers. In another study, Alam and colleagues [28] reported the testing of a technological solution, i.e., SafeAccess, for ensuring people’s safety with a system that could detect and recognize strangers present outside their homes. A smart door could send notifications to the inhabitants, allowing them to call for help. The ProACT project, active in Italy, Ireland, and Belgium, provides a cloud-based service with various devices, such as smart lights, motion sensors, air quality, cameras, and data collected, physiological signals, acquired with pulse oximeters and glucometers, etc. [29]. Another system, the Robotic Smart Home (RSH, [30]), was designed and installed in Japan to increase living comfort, safety, and security of the elderly and individuals with disabilities. It exploits three robotic assistive systems. The first, a mobility and transfer system, helped people with different disability severity move freely around the house. The second was an IoT-based operational system that helped inhabitants manage the house. The third was an information system connected with medical institutions or users’ devices for physiological monitoring.

Chen and colleagues [31] described another intelligent system for people with high severity motor disability, controlled by a Morse code-based interface. They evaluated the feasibility and efficacy of such a system for several months involving people with severe disabilities and total paralysis. Finally, Enshaeifar and colleagues described the Technology Integrated Health Management (TIHM) project [32], which integrates different IoT devices into a single platform capable of communicating with caregivers. The data collected regarding environmental signals, wearable technologies, and medical devices informed operators about the clinical conditions of dementia patients. The study adopted a co-design approach involving patients, caregivers, clinicians, and industrial partners. Therefore, the result was a system capable of caring for patients through predictive systems, such as detecting urinary infections from bathroom use and temperature or noticing dangerous events (i.e., falls).
There are also examples of the integration of prototypes with devices already on the market. A recent work [33] has detailed a framework that would allow people with different disabilities, such as blindness or deafness, to interact with the home environment. Another system from Mtshali and Khubisa [34] postulated the use of commercial voice assistants (i.e., Amazon Alexa, Google Home, or Apple Siri) to control the lighting system. Besides, a study performed in 2018 by Pradhan and collaborators [35] supports the opportunity of using commercial voice assistants (e.g., Amazon Echo) with people with different disabilities. Other studies have then confirmed the benefits of using commercial devices, such as Google Assistant and Apple Siri. In the study by Balasuriya et al. [36], the 72% of participants with disabilities reported as preferred means of interaction with smart devices the voice-based command.

Nevertheless, some research raises doubts, perplexities, and fears concerning using smart technologies considering people with physical or mental impairment [19]. The risk is that the person with disabilities, having reached a sufficient degree of independence, is left alone. For these reasons, while continuing to believe that IoT systems represent reasonable technological solutions aimed at improving the quality of life in the context of disability, we should emphasize that such systems cannot wholly replace the assistance provided by health care professionals or informal caregivers.

2 Project Description

This work describes the system that end-users will have at their disposal in the smart co-housing apartment. We highlight how we designed and developed the environment, describing the co-design phases that define the requirements of the involved end-users and caregivers. Moreover, to permit a positive user experience, smart technologies must be highly accessible and usable, aspects which will facilitate their acceptance. These design principles will influence the potential adoption and systematic use of technologies to carry out daily actions and guarantee individuals’ safety. Therefore, the control interfaces must be specifically conceived based on their physical, perceptual, and cognitive characteristics. Thus, the DOMHO apartment aims to support people with different disabilities, increase their independence, autonomy, safety, and quality of life, and consider the operators and their workload.

2.1 The Smart Apartment Structure

The residential apartment in Castelfranco Veneto (PD, Italy) is a 56 sqm structure consisting of two bedrooms (with a hallway), a large living room with a kitchen, and a bathroom equipped with an anteroom. The Co-housing experimentation will be organized during the weekends (i.e., Friday - Monday), with different groups of three residents and an educator from the Atlantis Center that will live in the structure. Most future home residents have a moderate/high degree of motor disability, and some users also present mild cognitive impairment. Before the project’s intervention, the apartment had been structurally modified and equipped with technological tools to minimize architectural barriers and increase its accessibility (e.g., external lift, automated beds and rail lifts in the bathroom and the bedrooms, Fig. 1). The renovation has also enlarged the smaller room.
Fig. 1. Useful elements for the reduction of architectural barriers. Figure 1a shows the controllable electric beds and the lights placed above them; Fig. 1b shows the motor that allows the automatic opening of doors; Fig. 1c shows the window shutter engine; Fig. 1d shows the elevator that will take the residents inside the apartment.

2.2 System Architecture

The system architecture is presented in Fig. 2.
The system technologies could communicate thanks to a smart gateway that will manage data exchanges (effectively encrypted and protected), integrating them with those coming from the Cloud. This gateway will allow communication between protocol languages (e.g., ZigBee, LoRaWAN). The system offers flexibility, modularity, and customization features (i.e., adding/removing devices) to adapt to the users’ preferences and needs.

More in detail, the DOMHO system will allow controlling, programming (e.g., creating routinary scenarios), and monitoring the system devices, divided into three categories: lighting, environmental sensors, and pieces of automation.

- **Lighting:** the applications will fully control the lights in the apartment. The adjustment will affect the on/off status and the control of the intensity. Using the RGB system, it is possible to adjust the temperature and colour of the lights placed above the beds (Fig. 3). These modifications increase the level of customization of the spaces based for instance on the activity (relaxed reading).

- **Environmental Sensors:** The different sensors inside the apartment aim to prevent accidents and ensure the inhabitants’ safety. Firstly, volatile organic compound (VOC) sensors have been installed in the living room. Another sensor will monitor air quality, room temperature, ambient brightness, and the presence of fine particles. In the bedroom, an additional ammonia device (NH3) is present to detect urine. Finally, the smart apartment is equipped with 3D cameras (Fig. 4) to count the number of people inside a room, detect their spatial positions, and individuals’ falls. The images collected by the video cameras will not be shared with other devices to preserve the user’s privacy and intimacy. Instead, data will be processed locally to extract only the valuable information linked to individual safety. We defined the places where to install the cameras using the co-design approach. We performed a series of Focus Groups (FG) in which the participants unanimously reported where they were more afraid to fall. Moreover, these smart cameras allow the system to be aware of possible collisions to prevent accidents and damage. All the environmental sensors can send eventual alarms and notifications to caregivers for timely interventions.
Automation: inside the apartment, the windows’ shutters, the blackout curtains, and the doors have been automated. For the first two elements, the system allows to open/close them and block their movement at any time. The doors, however, are controllable by the application and from an integrated system that calculates the movement of inhabitants to supervise them smartly. A complex machine learning algorithm applied to the 3D cameras will permit the system to predict people’s movement trajectories, anticipating their movements and opening automatically the doors.

The DOMHO system presents different user interfaces (i.e., smartphone, tablet, voice-based) to control lights and automation in real-time. Besides, the operator interface (i.e., smartphone) can control all the technologies (including the environmental sensors), program their operation, and create usage scenarios (which activate several IoT devices together). For example, if operators need to prepare the house for the night by closing all the shutters and curtains and turning off the lights, the operator interface allows them to create a scenario, rename it and decide the status (e.g., on/off, open/close) of all the considered devices. When necessary, they can activate it with a single tap. Furthermore, a scenario can be manually activated or programmed in advance to activate at a specific time (e.g., each day for a month, only one day of the week). Finally, the ability to manage everything listed so far through a voice-based interface makes DOMHO extremely accessible to all users involved. A preliminary investigation highlighted the feasibility of such means of control considering individuals with motor disabilities and mild cognitive impairments. We tested the Voice-based assistants with the future inhabitants of the smart apartment, finding that they could control smart devices utilizing their voices [37, 38].

2.3 Participatory Co-design

Recent literature reviews show that most studies have analyzed home automation systems’ technical and technological aspects, their performance, safety, etc. However, what is missing is the focus on end-users’ needs, expectations, and desires. Systems developed without considering these elements often prove to be an obstacle to the actual usage of new technologies [39]. DOMHO project has adopted a co-design approach involving users and stakeholders (e.g., caregivers). The first step is identifying the involved user’s types and collecting their needs and expectations with qualitative methods (e.g., Focus Group sessions). The data gathered carrying out these activities has informed the design
and development of the control interfaces and the selection of sensors and actuators included in the smart apartment.

Following this, a training phase involving caregivers and individuals with disabilities will be needed to familiarize themselves with the control interfaces in the smart apartment. Finally, trials in this real-world scenario will assess user experience, acceptance, usability, quality of life, and well-being of both end-users and caregivers. Overall, the attention to users is fundamental considering their limitations and characteristics, especially with the categories of users involved, i.e., people with disabilities. Below, the methods adopted, and the findings obtained so far in the project are listed (see also [10]):

- We conducted a series of Focus Groups (FG) to understand the end needs and expectations. The two FGs involving disabled users and caregivers collected precious information to inform the development of prototypes.
- The control interfaces prototypes (i.e., smartphones and tablets) were tested in a laboratory environment considering qualitative, such as computer-based video analysis [40], and quantitative methods, questionnaires [41] and performance analysis (i.e., time on task, accuracy). These research activities allowed us to obtain information regarding the created prototypes’ user experience, usability, and accessibility. These tests involved both disabled users and caregivers.
- A series of tests verified the usefulness of the voice-controlled interface. Overall, users positively accepted such interaction means and were capable of successfully controlling all the smart devices after various attempts. These tests involved only disabled users [37, 38].

3 Future Works

The smart co-housing trial focuses on the themes of disability and improvement of the quality of life and well-being of people with disabilities and their caregivers due to the introduction of an integrated IoT system. Future studies will test this innovative environment to verify the potential benefits that technologies could grant. Indeed, the researcher will observe different groups of participants (i.e., 2/3 individuals with disabilities and one caregiver) during weekends. The participants will live in the apartment utilizing the IoT technologies for their daily activities, and the data collection will regard log and self-reported data of their overall experience. In summarizing, the experimental sessions will permit the assess of:

- Inclusion (i.e., facilitating access to goods and services for all people despite their individual characteristics);
- Independence and Autonomy (i.e., people with disabilities);
- Security and Safety (i.e., indoor security issues related to intrusion, detection of gas leaks, fire starts, fall prevention and detection, access control);
- Quality of life and Well-Being (i.e., supporting social interactions, increasing enjoyment, reducing the burden for caregivers).
4 Conclusions

There is still much work to envision a smart home that will allow almost complete autonomy and independence for individuals with disabilities. Indeed, there is still the necessity for the presence of at least a caregiver to provide immediate assistance in case of accidents (e.g., falls). Nevertheless, a solution like the DOMHO apartment may enable people with disabilities to experience daily living with limited dependence on external support (i.e., caregivers). This occurrence has a clear twofold benefit. On the one hand, individuals with disabilities will get rid of the burden of always asking for help and will be more independent. On the other hand, caregivers will feel less worried about numerous continuous requests (e.g., turning on a light, opening a door) because disabled individuals can accomplish simple autonomous actions.

Changing communities to create supportive environments that promote physical and mental health is challenging; however, evidence exists that co-operatives, co-housing, and longhouses promote intergenerational social inclusion, increase well-being and efficacy. Besides, the co-housing experience of sharing living with individuals with the same needs serves as a promoter of socialization processes that positively affect health and well-being [42].

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Design and Applications of a Trustworthy AI System Favoring the Well Being of a Community of People

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Abstract. The work describes a socio-technical approach to the development of a support system against loneliness, which implies a large number of health and social problems, in particular for elderly people and for people with limitation of abilities. The application requires the adoption of innovative Artificial Intelligence techniques, where the ethical component to be faced is not limited to the aspect of privacy, but, much more important, to the intelligibility of the reasoning process. The paper considers the new interest about ethics in artificial intelligence, which is also under development due to the publication of important documents at the international level and presents a synthesis of the most important contribution in this sector, since research in this direction appears in various application sectors. As an example of a specific activity, a discussion on a preliminary list of questions directly referred to the specific application has been drawn up and an initial analysis is presented.

Keywords: Loneliness · Ethics · Support system

1 Introduction: Loneliness

Loneliness represents a severe critical aspect in the daily life of a large number of people, for example elderly people, whose network of social relationships is often reduced over time. It was demonstrated that this condition, even if it cannot be considered as a pathology, often facilitates different pathologies, such as depression or cardiovascular diseases [1].

In 2018, [2] the idea and the first steps of development of a computer and network-based recommendation application, “Never More Alone”, to overcome this negative condition was already presented. This application is supposed to suggest people with loneliness activities and/or contacts with components of a virtual group of persons, who allow knowledge by the system of their profile and present activity. The chosen approach is based on the WHO ICF classification of human functions and activities [3].

1 During the last months, the Covid19 emergency, which constrains all of us to social isolation, has highlighted even more this problem, and many applications are under development to reduce negative effects.
In ICF, the term functioning refers to all body functions, activities and participation, while disability is similarly an umbrella term for impairments, activity limitations and participation restrictions. Body functions are defined as the physiological functions of body systems (including psychological functions). Activities are defined as the execution of a task or action by an individual. In ICF, an entire chapter deals with interpersonal interactions and relationships (d7), as one of the main human activities. In particular, a section is specific for people living in the same building, d7501 “Informal relationships with neighbors: Creating and maintaining informal relationships with people who live in nearby dwellings or living areas”, since this represents a common life situation.

During the development of the application, the awareness emerged that its implementation was not only a technical problem, but it also involved important ethical problems, from two perspectives. The first is connected to privacy, because the application implicates the knowledge and monitoring of a personal psychological problem, the availability of the knowledge of this private status to other people and the collection and analysis of the general attitudes and real-time activity of the group of people. Then, it became clear that the application requires the use of artificial intelligence (AI) techniques for making it adaptive to the changes of the status of the user and the ongoing activities of the components of the group. These techniques at the moment are under analysis from the ethical perspective around the world.

2 Group Activity and Selection. First Ests with a Limited Set of Rules

The in-principle block diagram of “Never More Alone” application is shown in Fig. 1, which represent the general scheme of an Ambient Intelligent (AmI) environment. From a functional perspective it is made of: (i) a set of smart equipment used to get information from the environment and act on it, (ii) an intelligent control system, (iii) a user agent for communication with the user and her social network. In this case the social network is of particular relevance, because one of the important points of the paper is that a recommendation system to improve the condition of loneliness of a person needs to be based on the identification of a group of people, who agree, within strict privacy constraints, to make available to the system knowledge of their main interests and of their present activities, obviously with a real time control.

The recommendation system, on the basis of the knowledge of the interests of the person who is alone and of the ongoing activities of the people in her social environment defined above according to the ICF recommendation, is supposed to be able to suggest an activity (e.g. there is an interesting program on TV) or to contact a person, or a group of people, to allow interaction with them. This requires the identification of a specific and limited environmental context, on which relationships are mapped. For the first implementation of the application, a particular context has been identified: a condominium.

This is a limited space where relationships are easily mapped. Seven different profiles were identified and emulated in the system, including an elderly lady, an elderly couple, a couple with a baby, an elderly couple with a young grandchild, a young girl, a young doctor, and an elderly man, as shown in Table 1.
The application foresees that a set of technological tools acquires data about the user and, when the solitude is identified by the system, it can recommend possible activities, related to her interest, or to contact one of the members of the group of people, who is available. The user and each person in the group has been provided with a static profile, where their preferences are set with a starting default value. For example, whether or not and how much they like walking or listening to music, whether or not they have specific pathologies or limitations of activities. Irrespective of how it is implemented, it is necessary that the knowledge base contains information about:

- Activities to be carried out in the environment;
- Functionalities, necessary to carry out the necessary activities;
- Technology and their basic functionalities;

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margherita</td>
<td>An elderly lady</td>
</tr>
<tr>
<td>Franco e Anna</td>
<td>An elderly couple</td>
</tr>
<tr>
<td>Alessia, Pietro e Matteo</td>
<td>A couple with a baby</td>
</tr>
<tr>
<td>Aldo, Rosa e Filippo</td>
<td>An elderly couple with a young grandchild</td>
</tr>
<tr>
<td>Lucia</td>
<td>A young girl</td>
</tr>
<tr>
<td>Ugo</td>
<td>A young doctor</td>
</tr>
<tr>
<td>Lorenzo</td>
<td>An elderly man</td>
</tr>
</tbody>
</table>
• Interoperability, i.e. interfaces and communication protocols to use technology in an integrated form;
• Users: abilities of individual users and their requirements and preferences regarding the functionalities to be used to support them in carrying out the necessary activities with the preferred interaction devices and modalities;
• Interactions: available interaction devices and modalities.

An initial set of suggestions is made available, in order to select, at the beginning within a limited but defined set, the best suggestion in each condition. Even at this level, a number of ethical problems need to be considered, mainly related to the privacy.

3 Need of Reasoning and Learning: Artificial Intelligence

The first set of rules used for producing recommendations was based on expert’s evaluation, static profiles and experience of relatives, friends and caregivers. They were not completely satisfying, because the system must be able to change its behaviour in a dynamic way according to the variation of the behaviour of the user, her possible varying reactions to choices in different situations and the state of the members of the condominium. If a caregiver is taking care of the user, she can reason about the situations of the person, her activities during the day, possible bad news received in conversation she had with friends or relatives, and decide that she has a problem (e.g. solitude) and act to support her. Therefore, it is necessary to introduce in the support system the possibility of reacting to the present situation and of adapting its action to it.

Artificial Intelligence should be helpful in addressing problems such as the ones in the previous examples. As reported in [4], there are many definitions of artificial intelligence. Among them, the one considered in the present discussion refers to the idea that “the environment should be able to carry on activities related to decision making, problem solving”.

These considerations led to the study and adoption of more complex and advanced technologies, since the support system had to manage a learning decision making mechanism to optimise the selection of recommendations. Artificial Intelligence techniques had to be adopted in order to match different profiles, contexts and events. Expert systems and machine learning are the technologies that have been selected to create the mechanism for increasing the knowledge and reasoning capabilities of the system. The purpose is to provide to each user optimised results, depending on rules generated by the system itself, e.g. based on the reactions of people to the previous suggestions.

4 Ethical Problems: Not Only Privacy, But Trust in the System: How Does It Learn, How Does It Reason?

During the study and the application of reasoning and learning techniques, it was soon clear that a deep attention to the possible impact and importance of ethical aspects was mandatory, in addition to the privacy. For example, machine learning techniques may be able to learn from complex data and to give results which often are useful, but the process
through which they get to such results is often not sufficiently explained. This aspect is not particularly relevant if considered in an advertising environment, but it represents a key element for example in medicine or, as in this case, in systems to support people. The focus of the development is no longer strictly technological, but technological and ethical perspectives must be combined. In other terms, ethical considerations must be embedded in the development of the technology itself.

This kind of problems is well-known worldwide, since in recent years, research and development of applications in the field of artificial intelligence have had a remarkable development in many sectors, from medicine, to marketing, from transport to tourism, etc. Even in the field of Assistive Technology, and more in general for any kind of applications to support people in their everyday life, these activities have assumed a huge importance. As an example, the workshop, which took place in New York as a side event of the 12th Conference of States Parties (COSP) (11th–13th June 2019) can be cited. This event, among other aspects, “covered the topics of standards and political frameworks of AI regarding people with disabilities” and “highlighted the present uncertainty about the effects of AI driven technologies”.

This made the scientific researchers no longer able to postpone the urgency of comparing the technological development of an application with the social and legal aspects even and above all in the field of support applications, because the final impact of the product is at high risk of validation.

5 Worldwide Situation

A new interest about ethics in artificial intelligence is also under development due the publication of important documents at the international level. Research in this direction appears in various application sectors. At industrial level, we cite, by way of example, an IBM document, which is “Everyday Ethics for Artificial Intelligence” [5] which, by taking a practical approach, put in evidence five main areas: accountability, value assignment, explainability, fairness and user data right, and for each of them inserts a short description, a few recommended actions to take, elements to consider and questions to be discussed within the work-team during the development of a product.

It is important to introduce also the IEEE initiative [6], defined as “A Vision for Prioritizing Human Well-being with Autonomous and Intelligent Systems”. The introduction of the main document states that the pervasiveness of the so-called “autonomous and intelligent systems” (A/IS) require the adoption of specific guidelines, “in order for such systems to remain human-centric, serving humanity’s values and ethical principles”.

Since the starting point of the problem of ethics in Autonomous Intelligent Systems is the list of principles to be adopted for a technical analysis, it is useful to cite [7] the AI4People initiative which in a conclusive document, presents a synthesis of 7 different documents regarding ethics in AI, which highlight the different perspectives:

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The Asilomar AI Principles – these principles were developed in conjunction with the 2017 Asilomar conference in January 2017, under the auspices of the Future of Life Institute [8];

The Montreal Declaration for Responsible AI, from Université de Montréal, in collaboration with the Fonds de recherche du Québec, 5 December 2018 [9];

The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems and particularly the Ethically Aligned Design document, previously mentioned [7];

the Statement on Artificial Intelligence, Robotics and ‘Autonomous’ Systems, produced by the European Commission’s European Group on Ethics in Science and New Technologies in March 2018 [10];

Artificial Intelligence Committee’s report, “AI in the UK: ready, willing and able?”, published in April 2018 [11]; and

The Tenets of the Partnership on AI, Partnership on AI 2018 [12].

A list of forty-seven different principles are presented. However, the authors associate and reduce all these different principles to the four bioethical principles – beneficence, non-maleficence, autonomy and justice:

1. beneficence – promoting well-being, preserving dignity, and sustaining the planet;
2. non-maleficence – privacy, security and ‘capability caution’;
3. autonomy – the power to decide (whether to decide); and
4. justice – promoting prosperity and preserving solidarity.

The vast majority of these principles are present also in an additional document which can be consider at the moment as the reference document in this field: the AIHLEG ‘Ethics Guidelines for Trustworthy AI’ [13], which was published by European Commission in 2019. A trustworthy AI includes three main component, Lawful AI, Ethical AI and Robust AI, but only the two last aspects are considered in the document. The last aspect, more technical than social, moves the document towards a more holistic perspective. This document adopts four main principles: Respect for human autonomy, Prevention of harm, Fairness and Explicability. Explicability is a principle that enables the other principles through intelligibility and accountability.

The four main principles are then translated in seven requirements:

- human agency and oversight,
- technical robustness and safety,
- privacy and data governance,
- transparency,
- diversity, non-discrimination and fairness,
- environmental and societal well-being and
- accountability.

All these requirements are then combined in a concrete, even non-exhaustive, assessment list of 131 practical questions. This list represents a first tool in order to check the correspondence of the development activity with ethics criteria.
This is why a process of analysis of the loneliness application according to this assessment list is ongoing, together with the comparison with other reference documents for Recommender Systems [14]. Some preliminary results are inserted here.

For the Requirement “human agency and oversight”, we have considered that the system provides suggestions only, and these suggestions can also be rejected by the user: new suggestions can be selected from a list, even if commented with positive and negative aspects according to user profile, or new actions can be introduced in the systems. While for the oversight component, a procedure to safely abort an operation when needed is still lacking.

For the “technical robustness and safety”, since the application is still at prototype level, a number of these aspects have to be studies and introduced.

For “Privacy e Data Governance” we consider the impact of the AI system on the user’s fundamental rights. An external auditor for the purpose of performing personal data protection has been designated.

For the “Transparency”, an aspect to improve is the adoption of measures for the continuous assessment of the quality of the input data to the AI system, and the explanation of the decision adopted or suggested by the AI system to its end users.

A more in depth activities is required for the “diversity, non-discrimination and fairness”, even if the experience of the designers in the field of people with limitations of abilities guides in this process.

For “environmental and societal well-being” aspect, the possibility of negative impact of the AI system on the environment is under analysis.

For the aspect related to “accountability”, the method selected to ensure the adoption of the implementation of trustworthy AI is the creation of an “ethical review board” with various stakeholders, in order to monitor and assist the development process.

The document produced by the European Commission High Level Expert Group on Artificial Intelligence inserts also a list of Technical and non-technical methods to realise Trustworthy AI. This aspect represents the more important element on a scientific level, since on the one hand offers detailed elements for a technological research in Ethics field, on the other presents a list of elements to take into consideration during a product development.

Technical methods are represented by Architectures for Trustworthy AI, Ethics and rule of law by design (X-by-design), explanation methods, Testing and validating, Quality of Service Indicators, while as an example of non-technical methods the Codes of conducts or Standardisation can be cited.

The main idea is that artificial intelligence algorithms should incorporate the principles of democracy, the rule of law and fundamental rights from the stage of design. Therefore, an artificial intelligence (AI) system to ensure intelligibility, predictability and controllability, has to be able to guarantee the transparency principle at the moment of the algorithmic design. The recommendations on future policy developments of AI and ethical, legal and societal issues related to it, include socio-legal challenges regarding requirements that any artificial intelligence system should meet to be trustworthy.

In the automatic system under discussion where interaction is based on what a specific group are doing, the legal and ethical question is related to two types of data: personal and non-personal.
6 Official Documents and Open Questions

As an example, a short and non-exhaustive list of the questions to answer in order to check the availability of all information to consider ethical issues in the design of an automatic tool as “Never More alone” is discussed.

First of all, it is necessary to consider the need of knowing the details of the people who are supposed to be supported by the system.

- According to the fact that the tool is direct to elderly people, have the developers considered what the definition of “elderly people” is?
- Is the definition of “elderly people” derived from the EU law and internal rules? What kind of rules have been used?
- Do vulnerable persons use the tool?
- Have the developers defined who is a “vulnerable persons”?

Therefore, it is necessary to know in the detail the lack of abilities of the involved persons with particular reference to its usability (complexity of the application or its interaction) and its acceptability, also from the perspective of their ethical beliefs.

Then it is necessary to define the information to be collected and its sensitivity (e.g. if personal information must be collected and stored.

- What kind of information (personal or non-personal data) does the set of sensors and process collect?
- Does the collected information contain personal data?
- Are critical personal data necessary (such personal data revealing racial or ethnic origin, political opinions, religious or philosophical beliefs, or trade union membership, and the processing of genetic data, biometric data for the purpose of uniquely identifying a natural person, data concerning health or data concerning a natural person’s sex life or sexual orientation)?

In the case of the considered application, data about the members of the group must be collected. For the supported person, knowledge about her situation, including her psychological and/or psychiatric status, are necessary, but it is not necessary that this information is shared in the group. The group needs only to know that she at the moment feels alone. For other people in the group only information about their main interests are necessary in the database. Then, it is necessary to know their present activity, when the need of intervention occur. However, this is under the real-time control of the single users.

Another problem is the policy to be used in acquiring the consent for collecting and using the personal data of the members of the group in the processing going on in the system. It is necessary to classify the types of data made available, together with eventual limitations in their use and sharing in the group.

- Have the data owners given consent to the processing of his or her personal data for the specific purposes within the group?
• Are the data owners conscious that their information also if non-personal could be shared within the group?

It is also necessary to decide where the information is stored (in the user system, in a common database, in the cloud?), the level of security of the storage and to determine if, for example, it must be crypted. A policy for access to data must be defined, including the responsible of the data and the need of sharing (some of) them among the members of the group. It is also necessary to define who is authorised to access the data and what data each member is authorised to access.

• here and how are the data stored?
• Does the information stored need to be shared among the group? Better, is it possible that information – also if only the not personal data – might be known by the member of the group?

A distinction between the data that must be permanent in the system and those that are needed only for a limited time is necessary. A policy for deciding when each set of data are to be cancelled and how (a person or the system itself) must be defined.

• Are the personal data kept in a form which permits identification of data subjects for no longer than it is necessary for the purposes for which the personal data are processed?
• According to the fact that personal data must not be stored for long periods, has the developer evaluated the possibility that the information has to be conserved for a short time?

It is obviously possible that the situation of the user evolves in time and some of the members of the group change or their interests and availability change.

A very important aspect is to decide who is responsible of the data and if the system needs to be continuously controlled by a person (e.g. a care-giver) or if it can run as an automatic system, with only periodic interventions.

• Who is the personal data controller, if any?
• Who is the running controller, if any?

A technology not normally known by the user is deployed in her house and it is given the possibility of interfere in a very intimate situation, i.e. when she feels a sense of solitude. Therefore, the system must be deployed and interfaced in a way that, not only it is safe but also does not interfere with the user in an invasive way.

• Is it possible to demonstrate/to evaluate that the activities of the tool are not invasive and will not produce any kind of pain or stress on the people?

Finally, it may happen that minors are also part of the group. So, it must be decided from what age it is convenient to give them access to the application. However, it is always necessary for access to be authorized by one of the relatives.
If the group involves children, have appropriated measures been taken to be sure that the consent is given by the holder of parental responsibility for them?

Finally, it is necessary to analyse in the details all the Artificial Intelligence components, using only those whose functioning can be completely understood and controlled.

7 Conclusions

The work describes a socio-technical approach to the development of a support system against loneliness, which implies a large number of health and social problems, in particular for elderly people and for people with limitation of abilities. The application requires the adoption of innovative Artificial Intelligence techniques, where the ethical component to be faced is not limited to the aspect of privacy, but, much more important, to the intelligibility of the reasoning process. As an example a preliminary list of questions directly referred to the specific application has been drawn up and an initial analysis is presented.

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F360: Fitness 360° Outdoor

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Abstract. Ageing does not necessarily have to be synonymous with loneliness. However, the risk of social isolation increases with age. Looking for new interests, social opportunities in which to make new friendships, helps to get out of this context, and feel alive. Enormous progress has been made in increasing life expectancy and reducing some of the most common causes of death. Many of these causes are related to a rapid decay not only physical, but especially psychological, especially with advancing age and the onset of diseases due to lack of an adequate lifestyle in nutrition and physical activity. The contribution aims to promote a better understanding of how motor activity in the open air can aim at maintaining an active life and slow down cognitive decline. The goal is to create an industrial product that can encourage the adoption of an active lifestyle, through the use of devices, technologically advanced, but inclusive, simple and accessible in their use to support the movement and health of older people. The activities that can be carried out, transformed into a form of play, will lead to a greater commitment to exercise, stimulating healthy competition, more than towards others, towards oneself to measure the progress achieved by playful activity. Biofeedback will allow, through the collection of objectives, results and intuitive graphics, to obtain a rapid response of progress in real time.

Keywords: Active aging · Welfare · Fitness · Socialization · Inclusivity

1 Research Scenario

1.1 Oldest Old. The Ageing Phenomenon

Demographic analysis and employment data have long reported the emergence of a structural change in the composition of the population: a decrease in active people and a simultaneous increase in life expectancy for older people. This data is often defined in too conventional terms especially for the consequences in terms of social security, health and welfare spending, losing sight, however, of the positive opportunities for opening up new content and activities in that segment of the population especially as a result of the drastic reduction in the youth population due to the sharp reduction in birth rates. On people of mature age, the burden will shift more and more, not only to remain active for a better quality of life, but also to be protagonists of the processes of change and innovation in the generational change, with mechanisms that no longer appear replicable when the number of children becomes half that of parents.
1.2 Ageing Criteria

For many years we have been trying to establish which parameters allow us to define senile age and to identify its principle, since the natural aging process begins from birth. By aging we mean the process through which we change as a function of time. This term often implies a negative meaning, of loss, of decay, so the consequences of aging are considered in deficit terms. Two phases can be distinguished: aging, that is, the gradual modification at the tissue and cellular level, to which the structures of the organism are subjected over the years; senescence, which is the later phase of aging and concerns the quality of that modification and the appearance of deleterious forms of the organism that lead to its end. When does one begin to age? A first answer comes from biology. An elderly person is one who has reached a certain age level, generally indicated around 65 years of age. In biological terms, therefore, the word “aging”, indicates the complex of changes that the individual goes through in its structures and functions, in relation to the progress of age.

Sociology also sets chronological limits. According to the laws in force in our country, around the 65th year of age the productive age ends, the senile period begins and one enters the age of retirement. At the age of 60–65, most men and women abandon their work and begin to face new living conditions from an individual, family, social and economic point of view. A profound change takes place that brings psychological and behavioral changes. However, to say that socially one considers oneself old when retiring is limiting, because one can retire very early, one can become “socially” without being biologically so. Psychology underlines once again how man can develop his personality in cognitive, affective and motivational functions, grow in experiences, play significant roles until death. What we have said so far about aging can be understood as a “lesser being”: from the psychological one, instead, we can say that “the older you get, the more” you grow until the final act of life: death. Psychologically aging in a positive way means therefore to remain immersed in social life, to have a good level of self-esteem, not to delegate our choices to others, to know how to always pursue objectives useful to ourselves and to others, to tend to the protagonism and above all to autonomy, to add to adulthood all those experiences that life offers us without ever losing our own life project.

1.3 Physical Activity as Wellness for the Elderly

The importance of encouraging the practice of motor activity in all sections of the population is widely documented and supported by the scientific world. It is necessary to realize that the aging of the population is a completely irreversible process and that, in the face of this phenomenon, a collective awareness that leads to an authentic cultural re-foundation of our way of thinking and acting is a must. To exercise even in old age and compatibly with one’s condition helps to maintain good levels of health and a good quality of life. Physical activity plays a priority role in promoting healthy and active aging. Physical exercise helps to age better both physically and psychologically, reduces the average level of values of many clinical tests (blood pressure, blood sugar, cholesterol, triglycerides), reduces the risk of the consequences of osteoporosis and trauma from falling. In general, in the elderly, exercise is able to improve muscle tone
and movement capacity, as well as reduce osteoporosis and induce an increased release of neuromonal mediators such as endorphins and serotonin, which give a feeling of general well-being. The positive aspects of regular physical activity, especially among the elderly, are many:

- Reduction of the risk of sudden death, from heart attack or cardiovascular disease in general;
- Reduction of the risk, up to 50%, of developing colon tumors;
- Reduction of the risk, up to 50%, of development of type 2 diabetes;
- Prevention or reduction of hypertension;
- Prevention or reduction of osteoporosis, with up to 50% reduction in the risk of hip fracture in women;
- Reduction of the risk of development of osteoarticular pathologies;
- Reduction of the risk of developing cognitive deficit and dementia;
- Reduction of symptoms of anxiety, stress, depression, loneliness;
- Decrease in weight and decrease in the risk of obesity

Maintaining a physically active life at a late age is also important to increase energy needs and allow a relatively more abundant diet with adequate intake of vitamins, minerals and other essential nutrients.

2 Case Study

2.1 Introduction

It is widely recognized in the literature that physical activity is one of the most important tools for the prevention of chronic diseases by supporting and strengthening psychophysical well-being, in both sexes and at all ages. These considerations lead to the conclusion that the promotion of physical activity is important at the level of the individual, but especially in an overall view at the level of society and therefore requires a multidisciplinary and multi-sectoral approach, with a series of interventions involving the individual, the group and the community. In this regard, a state of the art at market level of different types of physical exercise devices has been performed in order to broaden the research application scenario, classifying them into five macro categories:

Advanced Fitness Systems

Represents the easiest way to do physical activity, automatically tracking repetitions, power and range of motion so you can immediately view performance in statistical form. You have the possibility to access customized programs, designed specifically for the user thanks to virtual coaches. They allow you to immerse yourself in virtual environments and in real time return stimulating feedback of control both postural and symmetry of gestures. The user’s figure is scanned and translated into a virtual figure.

System of Reactive Devices

This specific category includes highly advanced devices that incorporate the use of specialized and customized programming designed to train both brain and physical activities.
It offers fun and engaging workouts that help improve balance, cognition and memory. They facilitate rehabilitation by providing visual feedback through a pressure-sensitive surface and bright multicolor LED lights. They help to improve patient involvement by making therapy fun and stimulating. There are also systems that integrate interactive surfaces, floors, lights, sounds and pressure-sensitive sensors to create highly interactive experiences in gyms and fitness clubs.

**Virtual Medical System**
Includes all the tools that combine health information, virtual reality and physical therapy exercises to meet a wide range of functional rehabilitation needs. While patients perform the prescribed exercises, Kinect sensors detect and track their body movements, recommending a range of exercises. Interactive exercises and augmented reality help engage patients in their rehabilitation process and motivate them: The biofeedback offered encourages patients to self-correct, which accelerates the recovery process and allows patients to be more independent and more proactively involved in their rehabilitation.

**Outdoor Fitness System**
Outdoor fitness is low-impact, functional and helps the elderly to stay fit: prevent injury and maintain an independent healthy lifestyle in the open air. Each station includes exercises that aim to achieve and maintain physical well-being in order to carry out the activities of daily life independently. It encourages the use of multiple muscle groups at the same time rather than isolating the muscles by making them work independently, this type of training, day after day, trains the body to keep fit and perform all those essential movements of real life.

**Expressive Robotic Systems**
In this specific category were analyzed all the robots that have the ability to create empathy with the user: they entertain conversations and an emotional connection, which could help the elderly also from an emotional point of view. In addition, this technology could help to deal with chronic loneliness in providing company through the ability to communicate, listen and respond.

### 2.2 Passive Gymnastics Analysis

With reference to the exercises to be performed by the elderly user, we have analyzed the field of passive gymnastics, that is the type of activity that uses isometric contraction of muscles and, although it seems untraining, if performed with the right consistency is able to tone different parts of the body. In this specific case, four macro areas of intervention have been identified such as motor/cognitive development, coordination, stability and strength. The device will consist of an equipped surface where the user performs the exercises and a floor that in addition to circumscribing the training area, implements within it a platform that will give feedback related to balance (Fig. 1).
2.3 Interactions Analysis

The intent is to make simple exercises, so as to emulate similarities with existing equipment, preconceptions and confusion in the use of the device. Difficulty settings are hidden and each user’s attention is intentionally kept on himself through an interactive display. As far as the shape is concerned, Arcade Machine Gaming has been analyzed and generally consists of the following characterizing elements:

- Classic Arcade (Interaction with the screen)
- Boxing (Force interaction with the device)
- Konami Rhythm (Interaction Display + Arms)
- High Five (Interaction through feedback)
- Speed of Light (Physical interaction with the device)
- Dancing (Interaction with platform) (Fig. 2)

The common thread and the elements that are repeated between the various devices are the physical interaction, a footboard and the screen. The device will therefore have a shape inspired by Arcade Machine Game, allowing interaction through a display and tactile sensors. The result obtained from the training activity will be visible through graphs of the essential results reduced to an emoticon that will appear on the screen. The basic device, will have the ability to move and reach different heights, so as to meet the requirements of Design for All. Ultimately it was assumed that postural stability could be monitored through a platform positioned frontally to the dynamic surface connected.
via wifi and incorporated into the flooring. The aim of the project is to transform physical activity into a game, trying to create a level of empathy that allows the user to interact pleasantly with the device.

2.4 Project Requirements

Following the market analysis the following project requirements are drawn up:

- The outdoor location, placing the device in a park;
- Promoting socialization, with the possibility of carrying out activities in groups;
- Facilitate a better Expressiveness, with the possibility to interact with the device and return feedback;
- Physical activity as a game, transforming the motor/cognitive activity into a game through the possibility to verify one’s performance through scores;
- Device accessible to all;
- Morphological and structural simplicity;
- Ease of reading and translation of results.

The study of the shape relative to the dynamic surface will necessarily have to take into account elements such as:

- Accessibility for users also on mobile devices;
- The movement of the surface along an axis;
- Vertical side surfaces for performing passive gymnastics exercises;
- Use of the lateral surfaces of the device implementing with handles and attachments that allow to detect the state of fragility of the elderly and to allow the movements related to the shoulder joint; finger stairs to improve coordination through physical interaction and light feedback that identify the touched part; introduction of pressure sensors to allow the elderly user to perform strength exercises for the lower limbs;
- The two vertical surfaces will allow cognitive motor activity through physical interaction with the screen and the platform. On the other hand, there will be the possibility to perform guided exercises that allow you to control the movement through handles placed on the face (Figs. 3 and 4).
2.5 Concept Development

The design concept named Wellness 360 will make the activity more dynamic by making new combinations that will allow the user to stay focused.

The concept consists of:

- Vertical surfaces, which will allow the performance of training activities and physical interaction between user and device.
- Floor/footing, it allows you to circumscribe the training area and allows you to create workouts for the lower part of the body.
• Application that accompanies the entire process of using the device itself. The user has the possibility to keep track of the improvements made and to book training sessions whenever he wants.

The concept is equipped with a Stand-Alone charging system, i.e. an independent and autonomous energy supply system: the photovoltaic installation is not connected to the electricity grid but is connected to an autonomous energy storage system (Fig. 5).

The dynamic surface consists of a totem structure with four faces that respectively represent:

**Frontal Surface - Engine/Cognitive Development**
This side of the device allows you to exercise memory, through the combination of symbols, numbers, arrows and light feedback. The user has the ability to remain physically active while keeping his involvement high. The sounds played and the robotic icons released by the device allow you to create empathy with the user who is involved at 360 degrees.

**Rear Surface - Coordination and Postural Stability Development**
Interaction with the surface can take place in two different ways:

1. Through the use of a platform positioned on the ground that allows to replicate to the user the exercises related to stability and to detect the balance.
2. Through the sliding surface that, adapting to different heights, can be easily used by different users. The light is used to support the movement then dictates the time of execution of the exercises.
**Finger Stairs** is a very common exercise performed by older users. It allows coordination and in this case two blocks have been designed to generate a targeted training for both fingers, elbows and shoulders. The wide range of movements helps develop hand-eye coordination and concentration. These two skills are necessary in everyday life. Front elevations are great for implementing small, naturally loaded strength work with a high concentration of coordination. They, combined with light, make it possible to verify the position and dictate the time of execution.

The floor consists of five square modules, two of which are used respectively to fix the device to the ground and to house the exercise platform and four corner modules. The system is fixed to the ground by means of flanges that allow to restore stability to the base, and resistance to wind gusts on the surfaces themselves (Figs. 6 and 7).

The application allows you to book the device for the training session, and in addition to activating it through the QR code it allows you to keep track of the results. The maximum source of motivation lies in verifying the user’s progress in setting goals, in controlling measurements easily and effectively and in sharing data in a simple way. Intuitive graphics guide you to achieving fitness goals. You can receive information and view activity statistics using the sensors on your phone or smartwatch to record your heart rate, speed, movement and track your goals and progress over the last day, week and month. Once the application is installed on your mobile device, you can get started (Fig. 8):

![Rendering of the main parts of the Wellness 360 concept](image)
Fig. 7. Technical drawing device

- Open the app;
- Login with your account;
- Specify your profile information (height, weight, gender and date of birth);
- Keep your device with you to start monitoring your activities.

Subsequently, it is possible to establish personalized cards, through daily training: they are periodically updated by the personal trainer who carries out workouts in relation to the physical situation and the improvements obtained during the course. To get points just have your smartphone or smartwatch with you, compete with your virtual friends and see your position in the ranking. Daily progress control is done through MoveS (app section), which measures movement, and Cardio Points (app section), which allows you to earn movement points for all activities that increase the heartbeat and bring enormous benefits to heart and mind health (Fig. 9).
2.6 Analysis of the Interaction with the Design Concept

Turning on and Connecting with Other Devices

The ignition will be managed by the user through a specially designed application. The device will have the possibility to be used by reservation so that it can be used by different users. At the moment of switching on the device the user will have the possibility to access his account by connecting his mobile device by scanning the Qr Code. This is
Exercise Activities
The system must have the possibility to be used also by people with reduced motor skills, in fact through a sliding system the panel can reach different heights. This will facilitate the use and facilitate accessibility. Through special sensors, you will have the opportunity to monitor the progress made by the user through motor and cognitive exercises that will be carried out. The monitoring will detect results regarding coordination (position sensors), balance (through load cells) and motor and cognitive mobility (touch sensors). The intent is to make the surface interactive and to transform the motor activity into a game: visual, tactile and sound feedback allow to immerse the user at 360° within the dimension. The totem realized allows to stimulate the user to perform physical/cognitive exercises: this is allowed thanks to the luminous feedback that offers the possibility to dictate the execution time, the range of action and the direction of the movement with luminous feedback. The dynamic surface must have the possibility to express one’s emotions, offering the user visual and sound feedback on the execution of the exercise. It will therefore have the possibility to follow the movements performed and also return, through facial manifestations, the feedback given by the personal trainer during the
training session. For example, with the happy expression indicates a correct execution of the exercise; a negative emotion will indicate a wrong execution of the exercise.

**Power Off and User Information**

The user will have the opportunity to receive information about the score obtained thanks to the correct execution of the exercises. This will allow you to obtain a history of the workouts carried out and to have possibilities for improvement. Once the training session is finished, the user has the possibility to turn off the device through the application (Figs. 10 and 11).

![Fig. 11. Display with touch pads](image)

### 3 Conclusions

Getting old does not have to be a problem of marginalization with society. The risk of social isolation increases with age. The social network narrows and at the same time it becomes more difficult to cultivate new relationships. Looking for new interests, social opportunities in which to make new friendships, helps to get out of this context and feel alive and at stake again in social dynamics. This research project focuses its attention on strategies to support physical activity, active lifestyle and healthy ageing. Physical activity, in particular, is a key element to preserve functional independence in old age and to maintain a good quality of life. For this age group, it is proven that physical activity helps to age well: it increases the body’s endurance, slows down the physiological involution of the musculoskeletal and cardiovascular system and also benefits the psycho-intellectual abilities. The more the brain works, the less it deteriorates: you have to train it constantly and continuously, as you do with body movement. The intention is to address and deepen the theme of technology to support movement and health, able to encourage motor activity in people in the elderly age group. The research has represented a cognitive investigation on the needs of elderly citizens focusing on the elimination of architectural barriers, which prevent elderly users from a full enjoyment of the urban environment.
Often the inaccessibility of a place is not the fundamental problem for an elderly person, the real obstacle is the insecurity generated by uncertainty and confusion. The action, therefore, aims to promote a wellness service for the elderly that combines both physical and brain activity allowing socialization and promoting a new concept of outdoor fitness.

Outdoor gyms are implemented worldwide, but research has shown that, despite the intention, they are mostly unused by relatively inactive people due to three main reasons: lack of ease, accessibility and understanding about their use, lack of stimulation for fun and fear of not being up to their capabilities. Wellness 360, located in urban parks invites passers-by to stop for a moment, observe and consider their use. This service helps people to make simple steps forward in their physical fitness. It is a device that is accessible and understandable; it also allows people to do physical activity in a fun way, introducing the concept of gamification. It appeals exclusively to less fit people: there are no pull bars, jump blocks and heavy weights. Wellness 360 uses simple and short challenges, similar to games, to make the exercises interesting and fun. The intention is to provide an outdoor space so that older users can be physically and mentally active. The use of technology will create a network where users can view their updated improvements by creating a history of their workouts, suggesting new exercises based on the user’s habits. The aim is to involve older users trying, through daily physical activity, to increase the level of their account. But not only that, the technology will support the same equipment by training not only aerobic activity but also brain activity.

**References**

SHIP Project: Designing Inclusive, Accessible, and Sustainable Urban Parks

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Abstract. Urban green areas are of fundamental importance for the mental and physical well-being of citizens. However, these areas are often designed without considering the needs of all users, especially people with disabilities and the elderly.

To fill this gap, the SHIP project aims at designing and developing urban furniture, rides, and tools for physical activity and leisure to make a public park inclusive, accessible, and sustainable. Sustainability is intended from both an environmental and social point of view. Considering the former, recycled materials will be used. Regarding the latter, the design will include every potential target visitor in the logic of inclusion, accessibility, and social safety. Here we mainly describe the first phase of SHIP, characterized by activities of participatory design. In particular, to understand users’ needs, expectations and to collect design requirements, a series of Focus Group sessions were conducted, involving users with disabilities, the elderly, and their caregivers.

Findings showed habits and preferences of the target users related to public parks and their equipment, e.g., urban furniture. The main issue that emerged concerned the inclusiveness and accessibility of urban green areas. Indeed, participants highlighted the presence of physical barriers and the separation between areas for all and zones for people with disabilities, which severely limited the process of socialization. Furthermore, users showed enthusiasm in being involved directly in suggesting potential solutions regarding supplies, playground, sports, and well-being aspects. Finally, we report a set of preliminary design guidelines for outdoor recreational settings.

Keywords: Inclusiveness · Accessibility · Participatory design · Environmental sustainability · Urban park
1 Introduction

Spending time in natural environments has a regenerative value for all individuals, regardless of their age, provenance, and level of physical ability. This becomes even more important for people living in urban environments, where the landscape is dominated by concrete, artificial constructions, and city parks can be a true oasis [1–3]. Unfortunately, too often city parks are designed and developed considering able-bodied individuals and not people with disabilities [2]. Indeed, mobility barriers can be found in urban environments but also in natural areas, making people with disabilities feel out of place [4].

In the present work, we describe the SHIP project, which is meant to realize inclusive and accessible urban furniture, rides, and tools for physical activity and well-being for parks implementing the philosophy of environmental and social sustainability. To this end, the project will follow a Participatory Design (PD) approach. Here we report the initial stages of the project, which consisted of participatory activities carried out with users and stakeholders. In particular, users and stakeholders are involved in the process of designing and developing accessible and inclusive artifacts to create a path that is suited to their needs, requirements, and expectations.

The remainder of the paper is organized as follows: first, we introduce the SHIP project. Next, the most common accessibility issues to natural environments are described along with the usage of PD techniques to involve users with disabilities and the elderly in the design process. The description of the methods, experimental sample, and procedure follows. Finally, we report the findings and concluding remarks.

2 The SHIP Project

2.1 Project Description

The main goal of the SHIP project is to develop equipment and technologies for parks to encourage the implementation of actions and practices of environmental, social, and cultural sustainability. In this framework, the park is no longer considered a simple place for purely aesthetics and passive use, rather as a space to build new educational models and actions aimed at citizens’ psychophysical and social well-being.

Overall, it is intended to create an experimental path in an urban park featuring prototypes of inclusive urban furniture implemented during the project. The path will be highly accessible to all categories of users: users with different levels of motor, cognitive, and sensory disabilities, but also enjoyable and pleasant for their companions and other users. Moreover, the objects will be made out of recycled and reused materials, following the circular economy’s criteria and full respect for environmental sustainability.

In addition, end-users will actively participate first in design and then in the prototype evaluation phases, considering aspects related to user experience and usability. The results that will be obtained will help project partners to eventually redesign the prototypes for the subsequent evaluation phases.

The project features a multidisciplinary consortium of partners. More specifically, academic experts in Human Computer Interaction and biomedical science, will be
SHIP Project: Designing Inclusive, Accessible, and Sustainable

responsible for the PD activities, to inform the proper design of the pieces of furniture, and to evaluate the prototypes. A daycare center for older adults and individuals with disabilities will be in charge of building contacts and recruiting target users. Several companies will participate as well, to share their know-how on the waste material recycling, the production of pieces of furniture made of sustainable wood, and to realize urban furniture with an aesthetic value.

2.2 The (In)accessibility of Natural Environments

Natural environments, such as countryside, city parks, and woodland, are a precious resource for both the physical and mental well-being of individuals. More specifically, individuals with disabilities visit natural environments not for rehabilitative purposes, rather for leisure, restoration, and recreative activities [3, 4]. While organized outdoors activities typically can rely on resources and assistance that facilitate access and participation, informal outdoors activities, e.g., a simple walk at the park, are less supported [4].

Additionally, attending natural environments can also foster socialization and facilitate social bonding [4]. However, if the outdoor environment is not designed to be socially inclusive, the chances of interacting with others can be severely compromised [2].

Previous research highlighted that non-urban settings could present concrete hazards for wheelchair users related to the surface and steepness of the path on which the wheelchair rides, obstacles (e.g., curbs), and transfers from the wheelchair to another seat and vice versa [5]. While insightful, these findings were obtained using a questionnaire administered to individuals with impaired mobility, thereby failing to deepen their concerns and desires. Furthermore, to design inclusive outdoors, it is crucial to fully comprehend the context, the abilities of target users, how they interact with the environment, and what makes the environment enjoyable or hard to reach [4, 6].

2.3 Participatory Design

Participatory Design (PD) approach endorses the direct and active involvement of end users as an integral part of the design team. The contribution that PD activities can provide are especially valuable when designers, researchers, and target users do not share the same background, skills, and habits. Moreover, the resulting product is likely better received and accepted by end users, especially if they have disabilities [7]. This perspective aims at bringing target users’ voices into the design process by giving them the role of experts in their own life experiences [6]. Traditional PD techniques may not be fully effective when applied with users with disabilities. Indeed, if a particular technique relies on an ability that is compromised for that specific user group, then users’ effort is likely to be out of focus [8]. So far, several research works have adjusted traditional PD techniques to better involve different groups of users with disabilities and the elderly. All these methods entail the co-participation of target users, either older adults, and individuals with intellectual and/or motor disabilities, in the same environment with the researchers (e.g., [7, 9, 10]). Sharing the same setting is undoubtedly advantageous for building mutual knowledge and trust with users and facilitate the comprehension of their
requirements and habits. However, after the outbreak of the SARS-CoV-2, these user
groups must rigidly attain to the new behavioral regulations to prevent contamination
and risk for their own health. Therefore, we have organized Focus Group (FG) sessions
online involving children and adults with motor disabilities, their caregivers, older adults,
and relevant stakeholders. The aim of the activities was to understand what motivates
participants to visit urban parks and what are the main issues/barriers they typically
encounter in these outdoors areas.

3 Co-design Activities

3.1 Online Focus Group

The online FG sessions were conducted on the Zoom web platform. Participants were
trained and supported to use the platform by the educators of the daycare centers. For
those who needed more support, the operators attended the session at the participant’s
place to provide full assistance and facilitate attendance. In such cases both individuals
wore protective masks.

Sessions. Three FG sessions were run, each involved a different target user group.
More specifically, one session addressed adults with severe motor disabilities and their
formal caregivers, a second one included children with severe motor disabilities and
their informal caregivers, and finally older adults took part in a third session. Relevant
stakeholders were present at all the sessions. One moderator led the group discussion
supported by two observers.

The FG sessions had an average duration of 1 hour and a half. The entire sessions
were video recorded to allow offline analysis.

Ethics. Before each session, participants received an Informed Consent form describing
the aim of the activity, the data collection process, and data management, storage, and
protection policy. Educators of the daycare center facilitated the process of obtaining
consensus helping participants in filling out the documents. The form also included a
short demographic questionnaire.

Target Users. The first FG session was attended by adults with mild cognitive impair-
ments and severe motor disabilities (n = 4) and two professional caregivers who were
employed as educators at the daycare center (F = 2; average age = 27.5, SD = 3.54)
(Fig. 1). All of the end users (F = 2; average age = 37.33, SD = 11.69) reported to use
a mobility aid (i.e., wheelchair).

The second FG session (Fig. 2) was attended by children with severe motor disabil-
ities (n = 2) and their informal caregivers (n = 3), that are their parents (Fig. 2). Target
users (F = 2; average age = 8, SD = 1.41) needed mobility aids (i.e., wheelchair), and
one also uses a tripod or walker.

Finally, a group of older adults (n = 4) participated in the third FG session (Fig. 3).
The target users (F = 3; average age = 73.75, SD = 8.22) were 3 people who do not use
any mobility aid and one who uses a walker.
Procedure. At the beginning of the session, the moderator introduced him/herself and then briefly described the purpose and the rules of the discussion, along with the principles guiding the project in terms of accessibility, inclusiveness, environmental and social sustainability. The moderator then introduced the observers and explained their role in the discussion. After that, participants were invited to introduce themselves one by one, and the moderator asked opening/ice-breaking questions to create a familiar atmosphere.

Overall the topic was approached following the so-called funnel approach [11]. The moderator first made introductive questions, asking participants to recall recent episodes where respondents visited an urban park (e.g., Which park do you typically go to? Who do you go to the park with? What do you do at the park?). These questions were meant to investigate participants’ habits. Next, several aspects related to the motivation for visiting or not visiting parks were explored. Then, participants were asked to reflect on
what is currently missing in parks to serve their needs and what they would like to see in parks.

Participants were asked how they would imagine accessible and inclusive urban furniture (e.g., benches, tables), paths, and equipment for wellness and leisure. To facilitate participants’ focus on the actual topic, they were shown some pieces of furniture that meet accessible and inclusive principles. More specifically, the moderator shared the screen and displayed the images of some objects (selected and adapted for the different sessions according to the users’ characteristics) and described their structural and functional features. Then s/he asked for participants’ opinions and preferences.

In the final phase of the FGs, the moderator summarized what emerged during the meetings. This overview was followed by a final question for feedback and possible further reflections on potential aspects not yet explored during the FGs.

Throughout the session, the moderator committed to engage each participant in the discussion, calling them by name and inviting to share their view.

After the sessions that involved young individuals, participants were e-mailed a follow-up questionnaire. The questionnaire included the images of accessible and inclusive rides or tools for entertainment that were illustrated during the corresponding sessions. Participants were asked to score their preference for each item on a 10-point scale, were higher scores indicated stronger preferences.

3.2 Results

The videos of the sessions were analyzed by the observers (three researchers) to identify the most relevant themes. More specifically, each researcher examined the videos and his/her notes independently and listed the more relevant and more frequent themes that emerged in the FGs. Next, the researchers revised the three lists of topics and negotiated a unique list [12] which is reported below (Table 1).

Overall the participants in the three sessions actively contributed to the discussions and for many themes they reported similar answers or concerns. In general, the user group highlighted that the parks lack of accessible paths and inclusive and attractive equipment.

None of the participants goes to the park on their own; they go either with friends, family members, or educators (only for adults with motor disabilities). The activities undertaken vary based on participants’ age: impaired adults mainly chat, children play and older adults play with their grandchildren. Nevertheless, all participants in the three user groups reported similar issues when using urban furniture. The height of tables is inadequate for wheelchairs, and benches do not allow to accommodate wheelchairs users and able-bodied individuals. Older adults also pointed out the lack of inclusive equipment that can be enjoyed with their grandchildren or with their peers. Another issue that concerns wheelchair users is the quality of the paving: participants complained that wheelchairs are unstable and hard to control on the grass or on loose gravel. Additionally, uneven paving can make it dangerous to ride a wheelchair because it can gather too much speed. Children’s caregivers complained that playground equipment does not accommodate wheelchairs, thereby forcing them to transfer their children from the wheelchair to the equipment.
To overcome the issues reported above, participants suggested introducing tables with adjustable height and the possibility to adapt the distance between the table and the seat. Additionally, the tables should be circular and with center column to allow the accommodation of wheelchairs and foster socialization. Regarding the benches, participants claimed that they should be inclusive allowing both able-bodied individuals and wheelchair users. More specifically, they suggested that the bench should feature either movable seats that can create spaces for wheelchairs, or an empty space in the middle for a wheelchair. Older adults also proposed that the bench should feature specific elements to facilitate them while standing up, i.e., an armrest, a proper height (i.e., sufficiently high), and inclination of the seat.

Finally, age influenced the preferences concerning the type of equipment: older adults were more interested in equipment for gentle exercises that can be used with peers or grandchildren, and that can train various physical abilities (e.g., balance, strength). Participants with motor impairments showed a higher interest in playground equipment (e.g., slide, swing with seat).

Table 1. Relevant and frequent themes emerged in the FG sessions.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Adults with cognitive and motor impairments</th>
<th>Children with disabilities</th>
<th>Older adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>With whom you visit the park</td>
<td>• Friends (groups of 2/3 people), family members or educators</td>
<td>• Friends, family members</td>
<td>• Sons, friends’ sons, grandchildren</td>
</tr>
<tr>
<td>Activities at the park</td>
<td>• Chatting</td>
<td>• Rides (slide and swing)</td>
<td>• Playing with grandchildren</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Playground with sandpit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Inflatables (with caregiver difficulties)</td>
<td></td>
</tr>
<tr>
<td>Negative aspects of the park</td>
<td>• Tables too high to accommodate wheelchairs (both manual and electric)</td>
<td>• The size of tables and benches unsuitable for wheelchairs</td>
<td>• Lack of objects suitable and attractive for older adults</td>
</tr>
<tr>
<td></td>
<td>• Benches without space for wheelchairs</td>
<td>• Uneven paving complicates the control of the wheelchair</td>
<td>• Obstacles to mobility (e.g., pebbles prevent the use of walker)</td>
</tr>
<tr>
<td></td>
<td>• Mobility of the wheelchair hampered</td>
<td>• Mobility of the wheelchair hampered</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Absence of paths to move safely</td>
<td>• Difficulty in accessing playground</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Caregivers’ difficulty transferring children from a wheelchair to game equipment</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
### Table 1. (continued)

<table>
<thead>
<tr>
<th>Topics</th>
<th>Adults with cognitive and motor impairments</th>
<th>Children with disabilities</th>
<th>Older adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred solutions for playground/fitness equipment</td>
<td>• Basket swing with seat belts (operator support)</td>
<td>• Basket swing (no wheelchair and with friends)</td>
<td>• Equipment usable in groups (e.g., with peers or grandchildren)</td>
</tr>
<tr>
<td></td>
<td>• Garden tub</td>
<td>• Round sandpit</td>
<td>• Equipment to train shoulder stability tools with adjustable resistance</td>
</tr>
<tr>
<td></td>
<td>• Labyrinth, a path to learn how to control the wheelchair</td>
<td>• Spring rides (no wheelchair)</td>
<td>• Exercise Bike for Upper Limbs</td>
</tr>
<tr>
<td></td>
<td>• Slide</td>
<td>• Slide</td>
<td>• Adjustable rotating platform to improve balance</td>
</tr>
<tr>
<td></td>
<td>• Blackboard for leaving messages</td>
<td>• Whiteboard for leaving messages</td>
<td>• Multi-exercise station for lower limbs, back, and shoulder</td>
</tr>
<tr>
<td></td>
<td>• Magic mirror</td>
<td>• Magic mirror</td>
<td></td>
</tr>
<tr>
<td>Potential solutions for urban furniture</td>
<td>• Bench with proper space to accommodate a wheelchair in the middle</td>
<td>• Multi-exercise station for lower limbs, back, and shoulder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Bench with a movable seat to make space for wheelchair</td>
<td>• Adjustable distance between seat and table</td>
<td></td>
</tr>
</tbody>
</table>

### 4 Discussion and Conclusion

In the present paper, we described the SHIP project and reported on the initial Participatory Design activities that have been conducted to inform the design and development of accessible and inclusive urban furniture, rides, and tools for physical activity and well-being to equip a park following a perspective of environmental and social sustainability.

Different groups of target users, adults and children with severe motor disabilities and their caregivers, and older adults actively participated in online Focus Group sessions. Our findings indicate that the lack of accessible and inclusive facilities and infrastructure is the main reason for reducing the motivation of these individuals with disabilities and the elderly to visit urban parks more frequently. These places not only serve a restorative function but also foster socialization [4]. This limitation may severely compromise the opportunities of interacting with other people.

In addition, participants highlighted the importance of equipment that can be used by all users regardless of their individual and physical abilities. This aspect referred to the equipment for light physical activity and playground to be accessible, inclusive, and
enjoyable by older adults and their grandchildren, and to urban furniture that should accommodate individuals with various levels of motor abilities. Such a configuration would foster not only physical but also social inclusion [2].

We found that using a wheelchair in a park can be dangerous, especially because of the characteristics of the paving (i.e., paving material, steepness), thereby highlighting that proper paths are a crucial aspect to make the park truly accessible. This outcome expands previous findings, that categorized potential hazards [5].

Finally, this work also contributes to design guidelines for outdoor recreational environments. To equip an inclusive park, it is necessary to consider three different categories of tools: Supplies, Playground, Physical Activity & Well-being.

The Supplies category includes basic furnishings which comprehend inclusive facilities that allow users to reach the different areas of the park, meet, sit, eat and drink and take shelter from the sun and bad weather. In particular, the park areas must be easily accessible thanks to a pavement that does not hinder the passage of walking aids. The paths of the parks must be as flat as possible, to facilitate the control of walking aids by users. In addition, tables must have adequate (or adjustable) height to allow wheelchair users to use them, and benches and chairs must provide adequate (or adjustable) space to allow for the accommodation of a wheelchair or other walking aids. In addition, the seats must include aids (e.g., armrests) to help users sit down and resume an upright position and must be sloped to facilitate the transition from sitting to standing.

The Playground category includes equipment that must include adequate safety measures (e.g., belts) to secure the user to the structure and allow the user who needs walking aids to position himself on the tool independently or with minimal effort by the caregiver. Moreover, they must also be able to accommodate wheelchair users.

Finally, in the Physical Activity & Well-being category we find tools used to train specific functions that are suitable for adults, the elderly, children and users with disabilities. Physical activity equipment aimed at creating inclusive and accessible “life” trails must aim at training balance, mobility, the strength of the upper and lower limbs, and the core (muscle districts that include abdominals and erector spinal muscles). In addition, the equipment must include adjustable handlebars and grips to suit users of different sizes (e.g., height, shoulder width). Moreover, they must be capable of being used without the supervision of a professional (i.e., non-medical equipment). Finally, it must include mechanisms that are not susceptible to wear and tear and require minimal maintenance (e.g., rails are preferable to gears).

These guidelines will serve as a valuable source of information for the designers and developers that are part of the project consortium. Besides, additional online Focus Groups are already scheduled, recruiting individuals with disabilities and the elderly, to gather additional information from these categories of end users. Finally, expert consultants in design of outdoor environments and in biomedical science will be involved in the overall design and development process of aesthetically pleasant and highly accessible, inclusive, and sustainable tools.

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References


Adopting Assistive Technologies in Healthcare Processes: A Chatbot for Patients with Amyotrophic Lateral Sclerosis

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Abstract. The paper presents e-Health solutions for monitoring patients affected by Amyotrophic lateral sclerosis (ALS). Assistive technologies have a direct and positive impact on both the quality of life of patients and the overall management of the service. In the context of a wide project, we introduce an Ambient Assisted Living framework to investigate the adoption of telehealth and telemedicine applications in the healthcare process. First, we model the process of the hospital service where technological innovations have been applied. Second, we investigate the impact of a chatbot to improve the communications between operators and families. The chatbot obtained high adherence, compliance, and engagement of users. We provide evidence of how robust technological and organizational modeling can be successfully applied to support the staff of nutritionists staffs in ALS healthcare process. Furthermore, the solution discussed in this work provided a great impact during the COVID-19 emergency.

Keywords: Business process management · Assistive technologies · Amyotrophic lateral sclerosis · e-Health

1 Introduction

The improvement of healthcare processes is one of the typical applications of Ambient Assisted Living (AAL), a recent multidisciplinary research area [1]. Nowadays, the impact of new technologies, integrated with AI techniques and natural language processing, is finding multiple applications in a variety of domains, such as economics [2], social media [3], management [4]. Several studies also investigate the impact of technological solutions on well-being, quality of life, and healthcare services [5, 6]. The attention focuses on the adoption of technologies in e-Health systems and personal healthcare [7, 8].
The applied research proposes a wide range of methodologies such as monitoring services, patients’ location, and recognition of activities, data collection, and behavior detection [9]. In particular, assistive technologies focus the attention on the concepts of patient-centered care, which is actually worldwide recognized as an essential dimension for the quality of care, as well as the so-called patient empowerment. A literature review on the topic reveals how many recent works focus on the application of assistive technologies to different areas of health, as in the case of patient education or medical information management [10–13].

From an organizational perspective, several works explore the intersections between a Business Processes Management (BPM) [14] perspective and AAL in order to address healthcare managers, to better allocate the appropriate resources, to avoid bottlenecks and to improve the responsiveness of care to patients [10, 15, 16]. BPM and simulations are helpful to optimize the process of various healthcare service or hospital department [17], in the following directions: to reorganise existing resources in a more efficient way [18, 19]; to introduce some structural changes to the process by inserting medical devices, telemedicine or digitalization of documents [20]; to evaluate the possible activities of high clinical risk [21]; finally, to verify the regulatory compliance of the whole process [22].

In this paper, we introduce a general framework exploited in “La Casa nel Parco” (CANP) project\(^1\) for the analysis of business processes in an AAL healthcare context and the improvement of the process thanks to the introduction of some devices. In particular, this work focused on the Tertiary ALS Center (CRESLA) at “Maggiore della Carità Hospital”, Novara, Italy\(^2\). The Center provides care - as in-patients and out-patients visits - to people with Motor Neuron Diseases (MNDs), mainly Amyotrophic Lateral Sclerosis (ALS).

Recently, also considering the COVID-19 pandemic, and the related set of problems with access in the hospital, special attention concerns how to apply technological solutions to monitor these fragile patients. In fact, the possibilities regarding these technologies in clinical practice are often marginalized by issues of access and use. However, telemedicine and technological devices are effective tools for chronic patient monitoring, allowing patients to quickly access medical evaluation, in an efficient way and without travel.

ALS patients, as an example of patients with chronic neurological disease, are extremely complex in management, not only from a neurological point of view but also from multidisciplinary care [23, 24]. One of the most difficult goals with ALS patients is body weight stabilization and diet monitoring. Indeed, diet monitoring is extremely important for patients with ALS because it is well established in the literature that patients with a rapidly progressive loss of weight have a worse outcome. An increase in body mass index is associated with significantly better long-term overall survival and obesity is a strong predictor of a favorable long-term prognosis [25]. Also, it is established that nutrition supplementation promotes weight stabilisation or weight

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1 See website of the project: [http://casanelparco-project.it/](http://casanelparco-project.it/).

2 See website of the hospital service: [https://www.maggioreosp.novara.it/attivita-assistenziale/servizi-sanitari/centro-sla/](https://www.maggioreosp.novara.it/attivita-assistenziale/servizi-sanitari/centro-sla/).
gain in ALS. Following these patients with frequent monitoring turned out to be a useful approach in preventing further weight loss due to both the possibility of integrating caloric needs and dietary changes.

The adoption of an assistive technology allows the dietitians to monitor their patients continuously. In particular, a chatbot provides the patients with a tool to register their meals through a simple and carefully designed conversational interface [26].

The remainder of this paper is structured as follows: in Sect. 2 we describe the healthcare process perspective. Section 3 introduces the case study with a discussion of the related healthcare process, the main features of the device, and the expected improvements. The last section describes some concluding remarks and future work.

2 Methodological Framework

Process analysis in healthcare can be addressed by following a BPM perspective. Our approach can be detailed by four main steps:

- **The analysis of the context**: this step investigates the environment concerning the case study. An initial exam of existing documents, as well as data to understand the organisation. This analysis includes the main activities and actors involved in the healthcare process (e.g. duration of the activities, resources involved, analysis of stakeholders, analysis of costs, etc.).

- **The process engineering (As-Is model)**: this phase investigates the functioning of the system to define a model that has to be verified and validated with system experts in order to obtain the so-called As-Is model. In our case, this model consists of a visual diagram of processes (called process map or flowchart) adopting the BPMN standard language [27].

- **The analysis and the choice of the devices**: the CANP project involves 14 enterprises that provide different types of devices (telemedicine, platforms, etc.). In this phase, it is important to consider the context and the organization of the process in order to identify the better choice able to improve and optimize the tasks according to the needs of the business or to the stakeholders.

- **The re-engineering of the process for its reorganization and optimization**: in this final step there are shown scenarios to analyse and investigate the changes on the As-Is model by generating the new To-Be version. This is the purpose of the “what-if” analysis which explores parameter sweeping and Artificial Intelligence applications by computing performance indicators in different scenarios in both medium and long term. This phase includes solutions for restructuring the process, improving the detection, and the understanding of inefficiencies, bottlenecks, constraints, and risks [28].

This framework allows investigating the performance of the business process of the CRESLA with the introduction of a technological device consisting of a chatbot for Diet Management.
3 The Application of a Technological Device in Healthcare

3.1 CRESLA

CRESLA represents a national and international reference Centre for the diagnosis, treatment, and clinical research of MNDs, first of all, ALS. The public service offers a multidisciplinary and interdisciplinary approach including all the facilities for diagnosis, treatment, and care. Each year more than 400 patients (roughly 200 new patients and 200 controls), coming from Italian regions and some neighboring European countries, received visits (both as out-patients’ and in-patients’ visits) for diagnosis and treatment.

All patients are cared for by a multidisciplinary team. Experts from different disciplines (physicians including neurologists, pneumologists, dietologists, nurses, physiotherapists, psychologists, neuropsychologists, dieticians) work in a coordinated and organized manner. Besides, the Center participates in the definition of clinical protocols for the diagnosis and management of ALS patients, with other national and international organizations. The Centre has the structure, the expertise, the facilities, and the qualified personnel needed to conduct experimental clinical trials, cooperating as coordinator or Participating Centre in many national and international multicenter therapeutic trials in ALS.

Furthermore, in recent years, the scientific interest is focusing on translational research for MNDs, in collaboration with partners with expertise in preclinical/molecular research (e.g. genetic, histology, immunology). The creation of a large Biobank, in collaboration with the University of Piemonte Orientale, is allowing great storage of patients’ samples (including blood, faeces and cerebrospinal fluid).

4 Adoption of Technologies to Improve the Process

This section describes the output of the modeling effort. In particular, in the following images of BPMN diagrams are shown the As-Is models of the CRESLA service. As said, the As-Is describes what is the present situation, which are both the activities and the flow before the optimization effort (To-Be model) [14].

Thus, the Fig. 1 describes the initial contact with the Center (Step1) and the taking in charge of patients with the first visit (Step2). As detailed in Fig. 2, all patients are initially provided with necessary treatments (Step3) and evaluated with a quarterly multidisciplinary assessment (Step4). In this phase, all the needs related to the disease are evaluated through a preferential network of consultations. A weekly Day Service is dedicated to this purpose.

The model includes the analysis of health process resources. The Center is composed of 4 specialist in-patient clinics every week, with a short waiting time (roughly 15 days, also based on the urgency and level of disability). As described above, the team takes care of more than 200 new patients every year for both new diagnosis and diagnostic confirmation. The procedures are carried out as Day Service or Day Hospital. In a small part of cases (10%) patients need to be admitted to the Department of Neurology, mainly for reasons of geographical distance from the place of residence. Patients are taken over by the multidisciplinary team through scheduled visits and a network of telephone and telematic consulting. There is a dedicated telephone number (from Monday to Friday
from 9.00 to 17.30) and an email address for consultations, information, and reservations, added to a telephone number for urgent consultations.

Since September 2012 a home medical care program has been launched according to an experimental protocol for the management of patients in the terminal phases of the disease, in collaboration with the local palliative therapy units. At diagnosis, the diagnostic certification of rare disease and the therapeutic plan for regional patients are drawn up in the Regional Register of Rare Diseases.

The multidisciplinary visits provided in Step4 include the following activities:

1. neurological with physical evaluation
2. speech therapy evaluation
3. dietitian evaluation
4. spirometry and pneumological evaluation
5. psychological interview
6. neuropsychological evaluation
7. physiotherapy evaluation

If necessary, also other specialists are available (e.g. palliativist, gastroenterologist, occupational therapist, geneticist).

After each visit, the specialist draws up a report for the general practitioner containing the summary of the assessments, and the new therapeutic indications.

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**Fig. 1.** The process of CRESLA. In particular, the first column concerns the initial contacts between the Center and the patient (Step1). The second column describes the activities related to the first visit, for the diagnosis and the taking in charge of the patient (Step2).
Fig. 2. The process of CRESLA from the patients point of view. In particular, the first column shows the activities related the visits in the firsts three months (Step3). The second column shown the multidisciplinary visit phase (Step4).
4.1 Chatbot for Diet Management

Diet management is one of the problems that the CRESLA team has encountered over the years while interacting with patients. Patients diagnosed with ALS undergo a first hospital visit where they are taken in charge by the staff of nutritionists. During the visit they receive written or oral indications on the most suitable diet that meets their individual needs for energy and nutrients. Once they return home, they can record how much they ate on a paper food diary which is usually completed in the period before the checkup. The next appointment with the specialist takes place 3–4 months after the previous visit. During this period various events may occur: the patient may have lost weight or his ability to swallow may have deteriorated. At that point, the nutritionist has to trace back any problem that presented during those months, possibly provide late changes to the diet, or investigate if the patient had problems following the instructions provided.

By using a digital version of the diary, patients could register their meals more frequently and the data would be communicated in real-time to the dietician. The specialist would thus be able to monitor the nutritional status of the patient even in the absence of in-person visits and could highlight any significant deviation from the planned diet, as well as any swallowing problems related to the progression of the disease. Therefore, the analysis of user requirements revealed the need for patients and caregivers to be able to take advantage of asynchronous and digital assistance, in a conversational form. Conversational interfaces - used here as synonyms of agents or chatbots - allow humans to interact with devices using “natural language”, that is, the set of words and structures that are used daily to express themselves. Instead of communicating with the machine through a formal system that the computer can understand (like a programming language), the user can speak or write freely, delegating the interpretation of the message to mechanical components.

A textual chatbot allows the patient to compile their diary in an intuitive and asynchronous way. The interface does not include vocal components since the voice is a problematic element for ALS patients, being one of the abilities that vanish as the disease progresses. This decision is in line with the general design of the chatbot, which is supposed to be extremely simple to engage with. The goal was to build an interface that could be operated through the exclusive use of buttons and would not involve typing - except for one question. In this way, even in case of reduced mobility, it would still be possible for patients to successfully complete their diary.

The interface presents the patients with the compilation of their virtual food diary. There are different types of diets based on the consistency of food: regular, soft, minced, pureed, and semi-liquid. Each patient gets assigned one of the diets based on their swallowing ability (assessed by the speech therapist). For the purpose of processing the conversational interface, diets were into two large categories (solid and liquid) based on whether or not the patient needs to blend foods. A patient may then be assigned to the solid diet but may need to shift to the Liquid diet over time. It is therefore possible to change the diary interface over time.

Each diet interface contains the quantities of food required for an entire day. For each of the two diets, a schema was drawn up by the dietician with the portions of the food and the quantity of water to drink. The dietitian does not indicate the maximum
quantities of food, since the purpose is to report how much food the patient has been able to consume compared to the minimum quantity expected. In fact, the clinical situation of patients often generates a situation of inappetence with a consequent decrease in body mass. The goal is to verify that users are able to consume 100% of the prescribed meal every day, and possibly even something more. By the means of this it is possible to understand if the patient has consumed a quarter, half, three quarters or the whole of the expected portion. It is always possible to indicate that it has been consumed “more than expected”.

As for the amount of water to drink, the recommended portion is 8 glasses. However, the system accepts values from 0 to 20, thus including both the cases in which the user drinks less or more than expected.

The interaction takes place as follows: the users open the interface and authenticate themselves. For privacy reasons, they log in with an “anonymous” username, that is, with credentials through which it is not possible for the chatbot provider to recognize the patients. Depending on the diet that has been set for that user, the chatbot proposes the first meal in the list (for example, breakfast, as shown in Fig. 3). The user can fill in the meal in its sub-elements, or skip it. This feature is useful if the user has skipped a meal entirely, or that meal is not applicable to his case (e.g. not all patients have been prescribed supplements).

For each meal, the chatbot proposes its elements (e.g. for breakfast, biscuits/cereals, coffee/tea, etc.). The user can easily indicate the consumed fraction of the portion through the use of buttons that show the words “all”, “half”, etc. The process is repeated for each element of the various meals. Finally, the chatbot asks how many glasses of water were drunk that day. In this case, the interaction does not take place via buttons; the user must enter a number in the text field. It would have been impractical to create 21 buttons (from 0 to 20) and force the user to scroll through them all to the desired number. Once the registration phase of the actual foods has been completed, a final question is displayed every 15 days. This question is intended to periodically check for difficulties in chewing and swallowing that may arise as the disease progresses. The question, “Do you seem to have more difficulty eating?”, Requires a YES/NO answer. If the user answers YES, a free field appears in which the user can explain in her own words the difficulties she has encountered.

Once the entire list of meals in the diary has been exhausted, one last message informs the user that the compilation has been successfully completed. Users can press a button that signals a final greeting and they get automatically logged out from the interface. This behavior ensures that the diary is filled in from the beginning only after authentication. The data is saved continuously during the interaction, in order to save even partial data. If users interrupt the compilation in the middle and then forget to continue, the partial data of that day will not be lost.

From the physician’s point of view, the data extracted from each individual interaction is reported in a readable and easy-to-process format (e.g. an Excel file). The table shows a timestamp for each user, the answers provided for each meal and the answer (if any) to the last question. The dieticians can download these tables by accessing the interface through their set of credentials. The data can be used to process and monitor the patients’
nutritional clinical progress and it can also be stored - being totally anonymous - and used for further studies.

In conclusion, this chatbot has been used in recent months on 22 patients. The use of this device has helped to optimize the work of doctors as it has allowed doctors to have continuous monitoring of what are the food revenues in the medium-long term, net of what may be short-term fluctuations. Moreover, the data are immediately received by the medical staff who can then intervene in a short time if the situation requires it. Finally, the compilation of a diary via app is not binding for the patient, so you can maintain good compliance even for the long term without drop-out of patients. It should also be noted that this system was very useful during the Covid-19 period as it allowed continuous monitoring without exposing fragile patients to risk infections due to visits or dietary changes in presence.

5 Conclusions

This paper introduced a general framework involving Business Process Management to investigate a healthcare process by adopting a telemonitoring device, with the aim to optimize a healthcare service. The approach considers human-centered privacy by design approach, leading to fine-grained end-user control over data collection, processing, and sharing, subsequently increasing end-user trust. The main goal is to define a robust technological and organizational model to be successfully applied in other healthcare contexts. Healthcare process modeling has been adopted to investigate the effective quality improvement of assistive technologies. In the first application on 22 patients, the chatbot obtained high adherence, compliance and engagement of users.
Furthermore, we plan to improve the ALS Center process model by introducing other e-health devices for telemedicine and assistive technologies. This kind of tool demonstrated useful to support the staff of the hospital, as well as to increase the quality of life and well-being of the patients.

Furthermore, the BPMN model is an initial effort to address a process simulation, on the basis of the real parameters (arrival of patients, resources of the Center, the flow of the activities). Thanks to the collection of these data, we plan to investigate log files (event log) collected from chatbot in order to automatically detect deviations from the model, according to typical conformance checking approach, quite popular in the context of process mining discipline.

Moreover, this type of diet telemonitoring was also really useful during the first wave of COVID-19 period in which these fragile patients had, on one hand, the need for periodic monitoring and, on the other, forbiddance to leave the house.

Acknowledgment. This research is part of the project “CANP - CAsona Nel Parco” of Regione Piemonte funded by POR FESR PIEMONTE 2014–2020. This project is supported also by the AGING Project for Department of Excellence at the Department of Translational Medicine (DIMET), Università del Piemonte Orientale, Novara, Italy.

References


Co-designed Social Robotic System in Si-Robotics Project

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Abstract. Recent technological transformations lead to imagine a future in which men will be aided by innovative collaborative robotic solutions with advanced skills and socially acceptable behavior (social robotics). Design discipline can make a decisive contribution in terms of human-robot interaction, by investigating new and transversal approaches to the project. The hereby presented project is the result of the work developed by DAD (Architecture and Design Department) team at the University of Genoa within the PON research project called Si-robotics. This paper presents the results of the co-creation activity of a robotic system based on IDEO methodologic model. Starting from this consolidated model, through the interdisciplinary contribution of over seventeen public and private partners, new methods of participatory planning have been experimented on the theme of social robotics, an area where designers are rarely involved at this level and with these modalities. Therefore, among the results we present the definition of the concept within the project, but also the testing of a promising design method.

Keywords: Social robotics · Human-robot interaction · HCD model · Co-design · Ageing society

1 Introduction

1.1 Social Robotics Challenges

Ongoing political, social and technological revolutions have radically changed the way we live and work. Recent and impressive technological transformations lead to imagine a future in which men’s life will be massively aided by innovative collaborative robotic solutions with advanced skills and socially acceptable behavior (Social Robotics) (Breazeal 2002).

In this regard, Kaeser (2018), president and CEO of Siemens AG, states that the fourth industrial revolution does not only concern technology or business, but also society.

We can imagine future scenarios in which robots will perfectly adapt to work and cooperate in our homes, offices, hospitals and entertainment environments, playing their role as helpers and tutors. Turning these scenarios into concrete technological results requires progress in the sensorimotor and cognitive abilities of robotic systems, to such
an extent that one can reasonably question whether research efforts will be sufficient to bridge the gap between vision and reality.

Robots are becoming increasingly present among us and their number is growing very quickly. They have different shapes, destinations and level of intelligence, and can potentially respond to several of the main challenges that human society is facing nowadays. Despite this, we are very distant from the complete understanding of many mechanisms underlying the relationships that humans have with robots.

In recent years, industrial designers and service designers began to deeply investigate man-machine collaboration to try to understand the impact that robots will have on our experience, both as designers and as users, and the relevance that design choices on aesthetics and interactional features may have on the acceptability and success of the product.

2 The Project

2.1 Social Robotics for Active and Healthy Ageing

Nowadays the need to improve health services quality and make them more sustainable is a crucial aspect for many countries facing social challenges such as aging populations, in light of the global economic crisis. In this context, robotic, IoT and AI technologies can improve the life of the elderly, including those with difficulties in carrying out daily life activities and/or suffering from cognitive and physical pathologies; moreover, these technologies have the potential to develop a new assistance process (Vermesan et al. 2017).

Our project aims to conceive and develop new solutions in the field of ICT assistive robotic technologies proving capable of supporting people in carrying out health care services and acting with socially acceptable behavior. Si-Robotics is a research project co-funded by the European Union on “Research and Innovation 2014 and 2020” PON funds, pertaining to the Specialization Area “Technologies for Living Environments”.

The scientific objective of the project is to devise and implement easily adaptable technological solutions to help the elderly in daily activities and evaluate the progress of their physical and cognitive decline (fragility, dementia, slight cognitive impairment). It is based on the idea of creating socio-technical systems that integrate hardware technology (robots, sensors), software (traditional and intelligent SW) and human beings (elderly people, family members, assistance network composed of doctors, formal assistants, organizations, companies of services).

The technological objective of the project is to create connected robots capable of assuming increasingly “human” skills and traits, such as perception, adaptation, learning, manipulation and interaction. The distinctive feature of the project is the implementation of advanced behavioral and interaction models, designed to create a positive perception of care in order to encourage older people to participate in their care process. Our ambition is to provide and evaluate new assistance processes for continuous care carried out through a wide range of health services, including different levels and degrees of assistance at home and in residential areas.
Si-Robotics focuses on these issues and aims to design a holistic approach for assistance and monitoring interventions in the applications of assisted living assets, including:

- monitoring of physical activity (leisure and domestic activities) and coaching;
- physiological monitoring (chronic diseases, aging parameters, emotional state, stress level);
- recognition of habits, lifestyle changes and promotion of a healthy lifestyle; assessment and support of physical/cognitive decline;
- support for a correct lifestyle and physical/cognitive stimulation (nutrition, cooking, physical activity);
- advanced remote control with caregivers.

2.2 Approach to the Robotic Project

We accepted the challenge of this project by focusing on a UCD (User Centered Design) approach, in order to successfully design a User Experience capable of making the robot acceptable for our target market (Lockwood 2010), which consists of frail users with various levels of physical and/or cognitive impairments and their caregivers.

In the following paragraphs we will present a summary of the activities that took place during the first stages of the project, in order to define different use scenarios and design features for our robotic system, while investigating users’ perception and expectations regarding aesthetical and interactional features of the robot.

In particular, the co-design activities with end users were based on IDEO HCD model, which is based on three themes that IDEO’s designers find essential for a Human Centered Design process and thus form the acronym HCD: Hearing, Creating and Delivering (Cross 2011). Thanks to this approach, the user is lead through a participatory design process, which is supported by activities such as building listening skills, running workshops, and implementing ideas.

3 STEP 1: Analysis of Users’ Needs

3.1 Definition of the Scenario

The first phase of the project, which involved the seventeen partners on different levels, was focused on an accurate study of the needs of elderly and impaired users. Once concluded, the services that our robotic system must be able to provide were summarized. Twelve service themes divided into three different settings (hospital, home, social housing) were highlighted (Fig.1); these are not the main focus of this article but are thoroughly described in other papers related to Si-Robotics project (Bevilacqua et al. 2021).

The identified services were subsequently analyzed and transformed into four design features, the choice being based on criteria of marketability, innovation, feasibility and deployability.
3.2 Translating Services into Design Features

The system is composed of two customized robotic platforms (LITE and PRO), sensors and artificial intelligence algorithms. These platforms are based on the platform developed by Co-Robotics which exploits the principle of modular design (Patent request N° 10201800006410 and patent request N° 10201800006369).

The most suitable platforms in terms of size and technological complexity have been coupled to each service offered by the system, taking into account the level of interaction between man and robot (Table 1).

<table>
<thead>
<tr>
<th>Service</th>
<th>Name</th>
<th>Type of platform</th>
<th>Interaction level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>House</td>
<td>LITE</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Cohousing/residential</td>
<td>LITE</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Hospital/acceptance</td>
<td>PRO</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Hospital/therapist support</td>
<td>PRO</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Hospital/ patient monitoring</td>
<td>PRO</td>
<td>Low</td>
</tr>
</tbody>
</table>

As highlighted by the need analysis, elderly and healthcare professionals expressed different needs and expectations on robotic services. In order to make the system truly acceptable to all the stakeholders involved, procedures were defined through the use of workshops and co-creation phases. The following paragraphs briefly summarize the main phases of the UCD process, which made use of IDEO’s consolidated approach model to define the platform concept.
4  **STEP 2: Co-design Activities**

4.1 **Definition of the Activities**

The research team organized the co-design activities of the robotic system according to four distinct phases (Fig. 2). The research activities carried out were aimed at obtaining elements (formal and interactive) to be translated into the concept of the project. In the first phase, an attempt was made to translate the services offered into design features, that is, into the design requirements of the robot. In particular, great importance was given to the presence or absence of the face and the humanoid characteristics of the robot, as well as the presence of other interactive media, such as tablets (Casiddu et al. 2020a).

In other words, an attempt was made to identify the formal characteristics of the robots in relation to the scenario, supported by in-depth literature analysis on the formal characteristics of the robots already on the market, developed autonomously by DAD team (the analysis took into consideration and compared over 100 robots) (Casiddu et al. 2020b).

![Fig. 2. Scheme showing the phases of the co-design process of the robotic system.](image)

The second phase consisted in a co-design activity held with end users of the system, through a Design Thinking-style session. This activity produced a report that was used as a reference for the research and development activities of the third phase: participatory debriefing. The second and third phases are the main subject of this specific article. A fourth phase of implementation of the results will be held with the project leaders/partners (High level meeting), in full compliance with the iterative perspective of the HCD process.

4.2 **Co-design Workshop**

The activity was conducted by a multidisciplinary team of designers and architects supervised by a sociologist, working with focus groups of 5 participants, for a total of
20 individuals between 65 and 75 years old. It took place on November 20, 2019 at University of Genoa, Architecture and Design Department (DAD).

User enrollment was carried out in order to ensure homogeneity of sex and degree of school education. All the participants held a high school diploma. Also, all of them have a good level of autonomy: they live alone without support by human caregivers and have no cognitive diseases. On the other hand, confidence with technology was very various, ranging from people with work expertise in electronic engineering to people with no experience at all.

The activity carried out was aimed at investigating with users the formal and interactional aspects of the robot through three distinct phases: briefing, co-designing, debriefing. Specifically, it was decided to use participatory design game as a method, a prototyping process that allows participants to express their needs through practical game actions and/or physical composition.

For this purpose, special cards have been created, which depict the main components of a humanoid robot, in different iconic shapes and configurations (square, rectangle, circle) (Fig. 3). Participants were asked to compose their own robot by pasting the figures on a form to be filled in with further comments, opinions and explanations in relation to the choices made.

The activity with users was organized in four distinct moments:

1. *Introductory phase* (duration: one hour): introduction to the world of robotics and the project, explanation of the scenarios, ideal administration of robots for assistive care - consistent in terms of price range and task performance but presenting differences in formal characteristics (humanoid, humanized, anthropomorphic) – by video stimulus (duration 5 min);
2. *Participatory design game* (duration: one hour and a half): cards created by formal typology (square, rectangle, circle), to be composed in forms;
3. *Classification of documents by formal homogeneity* (duration: ten minutes): activity carried out by the sociologist;
4. *Participated debriefing in homogeneous groups* (duration: two hours): the maquettes classified by homogeneity in three categories (androids, structure with monitor, amorphous structure) were presented to the group to investigate perceptual and projective aspects (Fig. 4).

![A moment of the activity of participatory design game.](image)

**Fig. 4.** A moment of the activity of participatory design game.

5 **STEP 3: Participated Debriefing**

5.1 **Perceptual Investigation**

The activity was of great importance to the design and conception of the participatory debriefing structure which made use of a mix of consolidated and experimental sociological investigation techniques. In particular, the activity consisted of a first phase aimed at investigating “perceptual” aspects towards the social robot followed by a “projective” one, using the Critical Incident Technique (CIT) methodology (Butterfield et al. 2005).

The first phase (perceptual investigation) consists, in turn, of:

1. *Evaluation*
2. *Activities*
3. *Power*
Evaluation session was designed to investigate the perception of the shape of the robot in terms of:

- beautiful or ugly
- pleasant or unpleasant
- useful or useless
- familiar or foreign

From a formal point of view, the android aspect was investigated in terms of “skin” and materials (synthetic, metallic,...) and gender (male, neutral or female). The color and the possibility of attributing a name to the robot were also investigated.

Activities session was designed to investigate the “acting” aspects of the platform in the space shared with man. Aspects such as speed and slowness and tasks were investigated, i.e. the use cases of the platform as well as aspects related to sound (male or female human voice or inanimate sound emission).

Power session was designed to investigate perceptual aspects such as: reassuring/worrying, safe/dangerous, simple/complicated, stable/unstable. In addition, users were asked to make a choice between autonomous or remotely controlled movement, in confined or nonconfined space (possibility of the robot to access all rooms of the house) and, finally, the size of the platform.

5.2 Critical Incident Technique

The projective phase used the Critical Incident Technique (CIT) methodology, which allows users' opinions to be collected and classified systematically in relation to a service. The technique is based on the recording of events and moods expressed by users involved in a ‘critical incident’ (definable as an event linked to the provision of the service which contributes significantly to increasing or decreasing satisfaction); analyzing these critical episodes it is possible to identify the fundamental determinants of satisfaction. The information was collected through a semi-structured interview, following this structure:

A) Imagining the robot in a domestic context:
   - If you would ever need assistance could you use a similar robot to assist you in your daily activities?
   - What do you think could be the strengths of such a robot?
   - What do you think could be the critical points?

B1) Imagining the robot in a hospital or other institutionalized context performing functions of welcoming/informing users:

- What do you think could be the strengths of the robot in a similar situation?
- What do you think could be the problems of the robot in a similar situation?
- What would your feelings be if you were greeted by a robot in the hospital or other similar contest?
B2) *Imagining the robot in a hospital or other institutionalized context, if it were to monitor patients:*

- What would be your feelings being monitored by a robot during a hospital stay or similar contexts?
- What do you think could be the strengths of the robot in a similar situation?
- What do you think could be the problems of the robot in a similar situation?

### 5.3 Results

Generally speaking, the experimental co-design activity investigated the predisposition of users to the use of digital devices and analyzed opinions on the proposed robotic services and collected suggestions. The chosen methodology proved to be flexible, capable of gathering the interviewee’s point of view without forcing it, economic and capable of returning numerous useful information.

This co-design process led to the definition of several possible configuration of the reduced dimensions to facilitate movement in narrow spaces; furniture-like shape to allow a more graceful integration into domestic environments, clearer warning signals in case of emergency, illumination of the mobile base in order to support navigation even in low light conditions and integration in the interaction process of smartphones or tablets to enable the possibility of controlling the robot via mobile devices. Many users have expressed the desire not to delegate all daily activities to the robotic platform to maintain an active life, but they also expressed the desire to develop new platform features.

The robot was acknowledged as a useful tool for the safety of the elderly, even though its size and height, which were reckoned to be potentially excessive, can create a sense of oppression for the user.

A number of users claimed that the robot should aid the user movement and his social life: for this reason, recreational and telepresence applications was taken into account.

Users participating in the workshop repeatedly underlined the need to actively use the robot. The robot should be managed autonomously with different functions and it should be possible to move it easily and use it for emergency calls.

However, for a successful interaction the robot should maintain a simple shape.

Other highlighted elements are:

- the robot should be able to signal its movements and its presence should be evident within the house;
- the robot should be able to send visual and luminous feedback.

### 5.4 Live-Drawing Co-design Activity

The results obtained from the co-design activities created the basis for structuring a second participatory activity, in full compliance with the iterative design perspective. This experimental activity took place on December 12, 2019 at University of Genoa, Architecture and Design Department (DAD). The carried-out activity was aimed at
investigating with users the formal and interactional aspects of some concepts developed on the basis of previous activities.

The experimental methodology made use of an illustrator and a projector: the concepts were co-designed with users in real time and projected on a wall in 1:1 dimension. The illustrator prepared a few drawings of the concepts before the activity; these were then submitted to the users by the sociologist who moderated the co-design process. The user sample was formed by the same people who took part in the previous session, in order to offer them a full overview of the design process and receive their suggestions and opinions as their understanding of the theme evolved.

The activity was organized in three distinct moments:

1. **Preliminary phase** (duration: thirty minutes): presentation of the concepts projected in 1:1 dimension on the wall by the illustrator, with description of the design choices made by the team;
2. **Live drawing** (duration: one hour): guided by the sociologist, users started a discussion on the presented drawings. They proposed alterations and integrations to the designs, that were directly edited by the illustrator in a live drawing session (Fig. 5);
3. **De-briefing** (duration: thirty minutes): a final phase, guided again by the sociologist, was fundamental in order to collect all the ideas and come to a shared vision for the final design.

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![Fig. 5. Live-drawing co-design activity.](image-url)
5.5 Results

The activity was a great success regarding users’ engagement. In particular, the capability to see a full-sized drawing of the concept allowed users to have a deeper understanding of the design problems and possibilities. Without it, a person who is not used to draw and design wouldn’t have been able to clearly visualize the concept and positively interact with the designers.

After an initial shyness, users unlocked their creativity and were fully involved in the activity: they stood up from their chairs and started to discuss their opinion directly with the designers and the illustrator, proposing changes and addition to the concepts projected on the wall. These proposals were deeply insightful and will be taken in great consideration for the definition of the final design.

The activities were recorded and transcripted so that the sociologist was able to analyze it while designers analyzed the graphical results of the activities. The data analysis process will be described in further publications on the project (Fig. 6).

![Fig. 6. Sketches resulting from the live-drawing co-design activity.](image)

6 Conclusions

In dealing with the presented topic, the preliminary activity conducted does not pretend nor aim to be exhaustive. Its goal is to provide insights and stimulate further exploration of different points of view on the designing of assistive robots.
A correct robotic design needs attention to humans, to their needs and expectations, and the ways through which they interact with objects, spaces, systems or services with and into which they conduct working or daily activities, evaluating different dimensions of this relationship (physical, perceptual, cognitive, emotional).

How should social robots be designed? This question represents a research sector still in development, which generates further research questions to which the scientific community, in the field of design, has not yet provided certain answers.

References

Bio-data and Artificial Sensing in AAL Scenarios
Heart Rate Estimation Using the EVM Method, the FFT and MUSIC Algorithms Under Different Conditions

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Abstract. The detection of vital parameters is one of the first and foremost task to be performed on a patient to evaluate her/his health status. Among the vital signs, a great importance is assumed by the heart rate, which is defined as the number of heartbeats measured in a minute. Heart rate is generally measured using an electrocardiograph, which allows an accurate recording of the cardiac activity, but requires the placement of some electrodes in specific points of the body. Such an approach involves a direct contact between the device and the patient’s skin, which is often uncomfortable and impractical. In this paper we propose a contactless approach based on RGB video for heart rate extraction, avoiding any type of direct interaction. For this purpose, we exploit videos of the subjects' faces recorded via smartphone and we then apply the EVM method to estimate the heart rate obtained in a comfortable and non-invasive way. The results obtained with two different methodologies, based on Fast Fourier Transform (FFT) and on the MUltiple SIgnal Classification (MUSIC) algorithm, have been compared to three devices with clinical validity, i.e., a pulse oximeter, a Polar heart rate strap and a blood pressure monitor, which guarantee accuracy at a reduced cost and are easily commercially available. The high accuracy of the developed system is proved by the small difference achieved between the values measured with the developed contactless technique and those obtained with the wearable devices, which results in an error between 1.07% and 4.67%, regardless of the ambient light conditions under which the videos were captured.

Keywords: Contactless · EVM · Pulsoximeter · Polar · Sphygmomanometer · Heartbeat · Heart rate

1 Introduction

In the last years several methods have been proposed in literature for the extraction of the heart rate and other vital signs, such as the heart rate variability (HRV) and the respiratory frequency, based on the determination and analysis of photoplethysmography (PPG) and videoplethysmography (VPG) signals.
One of the most studied and implemented techniques is the Eulerian Video Magnification (EVM) [1].

The EVM method allows to emphasize the skin color variation on the faces of the subjects under test, following the phases of diastole and systole. During diastole, the heart cavities enlarge and fill with blood, leading to an increase in the volume of blood vessels. During systole, the opposite occurs and the cavities empty. This results in a different optical absorption of light by the tissues, which makes it possible to determine the color changes of the skin. By illuminating the skin, it is possible to measure the quantity of light transmitted and reflected, obtaining the PPG signal. The PPG signal becomes VPG [2] when the measurement is performed remotely via video. With the EVM method, we start from the acquisition of RGB video through a sequence of images captured as RGB (Red, Green, Blue) and subsequently transformed into YIQ (Y is the Luminance component, while I and Q represent the Chrominance components). We apply the well-known Viola and Jones algorithm [3] for the face detection, since the face region is more suitable for processing with respect to other parts of the body.

In the work of Gambi et al. [4] the heart rate was evaluated through the EVM algorithm by using a Microsoft Kinect v2 device, proving that the resulting error is minimal and that, moreover, it can be further reduced by knowing the lifestyle of the individual under test.

Another well known algorithm for the heart rate extraction is the Independent Component Analysis (ICA). In [5] the VPG signal was obtained by using the ICA method, with the aim of detecting the blood pressure through the analysis of the Pulse Transit Time (PTT), extracted from the VPG signal. In [6] the ICA method is used not only to obtain the HR, but also the HRV and the respiratory frequency, with good results for all the vital parameters. In particular, the Joint Approximate Diagonalization of Eigenmatrices (JADE) ICA method is considered, by selecting the principal component having the maximum peak in frequency. Once measured the VPG signal, peaks and RR intervals (where RR identifies the intervals between successive heartbeats, i.e. the distance between two consecutive R waves) are determined and the HRV and the respiratory frequency are derived from the tachogram.

ICA and EVM methods are compared in [7] by considering results of both methods for the HRV extraction. It is proved that the ICA has a better performance since the EVM shows a high level of noise at the high frequencies in the power spectrum of the tachogram.

Recently, an adaptive EVM approach has been proposed in [8] to amplify the signal of interest avoiding the noise amplification. Both an infrared camera and an iPad camera were used to capture videos of the subjects. Video captured with the iPad camera was processed with the EVM, using a wide band pass filter and a low amplification factor. The authors considered five Region of Interests (ROIs) to extract the signal representing the heart rate, namely the entire face, right cheek, forehead, a portion of the chest and one portion of the subject’s arm.
The EVM method proved to achieve excellent results also when compared with the electrocardiogram (ECG) signal. In [9] it is stated that the heart rate extracted with EVM differs from the ECG by less than 5%. However, the results showed that for subjects suffering from cardiovascular diseases (e.g., tachycardia, bradycardia), the algorithm needs further modifications (or a higher quality camera is required).

The color amplification from RGB video sequences often introduces noise. Therefore, several works have also been proposed for denoising using the EVM method. In [10] an approach to reduce amplified noise in videos both in color and in the involuntary movement made by subjects during acquisition is proposed. The video resulting from the EVM algorithm is denoised by means of a wavelet transform, a method widely used to localize the frequencies of the noise distributed on the different frequency bandwidths. This allowed the videos to be amplified with a higher amplification factor.

Another technique for the reduction of the noise amplified with the EVM is the principal component analysis (PCA), as explained in [11]. In this work an advanced EVM for the amplification of the signal amplitude in the presence of relatively high noise is presented. The PCA method is applied to decompose frames and components that need to be emphasized, i.e., those that are subjected to the most significant variations. The advantage of the PCA-based method is that even the slightest variations in signals can be considered with a denoising process carried out by spatial filtering. Experimental results show that PCA-based EVM can be employed with larger amplification factors to visualize smaller changes, resulting in less noise and artifacts.

The PCA method, before being used to derive the VPG signal through the analysis of video signals, has been applied directly to the PPG signal obtained from an oximeter to determine the vital parameters. In [12] PCA of a PPG signal is used to determine the respiratory frequency. The intensity variation of the PPG signal due to respiration is visible in the coefficients of the principal components.

In [13,14] the use of low-cost commercial devices originally designed for other purposes, i.e., a GoPro camera and an automotive radar, was considered to measure the heart rate. In this paper we propose a contactless methodology based on videos collected using a common smartphone, which currently represents a device easily available to everyone. One of the most convenient characteristics of a smartphone is that it allows to take measurements comfortably in very different settings. Among the approaches for the heart rate extraction proposed over the years, many of them [15–18] have in common the extraction method of the peak in frequency, i.e., the Fast Fourier Transform (FFT).

In this work, besides the FFT for the detection of the principal component in frequency of the signal which provides us with the average heartbeat, we consider the application of the MUltiple SIgnal Classification (MUSIC) algorithm [19,20]. MUSIC is a spatial spectrum estimation algorithm that has several advantages, such as performing high-precision measurements, a high spatial resolution, the possibility to be implemented in real time. The estimate of the heart rate is
therefore carried out with both methods to evaluate which one is able to achieve the best results when compared with the wearable devices taken as a reference.

The rest of the paper is organized as follows. In Sect. 2 we describe the methodology used to extract the heart rate from the video signal, describing the EVM method and the FFT and MUSIC algorithms. In Sect. 3 experimental results are shown, with some considerations on how the physical characteristics of the subjects under test and light conditions affect the accuracy of the measurements. Finally Sect. 4 concludes the paper.

2 Heart Rate Extraction Method

The EVM algorithm is based on the amplification of the small variations in the luminance of the video signal, due to the blood flow in the vessels. In order to emphasize the variation of the color of the face skin, we proceed through five main steps:

1. Face detection;
2. Application of the EVM method;
3. ROIs selection;
4. Extraction and filtering of the VPG signal;
5. FFT and MUSIC for the heart rate extraction.

2.1 Face Detection

First of all the algorithm must be able to detect and track the face and neck region, in order to reduce the amount of data input of the EVM process. It is therefore necessary to transform the video signal into a sequence of frames (for a total of 1200 frames, given the 40 s of acquisition and a sampling rate of 30 fps). The face detection is then elaborated using the Viola-Jones algorithm, applied iteratively on each of the frames. The minimum dimension of the box is set to $232 \times 232$ px to be sure that the face detector captures also the neck, as shown in Fig. 1.

2.2 EVM Method

Once obtained the face and neck box, we apply the EVM method in three phases:

- Space decomposition;
- Time filtering;
- Color magnification.

Spatial processing consists of the decomposition of the various frames containing the face and the neck of the subjects under test through a subsampling realized with a Gaussian pyramid having a predefined number of levels $L$ equal to 4, as shown is Fig. 2. The image final resolution is $14 \times 14$ px.
Fig. 1. Face image corresponding to the box of the face detector.

Fig. 2. Pyramidal decomposition in 4 levels.

The time processing is implemented for all spatial levels, and for all pixels within each level by applying an ideal Infinite impulse response (IIR) band-pass filter. In this work we consider a narrow-band filter with low cut-off frequency ($f_L$) equal 1 Hz and high frequency ($f_H$) equal 2 Hz, in order to include the frequencies related to a range of subjects with normal heart rate, going from 60 to 120 bpm in stationary conditions of the subject at rest.

The third and last phase characterizing the EVM is the color amplification, which consists in the multiplication of the extracted bandpassed signal transformed from the RGB color space to the YIQ one, taken only in the luminance component $Y$, by a magnification factor ($\alpha$-factor) empirically set to 50.
2.3 ROIs Selection

The ROIs selected for the heart rate extraction are the forehead, the cheeks and the neck. The neck in particular is considered because of the presence of carotid arteries, which allow to detect a remarkable color amplification in correspondence of the diastole and systole phases. In these regions the luminance is averaged to process the VPG signal in the frequency bandwidth of interest. The ROIs dimensions parameters are defined as the percentage from the edge of the face detector. The choice of the values that determined the ROIs positioning was made experimentally. The base and height of the cheek and neck boxes were considered equal to 10% of the total and the base and height of the forehead rectangle equal to 25% and 10%, the percentages with respect to the edges of the main box were varied in based on the physical characteristics of the individual, trying to select the most appropriate and least subject to possible interfering inputs. The percentages of the ROIs selection from the perimeter of the face detector are reported in Fig. 3.

Fig. 3. ROIs selection.

2.4 Extraction and Filtering of the VPG Signal

The next step requires that the pixels of the different ROI are converted from RGB to YIQ (note that Y represents the luminance component, while I and Q are the chrominance components). By adding up the average Y of all the pixels contained in the selected areas, we obtain the VPG signal in the time domain. The extracted signal is then filtered in the frequency bandwidth of interest [1,2] Hz through a pass-band Butterworth filter of the third order, as shown in Fig. 4.
2.5 FFT and MUSIC for the Heart Rate Extraction

For the heart rate extraction the VPG signal is then transformed into the frequency domain through the FFT (see Fig. 6) and the MUSIC (see Fig. 5) algorithms. The MUSIC in particular is computed over 64 points. For a more accurate evaluation the graph of their overlap is also considered, as shown in Fig. 7.

By determining the highest peak in frequency of the signal, we are able to measure the average heart rate evaluated in the acquisition interval. The conversion from Hz to bpm is obtained with a simple multiplication of the value by 60. For the example reported in Figs. 6, 5 and 7 we observe a peak at 1.33 Hz, which corresponds to a heartbeat of 80 bpm. Moreover it is possible to note that for this signal the frequency peaks extracted by FFT and MUSIC coincide. However, this is not the case for all subjects, in fact with MUSIC we obtain a value affected by a lower mean percentage error (MPE) when compared with the reference data.
3 Experimental Results

The dataset for the experiments consists of 8 disease-free subjects with age 33.5 ± 18.03, characterized by a normal lifestyle (not excessively sedentary or sporty). The video recording of the face, lasting 40s, was carried out with a Samsung A50 placed 0.5 m away from the single subject, with a resolution of 1920 × 1080 pixels and a frame rate of 30 fps. For each subject, who was asked to remain motionless in a sitting position and to breathe spontaneously, more acquisitions were made by varying the operating conditions, in order to extend the analysis of the heart rate to more complex cases.

We consider different light conditions, measured in lux through a smartphone app, Lux Meter, in order to evaluate the impact of the amount of light on the subjects’ faces. The light conditions are then distinguished between low and good
light in the cases were a few dozen or several thousand of lux were measured, respectively. We also take into account various possible hindrances which may influence the quality of the video acquisition and therefore the error achieved by the system, such as the presence of glasses, beard or make-up. We then compare the results obtained by measuring the variation of the MPE.

In this section we report the results achieved for two distinct groups of subjects. For the first group, we consider 24 signal elaborations obtained on 3 subjects wearing at the same time a Polar T31 heart rate strap and a pulse oximeter. The second group consists of 5 subjects who participated in 44 tests and who, simultaneously to the video acquisition, wore a sphygmomanometer. The described wearable devices are used as ground-truth since they are easily available on the market and guarantee accurate measurements together with a certified clinical validity. They represent a valid alternative to the measurements taken with the golden standard instrument, i.e., the ECG, that forces subjects to go to hospital environments and through which it is not possible to perform a daily monitoring of the heart rate in a domestic environment. To evaluate the average heart rate in the 40 s of acquisition, the values measured by the pulse oximeter and the Polar strap were averaged over time. The acquisition time of 40 s has been chosen in order to achieve a trade-off between the accuracy of results and the computational speed, which increases with the amount of time considered. Data were then used as a reference to compare the accuracy of the results obtained using the EVM algorithm.

3.1 Group 1

For the first group we analyse the results shown in Table 1. In Table 1 are also reported the characteristics of the subjects (S) under test, namely the presence of make-up, glasses (G) or beard, and the measurement of the environment light in LUX.

Each subject participated in a different number of tests based on her/his availability. It is possible to observe that the presence of beard in test 5 and make-up and glasses in test 24 lead to the greatest errors, despite the measured light intensity being sufficiently high and consequently the face well lit. These tests in fact have relative errors of 8.642% and of 10.606% respectively, both considering the FFT as heart rate extracting method and the Polar as a reference. We can therefore state that such characteristics constitute a source of error for acquisitions, even if the error remains quite limited. Table 2 reports the relative errors of the single acquisitions elaborated through the EVM method with both FFT and MUSIC algorithms.

For the obtained results we evaluate the MPEs, reported in Table 3, according to the following equation
Table 1. Test (T) results obtained with the EVM method through FFT and MUSIC, compared with the Polar T31 (PT31) and the pulse oximeter (POx). The symbol/stands for the absence of particular characteristics.

<table>
<thead>
<tr>
<th>T</th>
<th>S</th>
<th>I</th>
<th>LUX</th>
<th>FFT</th>
<th>MUSIC</th>
<th>POx</th>
<th>PT31</th>
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<tbody>
<tr>
<td>1</td>
<td>S1</td>
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<td>20</td>
<td>83</td>
<td>81</td>
<td>80</td>
<td>81</td>
</tr>
<tr>
<td>2</td>
<td>S1</td>
<td>Beard</td>
<td>20</td>
<td>79</td>
<td>79</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>3</td>
<td>S1</td>
<td>Beard</td>
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<td>83</td>
<td>79</td>
<td>80</td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td>S1</td>
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<td>86</td>
<td>86</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>5</td>
<td>S1</td>
<td>Beard</td>
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\[ MPE = \frac{100\%}{n} \sum_{t=1}^{n} \frac{|R_t - E_t|}{R_t}, \]  

where \( n \) is the number of different tests, \( R_t \) represents the reference value (pulse oximeter, Polar T31 or sphygmomanometer) and \( E_t \) is the value estimated using the EVM method.

We can note that the system benefits from the application of the MUSIC algorithm, which improves the quality of the measurements leading to a lower error.
3.2 Group 2

For the second group of subjects we analyze the results reported in Table 4. Also in this different physical characteristics and light conditions are considered. Also for this second group each subject participated in a different number of tests, according to her/his availability. The subjects in the table are sorted according to the acquisition order, in order to consistently report the measured light values.

Table 2. Relative errors calculated with the EVM method through FFT and MUSIC, compared with the Polar T31 (PT31) and the pulse oximeter (POx)

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<th>T</th>
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<th>Er% POx-FFT</th>
<th>Er% PT31-FFT</th>
<th>Er% POx-MUSIC</th>
<th>Er% PT31-MUSIC</th>
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</table>

Table 5 reports the relative errors of the single acquisitions elaborated through the EVM method with both FFT and MUSIC algorithms.

In this case the presence of make-up in test 11 (relative error $Er = 17.647\%$ considering the FFT as heart rate extracting method) and the probable presence of low light in test 44 ($Er = 17.333\%$ considering both the FFT and MUSIC methods).
algorithms) lead to the greatest errors. In the first case we have a high value for the light intensity (5130 LUX) while in the second case the error is due to the low light (only 29 LUX), since no physical obstacle is present between the subject and the camera. Also for this second group we evaluate the MPEs, reported in Table 6.

With respect to the previous case where Polar T31 and pulse oximeter were taken as references, the values of MPE for the second group of tests increase. Taking into consideration the presence of a larger dataset, we can assert that the algorithm for the heart rate extraction through video obtains optimal results if we consider the Polar T31 as the reference device. The error however results very low even considering the sphygmomanometer as a reference (4.1531% obtained with the MUSIC). It is therefore possible to conclude the MUSIC algorithm allows to achieve the best performance.

Table 3. MPE of the FFT and MUSIC methods with respect to the Polar T31 (PT31) and the pulse oximeter (POx) taken as a reference.

<table>
<thead>
<tr>
<th>Method</th>
<th>Percentage Error</th>
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</thead>
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<tr>
<td>POx-FFT</td>
<td>2.883%</td>
</tr>
<tr>
<td>PT31-FFT</td>
<td>3.046%</td>
</tr>
<tr>
<td>POx-MUSIC</td>
<td>2.103%</td>
</tr>
<tr>
<td>PT31-MUSIC</td>
<td>1.707%</td>
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</table>

Fig. 8. Error trend as a function of the light intensity for the subjects of the group 1.

Considering the light intensity, we can compare the results achieved by the two groups of subjects by observing Figs. 8 and 9. By analyzing Fig. 8 we note that for the Group 1 the relative percentage error computed with the MUSIC algorithm and compared with the Polar T31 (Er% MUSIC-PT31) does not depend on the light intensity, exhibiting a linear trend and an almost constant value. On the contrary from Fig. 9 we observe that for the Group 2 the relative
percentage error between values obtained with the MUSIC and those obtained by the sphygmomanometer (Er% MUSIC) slightly decreases with the increase of the light intensity.

We can eventually conclude that the errors affecting video acquisitions are mostly due to the obstacles between subject and camera that result on the face (beard, make-up, glasses) and in a small part to the light intensity at which the faces of the subjects are captured.

Table 4. Test (T) results obtained with the EVM method through FFT and MUSIC, compared with the sphygmomanometer (Sphyg) taken as a reference. The symbol / stands for the absence of particular characteristics.

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<th>LUX</th>
<th>FFT</th>
<th>MUSIC</th>
<th>Sphyg</th>
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Table 5. Relative errors calculated with the EVM method through FFT and MUSIC, compared with the sphygmomanometer (Sph) taken as a reference.

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<tr>
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<td>S3</td>
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</tr>
<tr>
<td>12</td>
<td>S3</td>
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<td>7.143</td>
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<td>S4</td>
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<tr>
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<td>S4</td>
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<tr>
<td>22</td>
<td>S4</td>
<td>2.703</td>
<td>8.108</td>
</tr>
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Table 6. MPE of the FFT and MUSIC methods with respect to the sphygmomanometer taken as a reference.

<table>
<thead>
<tr>
<th>MPE Sphyg-FFT</th>
<th>4.668%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPE Sphyg-MUSIC</td>
<td>4.153%</td>
</tr>
</tbody>
</table>

Fig. 9. Error trend as a function of the light intensity for the subjects of the group 1.
4 Conclusions

The remote monitoring of vital parameters through contactless technologies can be useful for different applications, included those in a domestic environment. The daily monitoring of people prone to chronic cardiovascular diseases in fact has a great relevance and allows the control of their vital conditions even in everyday situations. The goal of the system here proposed is to predict a risk situation through a constant contactless monitoring of the heart rate carried out using a smartphone, which is a device readily available to everyone. The heart rate detection through RGB video is characterized by a certain variability both in terms of ambient light conditions and physical characteristics (beard, make-up, glasses) of the subjects that can represent a source of noise for the face acquisition, as shown by the obtained results. Two groups of subjects have been considered in order to have a validation of the measurements carried out with respect to the ambient light and to the wearable device taken as a reference. Although in the first group the correlation between the measurements and the amount of light in the environment was small, it has been proven that in the entirety of the measurements the RGB video acquisitions depend, albeit to a lesser extent, on the ambient light conditions, since the error decreases with the increase of the light intensity in the room, especially in the second group analyzed. For these reasons, besides measuring the heart rate, it is important to understand how much the behavior of the system can vary when specific conditions change in order to evaluate its performance more accurately. From the results obtained and on the basis of the very low mean percentage error (MPE) achieved, we can state that the EVM method allows to obtain excellent results under the considered conditions, especially using the MUSIC algorithm, which has an error of 1.707%.

References

Vision-Based Heart Rate Monitoring in the Smart Living Domains

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Abstract. In AAL context the increasing demand to new developments in health-care technologies poses inevitability to the thought of easing the patient monitoring in a non-invasive manner, even with commercial and low cost digital cameras as reliable devices that can be employed to measure vital signs. A widely diffused method for contactless heart rate estimation is remote-photoplethysmography from facial video streams. A critical issue in this research area relates to not having always available frontal images of the subject’s face. A further critical aspect is represented by the distance from the vision sensor and by highly variable lighting conditions of the environment. In the proposed work, heart rate measurement of the observed subject was estimated through the design and implementation of a software algorithmic pipeline able to manage the aforementioned critical issues. The proposed system is able to detect faces “in the wild” without constraints and consequently improving its usability. The methodology includes data processing algorithmic steps which allow an adequate extraction of features from a ROI that includes pixels identified as facial skin and whose shape and size vary with the distance and orientation of the face. The findings of the preliminary experiments inferred promising results on three cohorts of subjects grouped by age, with a slightly higher average error expressed in terms of Root Mean Square Error for the group that includes elderly subjects, confirming that the approach considered is even suitable for contactless HR measurement of older people.

Keywords: AAL · Remote photoplethysmography · Heart rate · Contactless monitoring · Aging subjects

1 Introduction

Nowadays a continuous monitoring of vital signs is very important for assessing health and access to physiological data. This is not only necessary in clinical setting but it is becoming increasingly also in other environments like the house and applications related to telemedicine [1].

Currently, for the determination of Heart Rate (HR), conventional methods such as the electrocardiography (ECG) and wearable devices like smart watches or wrist bands are used, even if they have the disadvantage that end-users experience a great deal of
discomfort if any sensor is attached to their body parts. It is obvious how in the field of Ambient Assisted Living (AAL) a solution that enables more precise measurement of the HR of elderly or frailty subjects in their familiar environment has many advantages. In the era of ubiquitous computing mobile devices such as smartphones and tablet are omnipresent and cameras/webcams are sensors that in some cases are already available (i.e. for fall detection, activity recognition or affective computing) and thus particularly interesting for unobtrusively measuring vital signs. An analysis of the literature has shown that existing methods for detecting non-contact vital signs, starting from RGB images, can be divided into two main categories: a) movement-based methods and b) methods based on variations in color intensity. The latter are the most popular and performing methods. They are based on the analysis of the remote-plethysmographic signal (rPPG) captured by the vision sensor [2, 3].

The rPPG is a low-cost, non-contact and pervasive technique for HR estimation, but with rPPG signal is possible to infer other psychophysiological data including heart rate variability (HRV), BR, blood pressure and oxygenation. This signal is based on the following consideration: the blood absorbs the light in a superior way compared to the surrounding tissues and the variations in the volume of the blood influence the transmission and reflection of the light. This leads to subtle color changes on human skin, which are invisible to the human eye, but which can be recorded by a simple RGB vision sensor [4].

A lot of research has been done in the area of vision-based HR monitoring. For example, in [5] a method for PPG estimation by deriving chrominance features from the RGB spectrum of the digital camera was proposed, involving an approach of estimating the ratio of two orthogonal chrominance signals from the traces of the RGB spectrum. The RGB colors were transformed into chrominance colors by using an experimentally extracted fixed coefficients and finally the PPG signal were estimated by measuring the ratio between the orthogonal chrominance colors. Yan et al. [6] proposed a signal weighted analysis method to extract PPG signal using a strategy of considering the weighted average of the raw traces of the RGB color spectrum for maximizing the signal and minimizing the noise. Upon performing weighted signal analysis, the signal was processed for baseline drift removal and then denoised using wavelet transform to extract the PPG signal.

In the work of Fallet et al. [7] the spatial distribution of the HR-related information on the subject face was investigated, based on a partition of the facial region into 260 small ROIs. A power spectral density (PSD) analysis was performed to determine the amount of HR-related information in each ROI. Then, normalized color maps were used to visualize the spatial distribution of the HR-information and these features clearly showed that color fluctuations due to blood volume changes are always more pronounced in the forehead region.
More recently, to extract HR using a webcam, Cheng et al. [8] designed a robust method exploiting illumination variation by combining joint blind source separation (JBSS) and ensemble empirical mode decomposition (EEMD) to suppress the noise caused by illumination variation. However, this method is not free from motion artefacts as they only considered stationary subjects. Moreover, the illumination variation considered here was mostly controlled, which restricts real time applicability of the proposed method.

All the aforementioned approaches perform well if the facial region is frontal, close enough to the acquisition device, and if the lighting conditions of the environment are controlled. Moreover, almost all research work do not consider the significant differences in the PPG signal extracted from the face of elderly subjects.

It is also true that current literature on real-time contactless HR monitoring focuses on improvement over existing methodology by considering imaging acquisition factors (environmental lighting, subject movement, and image sensor spectrum sensitivity) and the age of the observed subject that, at this time, represent the main limitation to an optimal rPPG measurement and therefore to collect accurate physiological data, included HR.

There were also several attempts to estimate HR remotely using deep learning (DL) approaches [9–11]. But these studies have a series of drawbacks. In fact, DL approaches are almost never not end-to-end systems since they require pre-processing or post-processing steps involving handcrafted features. Moreover, they are based on 2D spatial neural network without considering the temporal context features, which are essential for the rPPG measurement problem. Last but not least, DL based algorithmic frameworks need appropriate (and not always low cost) hardware for their correct functioning, limiting the diffusion of aforementioned solutions.

The aim of this work is the design and implementation of an algorithmic pipeline independent from the image acquisition device and able to achieve more accurate non-contact HR estimation under challenging and practical conditions which are typical of the AAL context. Since researchers mainly considered healthy young participants as their subjects to do the experiments and did not use patients such as elderly people, a further objective of this work is to verify the effectiveness of the proposed pipeline as the age of the observed subject changes.

This paper is organized as follows. At first, the designed and implemented methodology for remote HR detection is introduced. Thereupon, the results at varying of orientation and distance of the facial region from the vision sensor are presented, considering moreover different illumination conditions which are frequent in a living environment. The results obtained are reported in correspondence with three groups of distinct subjects clearly separated according to age. Finally, the last section of the document concludes this work summarizing the main findings of the proposed approach and giving an outlook to future work.
2 Material and Methods

In this section the proposed methodology for HR evaluation using rPPG in AAL context is explained. Evaluating HR from a video streaming generally follows three basic procedures: (1) continuous frame acquisition; (2) image pre-processing, i.e., selection of relevant pixels of interest (e.g., face and/or skin detection), channel combination and color space conversion; (3) feature extraction (e.g., band-pass filtering based on Fourier or Wavelet transform, blind source separation of signals…). Some details of the implemented algorithmic pipeline (Fig. 1) are reported in the next subsections.

![Fig. 1. Overview of the implemented pipeline for contactless HR measurement](image)

2.1 Pre-processing

The task of detecting a face in the considered scenario is not an easy problem because many difficulties arise and must be taken into account. In a living environment, for example, the face of observed subject could occupy very little area in most images if the camera is not positioned near the end user. Moreover, faces can look very different depending on orientation, pose and age. Face detection went mainstream in the early 2000’s when Viola and Jones [12] invented a way to detect faces that was fast enough to run on cheap cameras. Today it is very close to being the de facto standard for solving face detection tasks. Given that the original Viola-Jones face detector has limitations for multi-view face detection, in the implemented pipeline a recent methodology that has met much success is proposed to tackle this problem.

Here the library with functions that mainly aiming real-time computer vision (i.e. last version of OpenCV) is selected. In particular, starting from OpenCV 3.3 a deep neural network (dnn) module that performs an accurate face detector is included. The
main advantage of this module is the ability to detect faces “in the wild” in real-time even if a PC without GPU is used for the processing. The aforementioned module is based on SSD framework (Single Shot MultiBox Detector), using a reduced ResNet-10 model [13] and its output is constituted by the coordinates of the bounding box of the facial region accompanied by a confidence index, useful in case it is necessary to set a reliability threshold with respect to the detection of the facial region.

Since the selection of a suitable ROI for the rPPG-based HR measuring is essential and challenging step, and considering that it has a direct impact on the accuracy of the overall algorithm, a skin detection algorithm is performed inside the cropped region output of the previous face detection step. The purpose of this pre-processing step is to filter out non-skin pixels that generally belong to the following areas: eyes, eyebrows, hair, and glasses. This skin segmentation process is done using a combination of two segmentation techniques performed in HSV and YCbCr color space together with Watershed region growing algorithm [14]. This approach works very well in real-time and permits to obtain a good detection of skin region with different skin tones, illumination conditions, quality of facial images and age of the subject (Fig. 2).

![Fig. 2. The resulting bounding box of the implemented face detection algorithm with the corresponding confidence index (top row); ROI extraction using the proposed skin detection algorithm (bottom row)](image)

It is well known how the noise generated by fluctuations in the light levels of the environment can disrupt continuous measurement of HR and consequently the management of this issue is very important within the considered context. To address this problem the extracted ROI is decomposed into the H (Hue), S (Saturation), and V (Lightness) color components and after decomposition the value $V'$ is calculated by normalizing the values of V in the ROI across the frames of a video segment. Then V values are replaced by $V'$ values for every pixel belonging to ROI in frame $i$ leaving the values of the H and S components unchanged. For a given video segment composed of $n$ frames, $V'_i$ is calculated using Eq. (1) where the mean of $V'_i$ over $n$ frames is denoted by $V_{avg}$ and the
standard deviation by $V_{std}$:

$$V'_i = \frac{V_i - V_{avg}}{V_{std}}$$

(1)

In a continuous monitoring scenario, the video segment is a sliding temporal window, and it refers to the length of video used to calculate one HR value. For the proposed approach, a sliding window of 30 s is adopted. In this way the ROI is reconstructed using the H, S and V' color components decreasing light fluctuation in the frames. Next, after HSV'-RGB color conversion step, the pipeline provides a block that takes as input an array representing RGB values of skin facial pixels and returns as output three individual monochromatic raw signals representing the red, green and blue components for each considered pixel. In order to constitute temporal signals, the final raw RGB signals were obtained by calculating the average pixel value of the skin-pixels within the ROI region.

Finally, after extracting the raw signals for each frame belonging to the sliding window, specific signal processing techniques are employed with the purpose to improve the quality of the signal for subsequent feature extraction step. Due to the noises caused by changing of the environmental parameters detrending is applied for removing the linear trends from the raw signal, and since the interest is in the periodicity of the signal the obtained raw signal is then normalized by dividing the raw signal by its maximum absolute value and smoothed using a sliding average filter. In this way a raw clarified signal is obtained for each color channel with absence of noise.

2.2 Feature Extraction and HR Estimation

After the application of pre-processing steps, it is necessary to filter out the obtained raw RGB signals to remove frequencies that are unrealistic for a human heart. Consequently, the raw signals are applied to a band-pass-filter with ideal behavior to eliminate high and low frequency noise. The filter removes components which exist outside the 0.7 Hz to 4 Hz frequency band. This band was commonly used in previous studies, and it corresponds to HR measurements between 42 and 240 bpm.

Generally, the identification of cyclic components in signals is routinely done using the power spectrum but this requires sufficient signal quality and signal length. The latter is not an option because all the parameters, including the periodic signal component, vary and the reasonably stationary HR signal is limited to a specific time interval. Moreover, filtering to increase the signal-to-noise (S/N) ratio is problematic because the noise spectrum is similar to the spectrum of the signal to be recovered. However, the obtained multiple noisy signals (the three raw RGB signals output of pre-processing) can be decomposed into basis source signals using Blind Source Separation (BSS) algorithms. Since the pre-processed raw RGB signals contain information about the HR in mixed components, Independent Component Analysis (ICA) is used to recover the source signals from these mixed signals. ICA is a type of BSS in the sense that it computes a linear sum $W$ of available data sets $y$ (raw RGB color channels) with such weights $w$ as to maximize one independent source at a time. In an ideal case, where the number of mixed data sets $y$ is the same as the number of perfectly statistically independent source components $x$, it gives full de-mixing of such sources. The data sources $x$ must
not have a Gaussian distribution and there may only be linear mixes $M$ of these unknown sources. The mixed data sets and the original independent components can be expressed by Eq. (2) and Eq. (3):

$$y(t) = Mx(t)$$  \hspace{1cm} (2)  \\
$$x(t) = Wy(t)$$  \hspace{1cm} (3)

Here, $M$ is the unknown mixing matrix, and its inverse $W$ is the de-mixing matrix found by the ICA. Several ICA algorithms are available. The main difference between them is in the criteria employed to identify the unique character of the individual unmixed components. In the proposed system, FastICA method is used to analyze the RGB signals and to reveal the original source signals. FastICA is an effective technique that can be utilized to eliminate noise artifacts, introduced for the first time in [15]. It uses fourth order moments (Kurtosis) to identify the independent components (three components in the proposed approach) and it is implemented using a fast fixed point iterative algorithm that finds the projections maximizing the non-Gaussian character of the sources. Although there is no ordering of the ICA components, the second component typically contained a strong plethysmography signal and consequently, for the sake of simplicity and automation, selected here as the desired source signal. Finally, Fast Fourier Transform (FFT) is applied on the selected component to obtain the power spectrum inside the aforementioned filtering operational scope [0.7, 4] Hz matching to [42, 240] bpm. The highest of power of the spectrum in the operational range will be the pulse frequency (Fig. 3).

A threshold for maximum change in HR between continuous measurements is used to reject artifacts and to improve the performance of system. In this work the threshold is set to 8 bpm, and if the difference between the result of current HR and the value of last HR went beyond the threshold, the current HR will be rejected and the next highest power frequency in the operational range will be searched. The last HR value will be retained if no frequency peaks were located.

**Fig. 3.** Feature extraction for contactless HR measurement. Three pre-processed RGB signals are extracted from ROI and subsequently filtered. FastICA is applied on the normalized, de-trended and smoothed RGB signals to recover three independent source signals. Finally, FFT is applied to second component and the highest of power of the spectrum is selected as the estimated HR.
3 Results and Discussion

The validation of the proposed algorithmic pipeline was carried out within the laboratory used as a “smart home”, located inside the Institute for Microelectronics and Microsystems (IMM) in Lecce. The experimental setup consisted of a D-Link™ DCS-8525LH camera that uses a high-resolution 2-megapixel sensor (with a video resolution of 1920 × 1080 at up to 30 fps) with motorized pan and tilt functions, providing 340° horizontal and 110° vertical viewing angle, and allowing the camera to patrol a wide area in the considered environment. A total of fifteen participants, six young (mean age of 34.8 years), five middle-aged (mean age of 53.1 years) and four older (mean age of 68.7 years) women and men participated in this study after providing voluntary consent. Table 1 presents the total number of participants in the preliminary experimentation, broken down by age group and gender:

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>(29–47)</th>
<th>(48–64)</th>
<th>(&gt;65)</th>
<th>Total (29–73)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>9</td>
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<tr>
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<td>2</td>
<td>2</td>
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<td>6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>

The acquisition time has been set to 120 s for each subject. Different kinds of metrics were proposed in this research area for evaluating the accuracy of HR measurement methods. The most common is the root mean squared error denoted as RMSE and expressed by Eqs. (4) and (5):

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} |HR_{error}(i)|^2}
\]

\[
HR_{error} = HR_{cam} - HR_{gt}
\]

where \( n \) is the number of times a HR measurement was obtained in the considered time interval, \( HR_{cam} \) is the HR estimated from video streaming whereas \( HR_{gt} \) represents the HR ground truth value that in the present work was evaluated using the commercial OXI-2 pulse oximeter produced by GIMA. Table 2 reports the RMSE obtained for each age group at varying of head poses and light conditions at a fixed distance from the vision sensor (0.5 mt.). The user’s head pose is captured by two angles: yaw and pitch. The angles are expressed in degrees, with values ranging from \(-40^\circ\) to \(+40^\circ\) for yaw angle and \(-20^\circ\) and \(+20^\circ\) for pitch angle. The light intensity instead has been measured by an Android application (Lux light meter) running on a smartphone placed next to the human face before starting the data acquisition to estimate the environmental light. The
considered values vary in the range 30–100 lumens per square meter (Lx), following the recommendations of Illuminating Engineering Society (IES) and considering as environment the living room (30 Lx) and the kitchen (100 Lx).

Table 2. RMSE for each age group at varying of light conditions (30 and 100 lx), yaw angle (between $-40^\circ$ and $+40^\circ$) and pitch angle (between $-20^\circ$ and $+20^\circ$).

<table>
<thead>
<tr>
<th>Lx</th>
<th>30</th>
<th>100</th>
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<tbody>
<tr>
<td></td>
<td>−40</td>
<td>−20</td>
</tr>
<tr>
<td></td>
<td>−40</td>
<td>−20</td>
</tr>
<tr>
<td>Young</td>
<td>5.38</td>
<td>3.56</td>
</tr>
<tr>
<td>Middle-Aged</td>
<td>6.21</td>
<td>4.50</td>
</tr>
<tr>
<td>Older</td>
<td>7.43</td>
<td>6.09</td>
</tr>
<tr>
<td>Pitch Angle</td>
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<td>0</td>
</tr>
<tr>
<td>Young</td>
<td>/</td>
<td>2.71</td>
</tr>
<tr>
<td>Middle-Aged</td>
<td>/</td>
<td>3.66</td>
</tr>
<tr>
<td>Older</td>
<td>/</td>
<td>5.12</td>
</tr>
</tbody>
</table>

The results obtained show that the implemented approach enables effective classification of HR even in the presence of significant changes in light conditions, that is a typical and unchecked event in domestic environments, with the RMSE that grows slightly as the lighting intensity decreases for each considered group of subjects. Moreover, analyzing the RMSE obtained at varying of yaw and pitch angle, it is evident how the proposed algorithmic pipeline is able to manage different orientations of the face, confirming the choice of the used pre-processing steps and set of features, even if a slight deterioration in the measurement of HR of elderly subjects is observed due to the difficulty in extracting the ROI by the skin detection module (generally the faces of the elderly have wrinkles and folds that make this process more difficult). The low variance value obtained by rotating the head vertically is probably motivated by the limited variation in size of the ROI, while rotating the head horizontally the ROI can also vary considerably and in some cases it includes facial regions not appropriate for rPPG signal extraction.

Moreover, the feasibility of the approach was evaluated by measuring the HR and related RMSE while the face subject stood at different distances from the vision sensor. For simplicity in this experiment the view of the face is frontal and the light intensity is fixed at 100 Lx. The results of this experiment are reported in Fig. 4 and show that the reliability of the contactless HR measuring method worsens as the distance from the camera increases and this is true for each considered group of subjects, probably because the credibility of the face detection method is reduced in detecting facial features, causing ROI loss and ROI drift.

Also, another problem is related to the reduction in the clarity of the pixel values not highlighting the microscopic color changes that amount to the PPG signal generation. However, this problem is easily avoided considering the use of vision sensors with better image resolution and zoom properties.
Remote HR measurements from face videos have improved during the last few years. Among the research in this domain, the designed models, parameter settings, chosen algorithms, and equipment are plenty, complex, and vary enormously. Some approaches achieve high accuracy under well-controlled situations but degrade with different pose of the face, illumination changes, distance from the vision sensor and different ages of the observed subject.

In this work, considering the convenience and the advantages of contactless HR measurement in AAL context, a novel algorithmic pipeline for HR estimation was proposed, which is robust to unconstrained scenarios. In order to capture substantial visual characteristics of HR from face videos, a series of algorithmic steps for managing various head poses, distance from the sensor and variations in illumination conditions of living environments were designed and implemented.

The algorithmic pipeline has made it possible to obtain acceptable performance in terms of RMSE even by measuring HR of older subjects, a problem still open in the recent research activity.

Another added value of this work is that the algorithmic stack can be used starting from RGB images acquired from any device that may already be present in the living environment, thus favoring a wider use and diffusion of the proposed solution.

Future work includes the evaluation of the methodology using as input video sequences available in benchmark databases with the purpose to compare the solution with the actual state of the art in this research area. Moreover, the algorithm should also be made robust against motion artefacts and one solution could be a feature tracking on the detected ROI. Additionally, the algorithmic pipeline could be extended for remote measurement of further physical signals, such as breath rate and heart rate variability.

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References

Combined Vision and Wearable System for Daily Activity Recognition

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\textbf{Abstract.} Social assistive robotics aims at improving the quality of life of elderly people and caregivers. Human Activity Recognition (HAR) is one of the capabilities the assistive robot should be endowed with, to allow aged people to independently live in their homes. This work deals with the problem of performing HAR by employing two wearable inertial sensors and one RGB-D camera, mounted on the social robot Pepper. Specifically, the main purpose is to prove that Pepper robot is able to correctly recognize daily living activities by exploiting the information coming from the RGB-D camera and one inertial sensor placed on the index finger of the subject. Ten users were asked to perform ten activities while wearing an inertial glove, SensHand, and while being recorded by the camera. Two different perspectives of the robot were studied to understand if a good activity recognition could be obtained when the robot is in front of the person and on his side. The results show that almost the same recognition performances are obtained when combining the visual sensor, no matter the chosen perspective, with the inertial sensor only on the index (95%), with respect to the fusion of the same camera with the inertial sensor on the index and on the wrist (96%). This supports the conclusion that elderly people could just wear a small ring on the index finger to allow the robot to recognize their activities, taking advantage from a system which is comfortable and easy-to-wear.

\textbf{Keywords:} HAR · Gesture recognition · Inertial sensors · Visual sensors · Machine learning

\section{1 Introduction}

Over the past decade, major neurocognitive disorder (NCD) has become a public health priority. The increasing number of people living with major NCD by 2050, according to the World Health Organization, raises the question of care, together with the risk of hospitalization, nursing home placement and the burden of professional and informal caregivers. As a consequence, it leads to
increased care costs. New initiatives based on psycho-social interventions, such as social-robot-based therapy, have been proposed as alternative solution to improve the quality of life of patients and caregivers [4,9,16]. Human Action Recognition (HAR) plays a vital role in the field of Human-Robot Interaction and it is widely researched for its potential applications [3]. It refers to an area of research that mainly involves automatic detection, recognition, and analysis of human actions from the data obtained from different types of sensors. Based on the specific applications, there are several activities that the HAR system is able to recognize. Activities of Daily Living (ADL) have given great importance to the monitoring of elderly people. In particular, in an Ambient Assisted Living (AAL) monitoring people while performing normal daily activities is essential [18]. In a AAL, activities like eating or drinking can be very important to help people keeping a healthy life-style, facilitating them to live longer in their family residential environments [11]. Different sensor modalities are employed in the HAR field. These include mainly RGB-D cameras and inertial wearable sensors. RGB-D video cameras are widely available and cost effective. They provide rich texture information of the scene and they are easy to operate. However, the vision-based approach is challenging many issues such as background clutter, occlusion, camera position, subject variations in performing actions and they are limited to a constrained space defined by the camera position and settings. To address such challenges, wearable inertial sensors are introduced to perform human action recognition. These include accelerometers and gyroscopes. This sensor technology has enabled coping with a much wider field of view as well as changing lighting conditions. Thanks to the lowering in the energy consumption and the increasing in the computational power of inertial sensors, long-term recordings have been enabled. These sensors allow to receive information directly from the movement of the users, detecting also fast and subtle movements without forcing them to stay in front of a camera. However, wearable inertial sensors have limitations as well. One of the main limitations is the sensor drift that may occur during long operation times; moreover, measurements are sensitive to sensor location on the body. In addition, for human action recognition, they require to be worn by subjects performing the actions, which creates the disadvantage of intrusiveness or inconvenience for the subjects. Even if a typical human action recognition system uses a single sensor, no single sensor modality can cope with various situations that may occur in real scenarios. One way to improve the performance of the human action recognition systems is to combine data from these two different modality sensors considering that images from a visual sensor and inertial signals from a wearable sensor provide complementary information. For example, images capture global (or full body) movement attributes while inertial signals capture fine movements, leading to a more robust recognition [6].

Therefore, the aim of this work is to combine inertial and visual data to obtain a system which can offer a robust activity recognition. Specifically, the main goal of this study is to go further the state of the art by evaluating whether an inertial sensor placed on the index finger, combined with visual data, is good enough to perform recognition of daily living activities. Skeleton data were obtained from
a RGB-D camera mounted over a social humanoid robot, Pepper, and they were combined with the inertial data acquired by a wearable glove, SensHand.

In a real-case scenario, a social robot could be very important to monitor the status of older people at home. Indeed, even if gesture recognition can be achieved by only exploiting fixed cameras and inertial data, it is much better that the camera, ideally characterized by robot’s perspective, can move in the environment following the elderly person when required; indeed, it is not feasible to think of mounting several cameras to cover all the possible perspective in the environments. In this sense, a not-fixed camera mounted on the robot could overcome this limitation and could always adapt its point of view changing its perspective when required (i.e. when the older person is moving and/or changing activity or room). It is also very important to highlight that the interaction of an elderly person with a social robot allows the former to have company and not feel alone [7,19].

In the proposed work, it is intended to simultaneously evaluate the performances of the system in two real-case scenarios, i.e. when the robot is in front of the person and when it is on the side. For this reason, during the experimental phase, two cameras were mounted frontally and laterally with respect to the subject performing the activity, to simulate the sight of the robot from two different perspectives. Such a system would improve the recognition rate of daily living gestures, by allowing the caregivers to monitor elderly people, and in particular people living with neurocognitive disorders, in any scenario.

The structure of the paper is herein presented: in Sect. 2 a general overview of the related works is provided, while in Sect. 3 the architecture of the system and the approach followed in this work are explained. Finally, in Sect. 5 and Sect. 6 the results of the previously performed data analysis are respectively presented and discussed.

2 Related Works

Several works focus on daily living activity recognition based on performed gestures detected by inertial and visual sensors. In their work, Dawar et al. [8] employed a wearable inertial sensor on the wrist and a Kinect v2 camera to recognize smart TV gestures. Acceleration and rotation signals from inertial sensors and skeleton data from depth cameras were extracted to train a Variable length Maximum Entropy Markov Model classifier. Action detection and recognition were performed continuously in real-time with the aim of separating actions of interest from actions of non-interest. Different scenarios were compared (subject-specific vs. subject-generic) with different values of the threshold probability p. The best performance in both the scenarios was observed at the threshold probability of p = 0.45, obtaining 92% of precision. Wearable depth cameras for on-body activity recognition in home environment were used by Voigt et al. [21] to recognize 10 daily living activities. In particular, the Google Project Tango platform, which provides both a depth and an inertial sensor, was employed. After segmenting the signal, for each segment mean and standard
deviation were extracted as basic temporal features for all the sensors. With a total of nine features, they were able to achieve accuracy levels >90%. However, due to the size and weight of the platform, the system is not comfortable enough to be worn over long periods of time. Many works have combined inertial and depth sensors to other devices to improve gesture recognition. Li et al. [12] considered tri-axial accelerometers, micro-doppler radar and Kinect depth cameras to classify 10 different activities. Fusing information from the three sensors the classification accuracy reached 86.9% with the quadratic-kernel SVM classifier, and up to 91.3% using an ensemble classifier. Manzi et al. [15] aimed to recognize ten daily living activities using data from inertial sensors, worn on the index finger and on the wrist, from a depth camera mounted on a mobile robot and from the robot position, since the platform was able to self-localize in the environment. The classifier used three different types of features: user location, provided by the navigation module of the mobile platform, skeleton activity features, extracted from the raw skeleton data, and inertial features: mean, standard deviation, variance, mean absolute deviation, root mean square, energy, and IAV (integral of the magnitude of the acceleration vector), extracted from the accelerations’ signals. Different combinations were tested and a decision-level fusion was applied. In their best configuration, namely fusion of depth camera, IMUs on wrist and index finger and location, accuracy levels of 70% were achieved. Supervised and unsupervised techniques are both used for classification. Usually a supervised classifier is used when the number of label and the actions to be recognized are already known. In particular, the most common ones are Support Vector Machine (SVM) [10,12], the Random Forest (RF) [10,12,15,21] and the K-Nearest Neighbors (KNN) [21]. Unsupervised approaches (e.g. k-means, Self-Organizing Map, and Hierarchical Clustering) were compared with supervised ones (RF, Multilayer Perceptron (MLP) and SVM) in [18]. The results reported in [18] about the intra-subject analysis, obtained as the mean value of 12 subject-dataset, were comparable with the results of the supervised analysis conducted with the 10-fold cross validation approach.

3 System Architecture

One of the aims of this work is to develop a not intrusive technology that can be adopted in real AAL scenarios as solution for monitoring the activity of elderly people. The activity recognition relies on a multimodal system composed by a wearable glove (i.e. Senshand) and a social humanoid robot (i.e. Pepper), as shown in Fig. 1.

SensHand is composed of four inertial modules positioned in correspondence to the wrist and to the thumb, index, and middle finger. Each module is composed of a complete 9-axis inertial sensor (6-axis geomagnetic module LSM303DLHC and 3-axis digital gyroscope L3G4200D, STMicroelectronics, Italy) and includes a microcontroller (ARM®-based 32-bit STM32F10RE MCU, STMicroelectronics, Italy) which can acquire, filter and store data at a frequency 100 Hz [20]. Each module is able to measure metrics and parameters related to
posture, orientation and movement of the human hand. It is very easy to wear and to use thanks to its miniaturised and light structure; it is independent from the physical build of the person wearing it and from artifacts caused by the movement, making it suitable for remote rehabilitation and self-monitoring [20]. The entire system weights about 50 g and its dimensions correspond to $3 \times 4$ cm as regards the wrist module and $1.5 \times 1.5$ cm for those on the fingers.

The system integrates a Pepper robot, which is the world’s first social humanoid robot able to recognize faces and basic human emotions [2]. It is characterized by a multimodal sensing (i.e. touch sensors, infrared, cameras and sonars) thanks to which it can interact with people and move in an autonomous way. To enrich the visual capability of the robot, a RGB-D camera (i.e. Intel Realsense) is mounted on its chest over its tablet.

![Fig. 1. Instrumentation employed: on the left, Pepper with the depth camera mounted above the tablet, and on the right, SensHand wearable glove.](image)

The connection to the devices has been established via Bluetooth to the SensHand and via WiFi to the robot. Inertial data from the wearable glove and skeleton data from the cameras have then been integrated through a Python interface; in particular, two Python executables have been created to start data acquisition and transmission from the glove, while visual data have been acquired using the Robot Operating System (ROS) framework.

3.1 Experimental Protocol

The choice of the activities was based on the comparison between two public datasets, the Cornell Activity Dataset (CAD-60 and CAD-120) and the MSR
Daily Activity 3D Dataset. As result, ten activities in common between the two datasets were chosen, in such a way that they were similar in pairs (see Table 1).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF: Eat with the fork</td>
<td>Take the fork from the table, eat and put the fork back continuously</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>DG: Drink from a glass</td>
<td>Take a glass from the table, drink and put it back repeatedly</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>BT: Brush teeth</td>
<td>Take the toothbrush, brush teeth and put it back</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>UL: Use laptop</td>
<td>Type on the keyboard with both hands</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>WP: Write on a paper</td>
<td>Take a pen and write on a paper continuously</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>TP: Talk on the phone</td>
<td>Take the phone, talk on it and put it back</td>
<td>Sitting on the chair</td>
</tr>
<tr>
<td>WK: Walk</td>
<td>Walk forward and backward repeatedly</td>
<td>Standing</td>
</tr>
<tr>
<td>SB: Sweep with the broom</td>
<td>Take the broom, sweep and put it back at the end</td>
<td>Standing</td>
</tr>
<tr>
<td>RC: Relax on the couch</td>
<td>Sit comfortably on the couch and relax</td>
<td>Sitting on the couch</td>
</tr>
<tr>
<td>RB: Read a book</td>
<td>Take the book, read it and turn pages repeatedly</td>
<td>Sitting on the couch</td>
</tr>
</tbody>
</table>

The experimental protocol consisted in the enrollment of 10 healthy participants, half males and half females, right-handed, from 19 to 44 years old. The experimental phase of this work was conducted in Sheffield (England), in the Smart Interactive Technology (SIT) research laboratory of Sheffield Hallam University. Study, design, and protocol, including subject privacy and sensitive data treatment, were approved by the Ethics Committee of Sheffield Hallam University. At the beginning of the experimental session, written informed consent was obtained from the participants. As a token of gratitude, participants received an Amazon e-voucher of £10 after successfully completing the experiment. During the experimentation, each subject simulated the ten activities, each for one minute, by wearing one SensHand glove on the dominant hand. The session was recorded by two cameras, one mounted over the robot and one located on the lateral side of the participant (Fig. 2) to acquire data from two different points of view, saving time, instead of asking the users to perform twice the protocol. The lateral camera is the same as the one mounted on Pepper and it was placed at the same height from the ground. The Pepper robot gave instructions about the
action to perform and how to perform it. It is worth mentioning that the participants were left free to grab the objects and act in the way they preferred, so no instruction was given in that sense. During the acquisition, each activity was labeled manually by an operator using an ad-hoc web interface. In particular, the interface has been appropriately created through an HTML code. It allowed to connect the sensors and, once selected the activity, to start the simultaneous data acquisition from the glove and the cameras.

At the end of the experimental trial, the participants were asked to fill in the System Usability Scale (SUS) questionnaire to assess the system usability. It consists of ten items with a five-point attitude Likert scale, providing a global view of subjective assessments of usability. A value equal or higher than 68 means that a certain technology is usable [1].

Fig. 2. Experimental setup in the Smart Interactive Technology (SIT) research laboratory of Sheffield Hallam University.

4 Data Analysis

The proposed activity recognition is performed on several steps. Firstly, data from the glove and the cameras have been analyzed on their own. This phase involved the extraction of the features from the sensors: the skeleton coordinates and inertial features. Then, the extracted features were organized in a database. The activity recognition was performed by employing supervised machine learning algorithms on unimodal data, collected in the dataset, and multimodal data, obtained by combining the previous ones. The multimodal classification was implemented at fusion-at-feature-level [22].

4.1 Pre-processing and Feature Extraction for IMU

Since the main frequencies of the inertial signal were between 0 and 5 Hz, a 4th order digital low-pass Butterworth filter was used, setting the cut-off frequency
5 Hz, similarly to [17]. In particular, acceleration and angular velocity data were filtered on their single components \((x, y, z)\) and they were concatenated computing the Euclidean norm. According to the results obtained in [17], only the data coming from the wrist and index finger sensors of the glove have been used for the activity recognition.

Inertial data were segmented by 50%-overlapping moving windows with a size of 3 s, considering that some individual actions were very short. For each window, many features were extracted. Table 2 shows the features extracted from acceleration and angular velocity signals. The final dataset has been composed by 10 features inherent to acceleration values and 6 features to angular velocities, for both wrist and index finger, for a total of 32 features.

<table>
<thead>
<tr>
<th>Data</th>
<th>Extracted features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>Mean value (t)</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation (t)</td>
</tr>
<tr>
<td></td>
<td>Variance (t)</td>
</tr>
<tr>
<td></td>
<td>MAD: Mean Absolute Deviation (t)</td>
</tr>
<tr>
<td></td>
<td>RMS: Root Mean Square (t)</td>
</tr>
<tr>
<td>Angular Velocity</td>
<td>Mean value (t)</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation (t)</td>
</tr>
<tr>
<td></td>
<td>Variance (t)</td>
</tr>
</tbody>
</table>

Table 2. Features extracted from inertial data in time (t) and frequency domain (f).

4.2 Pre-processing and Feature Extraction for Cameras

As concerns RGB images analysis, the Openpose software [5] was employed to obtain the skeleton features. In particular, 25 keypoints were estimated for the body (see Fig. 3), where each of them represents the \((x, y)\) pixels’ coordinates of the joints.

Some preliminary results show that a reduced set of joints could improve classification performances [13]. In the present study, a restricted set of joints was selected, namely composed by: head, neck, hands, feet and torso, which has been shown to be the most discriminative for activity recognition [14].

A normalization step was applied to the extracted features: the original reference frame was moved from the camera to the torso joint, and the joints were scaled with respect to the distance between the neck and the torso joint [14,15]. This normalization procedure yields data which are independent with respect to the person’s specific size and to the relative position of the camera. Formally, considering a skeleton with \(N\) joints, the skeleton feature vector, \(f\), is defined for each frame as in Eq. (1):
$f = [j_1, j_2, \ldots, j_i, \ldots, j_{N-1}]$, (1)

where each $j_i$ contains the normalized coordinates of the $i^{th}$ joint $J_i$ detected by the sensor. Finally, considering all the frames, $j_i$ expands to a vector and it is defined as in Eq. (2):

$$j_i = \frac{J_i - J_0}{||J_1 - J_0||}, \quad i = 1, 2, \ldots, N - 1$$ (2)

where $J_0$ and $J_1$ are the coordinates of the torso and the neck joint, respectively [14]. The number of attributes of the feature vector, $f$, is equal to $2(N - 1)$. Considering that in this case $N = 7$, the posture feature vector is composed by 12 attributes, which correspond to the x and y coordinates of the restricted set of joints, excluding the torso which was used as reference.

The signal containing the skeleton features for each frame was segmented by 50%-overlapping moving windows with a size of 3 s as the inertial ones, and for each window the mean x and y joints’ coordinates were extracted.

### 4.3 Features Reduction and Datasets Creation

At the end of the features extraction, a total of 32 features were extracted from inertial sensors (index and finger) and 12 from the skeleton data. The Kruskal Wallis test was applied to obtain the most significant feature vector in distinguishing the group of instances. This test confirmed that the ten gestures, which characterized the activities under investigation, were statistically different for all the above features ($p < 0.05$). Finally, a correlation analysis was performed in order to retain only the significantly uncorrelated features (Correlation Coefficient < 0.85). At the end, the remaining features were combined into different combination of sensors considering also the two cameras’ points of view (Table 3).
By knowing the acquisition frequency of the glove, i.e. 100 Hz, and the one of the cameras, i.e. about 30 frames per second (fps), both incoming data have been synchronised according to the recorded timestamps.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>Frontal camera</td>
</tr>
<tr>
<td>LC</td>
<td>Lateral camera</td>
</tr>
<tr>
<td>I</td>
<td>Index finger</td>
</tr>
<tr>
<td>IW</td>
<td>Index finger and Wrist</td>
</tr>
<tr>
<td>I+FC</td>
<td>Index finger with frontal camera</td>
</tr>
<tr>
<td>I+LC</td>
<td>Index finger with lateral camera</td>
</tr>
<tr>
<td>IW+FC</td>
<td>Index finger and wrist with frontal camera</td>
</tr>
<tr>
<td>IW+LC</td>
<td>Index finger and wrist with lateral camera</td>
</tr>
</tbody>
</table>

4.4 Classification

The stand-alone systems (i.e. I, I+W, FC, LC) have first been classified to evaluate their performances. Then, all the different combinations, above mentioned, have been classified as detailed in Fig. 5.

For each classification model, the training set is composed by the 70% of the original dataset, while the test set is composed by the remaining 30%. A 10-fold cross-validation was carried out on the training set. In particular, ten different models were created at the end of the training phase. The 10-fold cross-validation considers the 90% of the initial training set to train the model (train set) and the remaining 10% to evaluate it (validation set). The data in the mentioned sets change at each iteration, to prevent the model from overfitting.
The final classification results are based on an average of the performances. Three supervised machine learning algorithms were used in the stand-alone and in the combined classifications, reported in Table 3:

- Multiclass Support Vector Machine (SVM): it exploits the kernel trick to deal with multiclass problems. It maps the input space into a higher dimensional space by using kernels, to make the problem linearly separable, and then it finds the hyperplane that can separate the two classes with the largest margin. In this work, it has been trained by using Sequential Minimal Optimization (SMO).

- Random Forest (RF): it is an ensemble learning method for classification and regression. It operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes of the individual trees, with the goal of reducing the variance.

- K-Nearest Neighbor (KNN): it is a simple algorithm which stores all available cases and classifies new cases based on a similarity measures, which are distance functions. They are assigned to the most common class among its k nearest neighbors. If k = 1, the object is simply assigned to the class of that single nearest neighbor.

These classifiers were trained to recognize ten classes for each system, which correspond to the ten activities. The classification procedure was implemented and evaluated in MATLAB and the classification performances were evaluated in terms of accuracy, precision, recall and F-measure. In the following, the confusion matrices, corresponding to the configurations with the best accuracy, have been reported to understand the degree of recognition of the different gestures and to evaluate the performances also at gesture level.
5 Results

For the aim of this work, different combinations of sensors were evaluated and three classifiers were applied. The features retained after the feature selection described in Sec. 4.3 are reported in Table 4, for each combination. The classification results of the stand-alone system was taken as a gold-standard reference for comparison.

<table>
<thead>
<tr>
<th>Table 4. Features selected after correlation analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Index+Wrist</strong></td>
</tr>
<tr>
<td>Wrist acc. mean</td>
</tr>
<tr>
<td>Wrist acc. stdev</td>
</tr>
<tr>
<td>Wrist acc. RMS</td>
</tr>
<tr>
<td>Wrist acc. skewness</td>
</tr>
<tr>
<td>Wrist acc. kurtosis</td>
</tr>
<tr>
<td>Wrist acc. SMA</td>
</tr>
<tr>
<td>Wrist acc. power</td>
</tr>
<tr>
<td>Wrist ang. vel. mean</td>
</tr>
<tr>
<td>Wrist ang. vel. stdev</td>
</tr>
<tr>
<td>Wrist ang. vel. power</td>
</tr>
<tr>
<td></td>
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5.1 Stand-Alone Systems

**Inertial Sensors.** The system was evaluated by considering the index sensor (I) and the combination of the index and the wrist sensors (I+W). In the former case, the activity is described by a total of 10 features (first column of Table 4), while in the latter case 17 features are attributed to each activity. The results, shown in Table 5, suggest that inertial sensors are quite good in recognizing human gestures, especially when considering I+W combination (up to 86% of accuracy). Indeed, when considering only the inertial sensor on the index, values of 78% are obtained for accuracy, precision, recall and F-measure.

**Visual Sensors.** The feature selection steps returned that all the skeleton features were uncorrelated and relevant for the proposed task. As reported in Table 4, a total of 12 features for frontal camera and 12 features for lateral one were used as input to the classifiers. Classification results indicate that the frontal camera is able to recognize the activities with a 95% of accuracy by considering KNN classifier, with respect to the 87% of the lateral camera, as shown in Table 6. The results related to the lateral camera are comparable to the ones
Table 5. Results obtained by inertial sensors

<table>
<thead>
<tr>
<th></th>
<th>I+W</th>
<th></th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Precision</td>
<td>Recall</td>
</tr>
<tr>
<td>SVM</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>RF</td>
<td>0.84</td>
<td>0.84</td>
<td>0.84</td>
</tr>
<tr>
<td>KNN</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
</tbody>
</table>

achieved by inertial sensors alone when considering both wrist and index (86\% of accuracy), and higher than the ones obtained by the index sensor alone (78\% of accuracy).

Table 6. Results obtained by the cameras

<table>
<thead>
<tr>
<th></th>
<th>FC</th>
<th></th>
<th>LC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Precision</td>
<td>Recall</td>
</tr>
<tr>
<td>SVM</td>
<td>0.94</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>RF</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>KNN</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

The results reported in Tables 5 and 6 indicate that the RF algorithm is the worst among all, being unable to correctly classify the ten activities. On the contrary, SVM and KNN are comparable in the performance when considering inertial sensors alone (86\% and 78\% of accuracy for I+W and I, respectively). The results obtained by the cameras suggest that KNN classifier achieves the best performance in classifying skeleton features (95\% and 87\% of accuracy for frontal and lateral camera, respectively).

5.2 Fusion at Feature-Level

Four combination of sensors were considered. The combination of index-wrist sensor and frontal camera (IW+FC) is characterized by a total of 29 features, while the combination of the index sensor and the frontal camera (I+FC) describes the activity with 22 features (see Table 4). The same number of features characterized the combinations made by substituting the frontal camera with the lateral one. The results achieved by the feature-level fusion are shown in Tables 7 and 8.
Table 7. Fusion at feature-level’s results with frontal camera

<table>
<thead>
<tr>
<th></th>
<th>IW+FC</th>
<th>I+FC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Precision</td>
</tr>
<tr>
<td>SVM</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>RF</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>KNN</td>
<td>0.94</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Table 8. Fusion at feature-level’s results with lateral camera

<table>
<thead>
<tr>
<th></th>
<th>IW+LC</th>
<th>I+LC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Precision</td>
</tr>
<tr>
<td>SVM</td>
<td>0.84</td>
<td>0.87</td>
</tr>
<tr>
<td>RF</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>KNN</td>
<td>0.87</td>
<td>0.91</td>
</tr>
</tbody>
</table>

The classification performances obtained by the frontal camera and the inertial features are comparable to the ones achieved by the frontal camera classifier (accuracy is 95% and 94%, respectively). An improvement in the performances is obtained by combining the lateral camera with the inertial sensor. The lateral camera (LC) alone got an accuracy up to 87% (see Table 6). It improves up to the 96% when considering the lateral camera together with the inertial features (IW+LC). In the same way, precision, recall and F-measure improve up to 97%, 96% and 96%, respectively. Looking at the results obtained by using only the index sensor, the results are prominent. In the combination with the frontal camera (I+FC), the system obtains 95% of accuracy, precision, recall and F-measure, which slightly outperforms the IW+FC configuration (94% of accuracy, precision and recall). When considering the combination of the index sensor with the lateral camera (I+LC), 94% of accuracy is obtained, comparable to the 96% achieved when considering also the wrist sensor (IW+LC).

Comparing the performances of the classifiers on the fusion at feature-level, the results highlight a general good performance. In the IW+LC and I+LC cases, the RF got an higher accuracy (improved by 9%) with respect to the other algorithms. Both RF and KNN obtain the same performances in the IW+FC combination (94% of accuracy, precision, recall and F-measure), while SVM outperforms in the I+FC combination (95% of accuracy, precision, recall and F-measure).

To analyse the performances of the SVM classification at activity level, the normalized confusion matrices of I+FC and I+LC configurations are shown in Figs. 6 and 7, in which each cell value has been normalized by the number of observations that has the same predicted class. The system composed by index and frontal camera (see Fig. 6) can correctly recognize the activities ‘Talk on the phone (TP)’ and ‘Brush teeth (BT)’, while it encounters some difficulties in recognizing the activities ‘Relax on the couch (RC)’ and ‘Sweep with the broom (SB)’. The confusion matrix in Fig. 7 displays the performances of the I+LC
configuration. With respect to I+FC, the SVM classifier is not able to correctly recognize the activity ‘Brush teeth (BT)’ when considering the lateral camera. In this case, the best recognized activity is ‘Eat with the fork (EF)’, and good results are obtained also for ‘Relax on the couch (RC)’ and ‘Talk on the phone (TP)’ activities.

![Normalized confusion matrix obtained by SVM classifier for index and frontal camera](image)

**Fig. 6.** Normalized confusion matrix obtained by SVM classifier for index and frontal camera

![Normalized confusion matrix obtained by SVM and classifier for index and lateral camera](image)

**Fig. 7.** Normalized confusion matrix obtained by SVM and classifier for index and lateral camera
The data analysis show that the average SUS score was equal to 72.4 (Standard Deviation equal to 14.5), meaning that usability is good (grade B).

6 Discussion and Conclusion

In this work, cameras and wearable inertial sensors have been combined to enhance the capabilities of the robot to recognize human activities. One of the AAL aims is to develop a social robot which is able to recognize human gestures in a non invasive way (i.e. by only exploiting the visual information). The system employed in this work focused on life-like situations, where the users were free to perform the activities. Particularly, in this paper, two different visual perspectives (frontal and lateral) were introduced in the experimental session to explore how the relative position between the robot and the user can affect the recognition task. This work shows that high levels of accuracy are obtained when considering the frontal camera alone. This suggests that the robot can properly recognize the human activities if it is in front of the person. However, this is not a realistic situation. It is quite unlikely that the robot is always perfectly facing the subject. It will more likely be positioned slightly to the side, decreasing its recognition abilities due to occlusion’s problem. Moreover, in a life-like situation, the robot and the person could be in relative movement, leading to a decrease in the recognition performances. It is expected that the combination of visual sensors with inertial ones could limit these issues and greatly improve the performances, making the system able to monitor quite well the person in real-time in almost every scenario, avoiding as much as possible delays or mistakes that could affect elderly quality of life.

Four different configurations have been tested with a feature-level fusion approach, i.e. features from frontal camera, wrist and index (IW+FC), from frontal camera and wrist (I+FC), from lateral camera, wrist and index (IW+LC) and from lateral camera and index (I+LC), to understand which is the best combination of sensors.

The selection of gesture appropriately created is made of activities in which the hands are often moved to the head to perform the action, i.e. eating with the fork, drinking from a glass, brush teeth and talk on the phone. These actions are quite similar and difficult to recognize. However, by looking at the confusion matrices, it is possible to appreciate in which extent the system is able to recognize each of them: all the activities are well differentiated and there is no activity which is significantly exchanged for another one. These results suggest that the proposed multi-modal approach could overcome some limitations related to the camera occlusion and similarity between fine gestures.

The results obtained by this fusion of sensors suggested that inertial sensors need to be worn by the user to obtain the best possible gesture recognition. This implies that the person should wear at least two sensors (e.g. smart bracelets and smart ring) during his daily living activities to obtain a good recognition accuracy. There are limitations related to that, because the system could be cumbersome and not easy to wear and to use, especially for elderly people. It is important that
they can perform all the movements, which could already be impaired due to their ages, with as little encumbrance as possible. Comparing the performances of the combined classifiers, the results obtained when considering only index and camera are almost the same, and sometimes even better, with respect to the ones achieved by wrist, index and camera combination.

The results achieved in this work outperform the ones obtained by Manzi et al. [14]. In this work, accuracy levels up to 95% are obtained when considering I+FC combination, compared to the 71% achieved by Manzi et al. when considering skeleton data combined to location and wrist features. For this reason, it can be concluded that the use of an inertial ring on the index can be enough to recognise daily living activities and it can also be less bulky. The proposed system could easily become usable in different conditions, since the whole system can adapt to various situations: the robot can be positioned wherever in the room and the wearable sensors can be used everywhere.

In this work, the analysis of the data has been conducted offline. However, this application aims to achieve a system which is able to recognize the gestures in real-time by exploiting the combination of the two sensor modalities.

In conclusion, recognition of daily activities is crucial when monitoring elderly people at home. This is an additional challenge, as the accuracy, precision and usability of obtained data should be high enough to allow the caregivers to remotely monitor the patients, in particular people living with major neurocognitive disorders, allowing them to stay longer at their own place. In the proposed work, the experimentation has been carried out with young healthy people to evaluate whether the system composed by a camera and an inertial ring on the index finger could be used to recognise significant daily gestures, obtaining positive and promising results. However, it is necessary to test the system also with elderly people to check the performances of the same configuration of sensors. Hence, future experimentation will involve elderly people who could have physical impairment, linked to neurodegenerative diseases like Parkinson and Alzheimer Diseases.

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Novel Cloud-Based ICT Solution for Real-Time Heart Rate Variability Analysis: A Technical Essay

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Abstract. The growing diffusion of wearable devices capable of measuring physiological parameters and the new possibilities offered by cloud computation are opening new scenarios for modern Healthcare and Medicine, allowing the continuous collection of huge amounts of data and their processing in almost real time. This availability of an enormous quantity of information poses a new challenge to physicians, because examining directly all this information would often not be possible, as the flow of the information arriving to the system is greater than the information a person can process. A possible solution is the automatic processing of the data, with algorithms that identify anomalies and notify doctors, who can then analyze them for their diagnosis. The OMNIACARE platform has been used to develop an automatic analysis process that analyzes ECG data on the cloud in real-time, provides R-R patient data slots on the 24 h and performs the initial automated HRV analysis. In case of anomalies, doctors can manually examine each HRV time slot and eventually go deeper in data to formulate more accurate diagnoses.

Keywords: HRV · EGC · RR · Cloud · Real time

1 Introduction

During the recent decade, rapid advancements in healthcare services and low-cost wireless communication have greatly assisted in coping with the problem of fewer medical facilities. The use of technology as a support and medical attention to different types of diseases is now a common feature in several research projects conducted at European and national level. The integration of mobile communications with wearable sensors has facilitated the shift of healthcare services from clinic-centric to patient-centric and is termed as “Telemedicine” in the literature [1].

According to existing medical surveys, telemedicine has been adopted to take care of the patients with cardiac diseases, diabetes, hypotension, hypertension, hyperthermia, and hypothermia. The most promising application is in real-time monitoring of chronic
illnesses such as cardiopulmonary disease, asthma, and heart failure in patients located far from the medical care facilities through wireless monitoring systems.

According to American Heart Association (AHA), 90% of the patients cannot recognize themselves as being at high risk before cardiac attack [2]. Hence, the risk can be minimized by giving them medically calibrated wearable sensors with alarms in case of abnormality. AHA recommended that ideal time in between sudden fall or rise in cardiac vital signs and sending an alarm message to cardiologist is in between 4 to 6 min which is called the golden period of saving a heart patient. The time required for an alarm message in proposed monitoring system is less than the golden period. Even in outskirt areas with poor network, the data transmission rates are quite acceptable as per medical standards. Present study demonstrates the applicability of remote care monitoring and it assures 24/7 continuous screening of patients residing at a considerable distance from super specialty hospitals. Indeed, we present a solution based on a cloud platform to compute the Heart Rate Variability (HRV) for detection of arrhythmia episodes and reconstruction of core patient’s rhythm, by the application of standard and innovative methods for HRV analysis, thanks to the use of wearable monitoring devices.

The study of HRV is based on measuring time intervals between R-peaks (R-R intervals) of an electrocardiogram (ECG). Once data about R-R interval is collected, various mathematical methods are used to compute the HRV that are classified as Time-Domain, Frequency-Domain and Nonlinear. Existing standards of HRV technology limit its use to sinus rhythm [3]. However, it is important to expand the indicated limits of the applicability of the HRV technology. This specially regards the cases when the HRV technology looks promising in the diagnostics, as, for example, in atrial fibrillation and atrial flutter. An atrial flutter is the most common arrhythmia, the development of which is associated with arrhythmogenic cardiomyopathy, disorders of the pumping function of the heart, the occurrence and/or progression of heart failure, stroke and other complications [4–6].

Some existing studies about Smart Vest and LOBIN share a similar approach to monitor remote patients using wearable textiles [7]. Smart Vest uses wireless transmission from textile to a remote web server whereas LOBIN uses wireless transmission boards and distribution points in remote areas. Despite advantages of the systems, there are some concerns, like patient’s comfort; they may find garments with wired sensors uncomfortable. By overcoming the concern, our system uses wearable sensors that are physically comfortable for wearing. Another important feature of the developed system is the use of 3G/4G network which provides wide coverage area as compared to existing systems. This wide area coverage allows free mobility of the patient which helps the patient to perform daily without disturbance while being monitored. In contrast, the systems proposed in the literature provided limited coverage area.

The novelty technical element of the OMNIACARE system for HRV analysis stands out at its inception: it is conceived to be able to monitor a large base of patients at the same time. Commercially, it is aimed to record medical data in a secure and privacy-preserving way for up to tens of thousands of patients. Such numbers go beyond the capabilities of even a large staff of medical doctors to analyze and interpret the results. The possibility of having an automated process to perform the computation and send out warnings in case of particular situations, thus concentrating the attention of clinical
staff where it should be paid, can be extremely valuable. Moreover, from a technical point of view, considered that the sampling rate of the single-track ECG for detection of the R-R interval can reach 100 Hz, this means that one hundred data samples must be recorded at every second for every patient. Computation of such samples in order to retrieve the HRV analysis is complex. All this accounts for a very large amount of data and for a wide-scale system, that in no way can be managed by ordinary server-client architectures. Such a system can only be implemented on a scalable cloud architecture, by properly designing a platform based on scalable micro services and exploiting big-data paradigms. No comparable approach for such a large-scale user base is to be find in other traditional HRV computation and analysis systems.

2 Materials and Methods

The solution is based on the OMNIACARE platform, that is a multifunctional ICT system designed specifically for the social welfare and healthcare sector. Expressly created with the aim of improving the social welfare and supporting the healthcare sector, the hardware/software OMNIACARE system provides vulnerable people and their cares with useful tools and capabilities. The system uses advanced technologies that allow constant monitoring of the health status of the senior or frail users. Thanks to it, caregivers and health professionals can provide remote assistance, checking the situation at any time, receiving warnings in case of alert situations and can communicate directly with their cared. The OMNIACARE system is built modularly, in a way to make possible to implement a greater or lesser number of functionalities and make the architecture open to potential developments, through the addition of new modules [8].

For this work, a cloud infrastructure was devised for OMNIACARE to receive ECG data from a specific device and compute it. To this extent, the solution makes use of a wearable chest belt that can acquire ECG data H24. The data are received from the OMNIACARE Cardio App which in turn sends them as a continuous flow to the OMNIACARE Cloud server, using the MQTT protocol. A specific OMNIACARE module for HRV analysis has been developed using cloud computation to offer a real-time heart monitoring service to doctors for their diagnosis. These elements are described from here on.

The chosen device to detect the ECG parameters is the Zephyr™ BioHarness 3. It allows the measurement of numerous parameters, in particular a single-track ECG, which is used to detect the R-R Interval. It is non-invasive for the patient as it is small and lightweight, and it can be applied using a chest strap with electrodes. It has a battery with a duration of more than 24 h, with charging time of approximately three hours, and permits configuration and data acquisition via software, allowing for the development of customized applications. The device also detects and transmits records for breath frequency, position and activity level, therefore we have the possibility to collect not only the ECG abnormalities during the day (arrhythmias or conduction defects) but also the neurovegetative assessment during the normal activity and the body performances. It is a highly reliable device, as proved in [9, 10].

After the identification of the most appropriate monitoring device, an app for Android smartphones was designed (called Cardio app) and created to communicate with the Zephyr™ device and the OMNIACARE platform for the acquisition, transmission, and
local processing and displaying of the detected ECG signal data. The Bluetooth protocol was chosen as the method of communication of the app with the device due to its diffusion and its low-battery consumption. As concerns the method for transferring the ECG data in real time to the OMNIACARE platform, we decided to use the MQTT protocol, due to its low latency, low impact and limited bandwidth qualities. For the signals relating to other vital parameters characterized by far lower rate than an ECG, such as respiratory rate, posture, temperature, we opted for the use of Web services in REST mode configured on the OMNIACARE Cloud server and used by the Cardio app. All exchanged data is anonymized, a patient identification code being used as data label instead of name. This guarantees respect of privacy about sensitive data. The app also notifies of low battery on device, so that the patient can replace it on the strap belt with a charged one.

The OMNIACARE platform was configured to develop an automatic analysis process that analyzes ECG data on the cloud in real time, provides R-R patient data slots on the 24 h and performs the initial automated HRV analysis [11]. A preliminary analysis of existing libraries was carried out for HRV analysis, selecting open source libraries in the Matlab® environment. We then proceeded to the integration and implementation of the Matlab® libraries to be used for the aforementioned analysis, with particular reference to:

- Design of the acquisition of an ECG
- Real-time identification of an R-R track
- Data filtering
- Time domain analysis
- Analysis in the frequency domain
- Poincarè graphs
- Nonlinear analysis

All of such math processing is exploited to return a navigable graph in OMNIACARE, shown in Fig. 1. In case of anomalies, doctors can manually examine each HRV shown in the graphical interface, eventually alter the processing parameters and require a new analysis, based on their experience and competence.

Finally, a comprehensive medical record management was made available to practitioners in OMNIACARE. It deals with the integrated administration of the cycle of patient acceptance, examination and care and eases diagnosis, containing all the patient information included co-morbidities, drugs prescriptions and therapies, history of diseases and health issues. The developed module also enforces the privacy and data protection policy set forth for the work, because this is the only place in the solution where data are associated to patient names: the identification code label in the data is searched for in an encrypted table in the local database which contains patient personal data. The association process runs in a separate sandbox instance on the server volatile memory and data are shown as pictures. No personal information can therefore be hacked out or found by eventually intercepting vital data transmission. This function was created upon precise specifications by the involved cardiology department.
The OMNIACARE platform has been applied on 54 patients. Data corresponding to 14 of these patients have been used in order to calibrate the system and evaluate its potential. Then, the device has been applied on the other 40 patients, who are senior patients suffering from arterial hypertension and looked after by a geriatric center. Among the latter, datasets related to those patients affected by serious arrhythmias (10 cases of atrial fibrillation) and datasets with presence of tremors or excessive background noise disturbing the registration (6 cases) have been excluded from the analysis. Furthermore, some of the 24 analyzed hypertensive patients shown other comorbidities (4 COPDs, 3 diabetes, and 4 had diagnosis of heart failure in their case history). All the patients were treated with conventional therapies for their specific pathologies and shown blood pressure values within an ordinary range.

3 Technical Achievements

The major technical challenges were experienced in building the ECG signal analysis software module. The data transmission interface was designed to be device independent, being able to acquire ECG data from several devices, through a MQTT protocol. This leaves the possibility open to develop specific modules for new devices, in order to have an input data flow with a common structure, as shown in Fig. 2.

The modules used for cloud processing have been designed to be Cloud-Agnostic, so that they can be implemented on any cloud vendor. A suitable architecture was designed on the specific purpose of HRV Analysis, shown in Fig. 3. Following is the description of this data pipeline architecture implemented in the OMNIACARE platform in order to acquire ECG data in real time, ingest and process the data and extract the R-R signal for the subsequent analysis.

The first component of the architecture is responsible for Data Acquisition from the wearable devices using MQTT protocol, and it makes use of VerneMQ message broker.
MQTT is an open industry standard (developed by OASIS), specifying a lightweight publish-subscribe messaging protocol. It was chosen because it is specifically designed for large-scale Internet of Things applications and high-performance mobile messaging. VerneMQ is a high-performance, distributed MQTT broker. It scales horizontally and vertically to support a high number of concurrent publishers and consumers while maintaining low latency and fault tolerance.

In order to interact with the components and monitor data flow, a set of REST web services have been developed. Those services are made available using Payara Server, an open-source application server, cloud-native and optimized for production deployments. Data arriving to the MQTT Broker is acquired by an MQTT subscriber, made in Python, which forwards the data to Apache Kafka, a messaging and streaming platform used for building real-time data pipelines and streaming apps. Kafka is horizontally scalable, fault-tolerant, fast and is used to optimize the transmission and processing of data flows that are coming from VerneMQ. Acting as a messaging instance between sender and receiver, is also able to solve the problem of the temporary storage of data or messages, when the recipient (for example due to network problems) is not available. The system makes use of multiple instances of Kafka nodes, dynamically generated, which are coordinated by Apache Zookeeper, a distributed, open-source configuration, synchronization service which takes care of discovery, resource allocation, leader election, and high priority notifications between Kafka nodes. Data acquired by Kafka is managed
by Python libraries, to convert the JSON data of the data frame in a binary format and
to create a structured streaming to Apache Spark. Spark is an analytics engine for dis-tributed large-scale data processing. The Spark application listens to the Kafka topic, supporting multiple application attempts and is configured for “data locality” for data in Hadoop Distributed File System (HDFS), a distributed file system which is highly fault-tolerant, designed to store data reliably even in the presence of failures. The data stream is then processed in real time by a Python computation algorithm and both ECG data and computed R-R are stored in Apache Kudu, a column-oriented data store of the Apache Hadoop ecosystem. Kudu provides fast insert and update capabilities and fast searching to allow for faster analytics. The computed R-R is then sent to Kafka in order to create a Data Stream toward a Bokeh server in order to create real-time dynamic graphics that provide a visual representation of both ECG and R-R data accessible with a web browser.

The above illustrated data pipeline processes the ECG data flow in real time, extracts the R-R data and also performs calculation of Tpeak to Tend interval (TpTe) [12], which is the time interval in the ECG shown in Fig. 4.

![Figure 4. TpTe interval.](image)

Prolonged TpTe has been associated with increased risk of mortality in congenital and acquired long-QT syndromes [13–16], so it is an important indicator for specific pathologies. This is still an experimental feature and has limitations, the determination of TpTe is possible only on ECG with a well-defined wave structure. The algorithm is being refined to increase accuracy and extend applicability.

The R-R data stored in Kudu is split out in slots of 10-min recordings. One important step of OMNIACARE HRV analysis is the filtering of the R-R data, in order to remove the fluctuations that could be caused by changes in heart rate due to cardiac rhythm and by conduction disturbances. Arrhythmic beats and artefacts that are undetected during the ECG signal preprocessing can in fact seriously affect the power spectrum of the HRV. Therefore, the series of R-R intervals is analyzed to remove spikes and other artefacts [17]. Each time slot is available for further processing by the doctors which can apply additional filters, by a specific console mask shown in Fig. 5. This processing can be applied in real time, scheduled or on demand and can be applied to each of the time slots, which could potentially cover all the 24 h of the day.
Fig. 5. HRV filtering.

The set of filters includes a specific filter, developed by Prof. A. Martynenko (from V.N. Karazin Kharkiv National University). It is possible at any time for physicians to alter the preset values to obtain a better filtering for specific cases and execute a new HRV analysis. In the case, OMNIACARE marks this analysis as “validated from physician” in order to keep trace that it has been examined and validated by a doctor. Figure 6 shows the OMNIACARE graph that allows to see both the original R-R track (in blue) and the filtered track (in red) and the corresponding ECG track.

Fig. 6. Original and filtered ECG track.

4 Implemented Analyses

The implemented set of analyses in OMNIACARE allows to evaluate several parameters in different domains, as advised by the acknowledged medical standards [18, 19].

Time domain analysis, shown in Fig. 7, quantifies the amount of variance in the interbeat interval (IBI) using statistical measures. Time domain measures do not provide a means to adequately quantify autonomic dynamics or determine the rhythmic or oscillatory activity generated by the different physiological control systems. However, since they are always calculated the same way, data collected by different sources are comparable, if the recordings are the same length of time and the data are collected under
the same conditions. OMNIACARE not only reports all most important time domain measures, but it performs the calculation of entropy (EnRE) using the robust estimation algorithm, which performs the calculation with a much higher accuracy than traditional algorithms [20].

Frequency Domain Analysis is a complex analysis technique that shows how much of a signal lies within one or more frequency bands (ranges) that tend to correlate with certain physiological phenomenon, such as Parasympathetic nervous system activity [21]. In particular the LF/HF Ratio is often considered indicative of Sympathetic to Parasympathetic Autonomic Balance. The Poincaré plot analysis provides a geometrical
and nonlinear method to assess the dynamics of HRV. Both types of analyses are shown in Fig. 8.

**Fig. 8.** Frequency domain and poincare analysis.

Nonlinear analysis methods differs from the previous methods because it does not assess the magnitude of variability but rather the quality, scaling, and correlation properties of the signals. So it is related with the unpredictability, fractability and complexity of the signal. Time-frequency analysis is commonly used to investigate the time-related HRV characteristics. An alteration of the autonomic regulation resulting in a change in mean heart rate induces a transient component in heart rate, which, with any analysis method based on signals from multiple beats, results in the apparent spread of the spectrum of frequencies [22]. Both types of analyses are shown in Fig. 9.

**Fig. 9.** Nonlinear and time frequency analysis.

### 5 Results

As said before, the proposed system has several capabilities. A first goal is to evaluate the neurovegetative cardiovascular regulation by taking advantage of the variability of oscillatory signals, of which heart rate is the classical indicator. This is possible thanks to the application of linear methodologies in the time domain (base statistics focused on the analysis of standard deviation and its derived quantities), in the frequency domain
(spectral analysis which enables the sympatho-vagal cardiac balance to be evaluated) and non-linear methodologies based on indexes (Detrended Fluctuation Analysis, Poincarè plot, entropy) which are less sensitive to external interferences which produce artefacts often due to movements. A first key result from the pilot study is the identification of 7 patients with early observation of atrial fibrillation. The second result is the observation of normal indexes of cardiac conduction or evidence of ischemic heart disease.

OMNIACARE, thanks to the automatic execution, can automatically elaborate the HRV analysis and provide the reference parameters for all patients for the whole day, and can automatically notify to physician situations that could potentially be related to heart problems. It also allows to have a single report with all the results together for a general overview, allowing single physician to check a high number of patients in a long monitoring interval, as shown in Fig. 10.

![Patient overview report.](image)

The parameters evaluated with the HRV analysis should allow the physician to have a clear view of a patient heart status, but could not cover specific cases where a customized in-depth analysis is needed. To cover those cases also, OMNIACARE allows to export the R-R data to external system in CSV format, which can be imported in external programs or directly used in a worksheet.

However, the main result of this study was the possibility to remotely evaluating not only ECG signals but also the neurovegetative cardiovascular regulation during the whole day, both a posteriori and in real time. It is also possible to couple this aspect with the level of activity, the respiratory rate and the heart rate. In this way, it is possible not only to remotely monitor the medical conditions but, if necessary, modify the therapy as well.

As a reference, Table 1 shows the aggregate results of the HRV analysis in the 24 examined hypertensive patients. The parameters evaluated by means of the HRV analysis
in this pilot study should allow the medical doctor to have a clear view of the patient’s cardiac status.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UM</th>
<th>85.4 ± 6.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>b/min</td>
<td>15.7 ± 2.4</td>
</tr>
<tr>
<td>RR</td>
<td>msec</td>
<td>775.5 ± 133.8</td>
</tr>
<tr>
<td>SDNN</td>
<td>msec</td>
<td>95.6 ± 68.9</td>
</tr>
<tr>
<td>RMSDD</td>
<td>msec</td>
<td>86.2 ± 85.5</td>
</tr>
<tr>
<td>LF (un)</td>
<td></td>
<td>49.8 ± 26.2</td>
</tr>
<tr>
<td>HF (un)</td>
<td></td>
<td>49.1 ± 26.0</td>
</tr>
<tr>
<td>LF/HF</td>
<td></td>
<td>2.3 ± 3.2</td>
</tr>
<tr>
<td>SD1</td>
<td>msec</td>
<td>59.7 ± 61.2</td>
</tr>
<tr>
<td>SD2</td>
<td>msec</td>
<td>114.3 ± 83.2</td>
</tr>
<tr>
<td>a1</td>
<td></td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>a2</td>
<td></td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>SampEn</td>
<td></td>
<td>1.2 ± 0.5</td>
</tr>
<tr>
<td>EnRe</td>
<td></td>
<td>6.1 ± 1.0</td>
</tr>
</tbody>
</table>

The trial was interrupted due to the Covid epidemic but will resume as soon as possible both on patients (planning to study patients with heart failure) and on normal subjects to evaluate the effects of training with various different muscular exercise on the cardiorespiratory system, and extend it to patients suffering from cardiorespiratory pathologies.

6 Conclusions

Telemedicine applications play an increasingly important role in health care. They offer indispensable tools for home healthcare, remote patient monitoring, and disease management, not only for rural health and home care, but also for nursing home and assisted living facilities. Although this is a pilot study, our goal has been to develop a large-scale solution for the domestic, cardiovascular, and motoric control of patients with different pathologies. The innovation of this proposal lied on the development of an integrated system allowing storage and transmission of very large volumes of information and data, generated not only by the senior (user) and the family carers or professionals but also by automatic devices.

The device and OMNIACARE software are capable to record symptomatic and asymptomatic events and are indicated both for home and ambulatory monitoring of non-lethal cardiac arrhythmias. The wireless capability enables different applications of the device to be realized and different monitoring modalities to be employed, which
range from the real time monitoring to the long-term recording of biological signals. The proposed system can be a valid support for medical doctors and caregivers in patients’ supervision. The implementation of this model can facilitate either the accessibility and the availability of customized monitors and therapies.

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References

Integrated Measurement and Management System for Sarcopenia Diagnosis

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Abstract. Sarcopenia, defined as the progressive loss of mass and muscular function, is an important public health problem with significant economic and social consequences. The implementation of effective preventive and therapeutic interventions is a major challenge due to the increasing number of elderly people suffering from this syndrome and its debilitating complications. The diagnosis of sarcopenia requires the measurement of muscle mass and strength, and physical performance. Each evaluation method has significant limitations in terms of sensitivity and/or specificity. The goal of this work is to develop an integrated technological system, consisting of measuring devices, including mobile and wearable devices, interfacing with a data collection and processing software system, for clinical monitoring and management of the analyzed case studies. The system has been designed to both preventive (early diagnosis) and monitoring purposes of the patient’s condition over time. The diagnosis will support medical personnel in identifying appropriate interventions to prevent or reduce sarcopenia, which can be communicated via apps on smartphones to patients and caregivers, and monitored by medical personnel.

Keywords: Healthy · Active and assisted living · Internet of Things · Sarcopenia

1 Introduction

Sarcopenia is a condition characterized by a progressive loss of muscle mass and muscle strength which results in reduced physical performance. The body composition undergoes physiological changes with the passage of age: the peak of muscle mass is reached around 40–50 years of age, subsequently we lose about 8% of muscle mass every decade up to 70 years, after this process it accelerates and even loses 15% every decade [1]. The causes of sarcopenia are various: lodging, hormonal changes, chronic pathologies, inflammation, nutritional deficiencies, insulin resistance. The prevalence of sarcopenia...
is approximately 10% in the general population, even if it is thought to be largely underestimated and increases with age [2]; it is associated, especially in the elderly, with a series of negative outcomes such as: greater risk of falls and therefore of fractures [3–5], greater rate and duration of hospitalization [6, 7], increased mortality and disability [8] with significant economic costs [9]. Ultimately, we can say that sarcopenia is related to a series of direct and indirect adverse events that can negatively affect the physical efficiency and quality of life of the subject. Despite this, still today the screening and diagnosis of sarcopenia are not an integral part of daily clinical activity but are the prerogative of research centers only and this mainly depends on the difficulty in applying the diagnostic criteria. According to the European Working Group on Sarcopenia in Older People (EWGSOP) study [10], the diagnosis of sarcopenia involves a first screening by administering the SARC-F questionnaire to identify the subjects at risk; they are then subjected to: (1) a handgrip muscle strength assessment, (2) the assessment of muscle mass with various methods (BIA, DEXA, MRI) that can be more or less invasive or require exposure to ionizing radiation, and (3) the assessment of physical performance by means of the walking test. Moreover, during last years, several works in literature have focused their attention on the use of the surface ElectroMyoGraphy signals (sEMG) for the assessment of age-related changes in gait. The sEMG method presents good performance in the muscle action potential monitoring and can be suitable for the evaluation of muscle strength loss, useful for diagnosis in sarcopenia pathology [8, 9]. The patient is considered sarcopenic if he has a reduction in both strength and muscle mass, while a compromise in physical performance also identifies the subject as suffering from severe sarcopenia [11–13]. The recent significant technological development has led to the design of mechanical and digital instruments connected to the Internet and capable of detecting numerous variables, and transmitting data to processing centers without any human-human or human-computer interaction. These new technologies also known as the Internet of Things (IoT) are currently in use in various fields of our life (e.g. smart home, some forms of telemedicine) [14].

The purpose of the study is to compare the standard clinical protocol for the diagnosis of sarcopenia with such integrated technological system, which should be able to detect the three fundamental components of sarcopenia in a non-invasive way, allowing not only the diagnosis but possibly also the monitoring over time of the sarcopenic patient in hospital and at home context. The system would not present the need to expose the patient to ionizing radiation. Secondary objective is to explore a possible role of surface electromyography in screening and possibly in the diagnosis of sarcopenia, according to User Centered Design paradigm [15].

2 User Needs and Player Interaction Model

2.1 User Needs by Specific Co-planning Phases

The activity led to the following results:

- Identification of the clinical parameters to be measured and the operating conditions in which these parameters will be measured;
• Definition of the requirements of the technological devices for interfacing with the software platform;
• Report on the scouting of technological devices existing on the market.

2.2 Definition of the Interaction Model Between the Different Actors Involved

We have followed the approach called “User-Centered Design” (UCD), i.e. a design philosophy based on the assumption that the needs, desires and limits of the user on the final product are given great attention in every step of the design process to maximize the usability of the product itself. From a technical point of view, we have defined the use scenarios, intended as daily study conditions, which will constitute the context for the development of the analysis of the project requirements. The integrated prototype foresees two different application scenarios:

• Hospital scenario: a geriatric hospitalized patient has to fill a SARC-F questionnaire. If the patient has a sarcopenia risk, according to the results of the questionnaire, and agrees to participate to the experimentation, he can access to the gateway app installed in a smartphone supplied from the hospital. Then the doctor measures grip strength, EMG and walking speed by using the sarcopenia device (i.e. a prototype hardware device capable of detecting muscle strength, walking speed and EMG which has been designed and built within this project). As a control test, grip strength and muscle mass are measured in hospital with traditional equipment, namely: BIA (bioimpedance analysis), and hand-grip by means of a dynamometer. As a result of all the measurements, the patient is identified as sarcopenic; the doctor gives him a list of physical exercises and an ad hoc diet. The therapy can be viewed by the patient in the gateway app, as well as the date and the hour of the next control examination.

• Home scenario: the doctor examines the patient in the surgery and measures grip strength, muscle mass, and walk speed with hospital equipment and EMG device. If the patient agrees, a measurement kit, composed by the sarcopenia device and a smartphone, is given to him/her in order to repeat measurements at home. The gateway app is installed on the smartphone; by accessing it, the patient is able to view the physical exercises as well as the measurement frequencies decided by the doctor. Each time the patient measures the sarcopenia parameters, data are sent by the gateway app to the cloud platform. The doctor can access the data in the web-app. On the basis of such data, the doctor can modify the exercises and/or the date for the next control examination. When the patient comes back to the hospital for control examination, the doctor measures sarcopenia parameters with hospital equipment and EMG device. These data are compared with the data measured by the sarcopenia device.

The risk of sending incorrect measurements to the server is minimal even if the measurements are taken independently by the patient at home. Indeed, simple instructions on how to position the device on the arm and on the exercises that should be performed during each measurement will be included in the kit to ensure proper device use. However, in subsequent versions of the same prototype or during the industrialization stage, we will redesign the package to reduce possibility of incorrect device positioning. Long gloves or forearm belts, for example, could incorporate the device. With regard to the mobile
application, there are only a few simple steps that elderly patients, who are becoming more accustomed to using mobile devices and related applications, must follow to take measurements.

3 Technological Framework and Related Functionalities

As a result of the “User needs by specific co-planning phases” activity, integrated multi-functional devices to be installed in medical offices and wearable devices to be worn by the user were preferred. Evaluation criteria were: low intrusiveness in use (favoring wireless solutions where possible), low purchase and maintenance costs, low consumption and above all the availability of open and unconstrained programming interfaces (APIs). These requirements resulted in the choice of Bluetooth as a wireless technology to be used for communication between prototype and wearable hardware devices with the software component (i.e. app for smartphones) that carries out the role of gateway to the cloud platform. State-of-the-art EMG technologies (i.e. BTS Bioengineering FreeEMG 1000 System) were also selected.

Figure 1 shows the system architecture. It consists of three main components:

- Wearable measuring devices. There are two prototypical devices. Downstream of the requirements analysis, a sarcopenia device (namely a prototype hardware device capable of detecting muscle strength, walking speed and EMG) has been designed and built. The device created satisfies the requirements identified during the analysis phase, namely portability, low cost, non-invasiveness and low consumption. A preliminary study of the operating procedures for the use of the surface EMG system has also been started.
- Gateway app. It is designed to be installed on an Android smartphone. It is able to connect to the sarcopenia device by means of Bluetooth connection in order to receive the data measured by that device and to send those data to the SIMMS web-application back-end server. The gateway app can be used by both patients and doctors, on smartphones owned by patients or supplied by the hospital.
- Web application. It is designed to be installed on a PC or tablet. It enables doctors to access the patients’ registry and to diagnose sarcopenia by analyzing the data received from the gateway app as well as the data received directly from the EMG device.

The system hardware architecture also includes:

- Communication technologies such as Bluetooth REST type web services;
- Remote data collection servers.

Based on the development of the hardware and software components and the related integration components, the prototype of the proposed solution is completed. A first version of the prototype is available for the next testing phase.
3.1 Surface EMG-Based System for Evaluation of Muscle Strength Loss

To evaluate the muscle strength loss, useful for diagnosis in sarcopenia pathology, a sEMG based hardware-software platform was realized for the minimally invasive and long-term monitoring of the lower limb muscles. The research has been focused on the electromyography patterns evaluation of the two Gastrocnemius Lateralis muscles groups, that are relevant in lower limb muscle behavior assessment. Through the platform it will be possible to detect, over time, a muscle decay in users who wear sEMG sensors and perform exercises normally used to evaluate muscle loss, in clinical contest.

The hardware platform consists of an elaboration unit and a data acquisition system. For the acquisition setup system, the BTS Bioengineering FREEEMG1000 device has been used. It is made up of wireless, wearable sEMG probes and an USB receiver, produced by the BTS Bioengineering [16]. Whereas, the elaboration unit consists of an embedded PC (CPU i7@2.40 GHz with a RAM of 8 GB DDR3). The sEMG probes are lightweight (about 10 gr) and small (41.5 × 24.8 × 14 mm for the mother electrode and 16 × 12 mm for the satellite electrode). In Fig. 2a the BTS FREEEMEG1000 system is shown. The sensors are worn through the common pre-gelled Ag/AgCl electrodes by using clips, allowing a fast, simple and resistant wearability to the user’s movements. The data can be sent during a period of about 8 h in streaming mode with a 1 kHz sampling rate and 16-bit resolution.

The main computational steps of the software architecture are: a) Pre-processing; b) Calibration; and c) Feature extraction. For the pre-processing phase, the raw data have been band-pass filtered with cut frequencies between 20 Hz and 450 Hz, to reduce the
artefacts and to avoid signal aliasing. Then, to compare the EMG-tension relationship the signals have been processed by generating their full wave rectification and their linear envelope. The calibration procedure has been accomplished by recovering the initial condition after device mounting. In particular, to calculate the baseline of the signals, the signals average for each sensor was calculated while the user wore the devices in a still standing position for 5 s [17]. Moreover, to reduce the inter-individual variability of sEMG, the maximum signal amplitude values for the right and left Gastrocnemius muscles have been evaluated.

For the Feature extraction phase, time domain features present in literature for the lower limb muscles evaluation have been considered [18], and those with higher performance will be chosen after the elaboration of data obtained through the tests in hospital contest. In this regard, mainly the Sit To Stand test will be performed, since it is commonly used in clinics for evaluating lower limb muscle function in the elderly [19]. In Fig. 2b the test setup is shown.

![Fig. 2. (a) EMG FREEEMG1000 acquisition system; (b) Sit To Stand test setup.](image)

### 3.2 Prototypal Wearable Device to Measure Grip Strength, EMG and Walking Speed

A prototypal wearable device has been designed and realized in order to detect the three identified sarcopenia related parameters, namely muscle mass, muscle strength, and gait speed (Fig. 3a). An Arduino Nano board [20] has been equipped with small and low-cost sensors able to provide these parameters and, in details:

- **Muscle mass.** The MyoWare board [21] has been used to detect EMG measures useful to obtain information about the muscle mass.
- **Muscle strength.** This measure has been obtained by exploiting a HX711 board [22]. This board embeds both a load cell and a circuit to amplify the signal.
- **Gait speed.** To detect this parameter, a GY-521 board embedding the InvenSense MPU-6050 chip [23] with a 3-axis MEMS accelerometer and a 3-axis MEMS gyroscope is used.
More details about sensors operation and configuration are reported in [24].

Moreover, the HC-06 serial Bluetooth converter [25] connected to the Arduino board allows to receive data from connected sensors and to convert these data in Bluetooth signal intended for the gateway (i.e. the mobile application). The wearable device is also equipped with a 700 mAh 9 V battery capable of guaranteeing an operating life of about 9 h. Finally, a 3D printed box has been realized to contain all the listed components and their connections with the exception of the three electrodes for measuring muscle mass, two of which are fixed on the back of the box while the third appears outside the box through a small cable. The box has been equipped with a switch that allows easily on/off the device.

For a correct operation, the patient (alone or supported by the caregiver or doctor) has to perform a few simple actions before starting the acquisition procedure:

- wear the device at the level of the forearm, in correspondence of the dominant hand for detecting muscle strength, through the appropriate bands with Velcro placed on the box;
- attach the two adhesive EMG electrodes placed on the back of the device along the superficial extensor muscles of the forearm whereas place the third adhesive electrode (reference electrode) away from the same muscle (e.g. in correspondence of the cartilage);
- switch on the device end proceed with the measures using the mobile application.

The Fig. 3b shows how the device must be worn to allow a correct acquisition of the sarcopenia parameters.

![Fig. 3. (a) The proposed prototypal wearable device; (b) the realized device worn by a patient.](image)

Because sarcopenia is an age-related disease, it is obvious that the prototypal device and the mobile app can be used by elderly people in a home care scenario. In order to alleviate this problem, as introduced in Sect. 2.2, the wearable device is given to patients with some simple instructions at this stage. Furthermore, the exercises that patients must complete to measure sarcopenia-related parameters are very simple, and the mobile application was developed using best practices for simple and practical mobile apps. When the prototype will be turned into a commercial device in the future, it will
be integrated into a long glove or a forearm band, for example, to reduce the risk of incorrect device positioning.

4 Clinical Testing Protocol and Validation

The clinical trial protocol has been designed. The testing phase will take 6 months and will be performed at Casa Sollievo della Sofferenza Hospital on a randomized cohort of 100 patients aged ≥65 years and at risk or suffering from sarcopenia (i.e. ADL ≥ 4 and SARC-F ≥ 4), either admitted to the Geriatrics Operational Unit or evaluated at the Geriatrics clinic. The study involves a first phase in which the assessment of sarcopenia will be carried out according to the 2019 EWGSOP guidelines in which muscle strength, muscle mass and functional status will be determined. For the determination of muscle strength, we will use a portable electronic dynamometer certified as a medical device. The execution of the handgrip will be carried out following the standard protocol indicated by the American Society of Hand Therapists [26]. The patient will undergo an assessment of body composition including the determination of muscle mass and total body fat by means of Dual energy X-Ray absorptiometry (DXA) which will be carried out at the Radiology Operational Unit at Casa Sollievo della Sofferenza. The total body skeletal muscle mass (SMM) and the appendicular skeletal muscle mass (ASM) will be determined; their values will then be corrected for BMI. The physical performance will be assessed through the gait test; the patient will be asked to walk, at a speed not different from his usual one, wearing comfortable footwear, in a straight line along a path of 4 m, timing the time taken and deriving the average speed. The one indicated by ESWGOT (i.e. 0.8 m/s) is used as a cut-off. All data will be recorded and subsequently entered in a digital platform through the mobile app. We are starting to execute the experimentation and then we will gather and analyze data from experiments, as well as verify and validate the experimentation. Casa Sollievo della Sofferenza began testing on some of their patients the device developed by IDA Lab and the two apps developed in the project in February 2020. The trial has been slowed down due to the emergency linked to COVID-19. In February 2021 it was possible to resume at full capacity thanks to the full cooperation of the entire partnership and to organizational and staff flexibility that made it possible to achieve the set objectives. 101 elderly patients were recruited during the trial. Overall, the user experience in using the prototype was satisfactory and the feedback received was positive. The software platform was clear and with a fast learning curve.

5 Conclusions

The presented study is referred to the development of an integrated technological system, consisting of measuring devices, including mobile and wearable devices, interfacing with a data collection and processing software system, that can be used for early diagnosis and monitoring of sarcopenic patients.

The devices included in the technological system are able to both detect sarcopenia-related parameters (i.e. grip strength, EMG and walking speed) through a wearable device and provide EMG and cinematic evaluation through a portable system. All collected
information is sent to a software platform through an app developed on smartphones for patients, caregivers or doctors and can be consulted by medical personnel through a web application for diagnosis and interventions.

The data deriving from experimentation will be analyzed both with parametric and non-parametric methods on the basis of the distribution of the analyzed variable and the sample size. Comparison and correlation studies will be carried out for muscle strength and walking speed. For the EMG data, correlation data will be extrapolated and statistical analyzes will be carried out on time series to try to define the characteristic features of sarcopenia in one of the three domains analyzed.

References


An Innovative Telemonitoring System for Older Adults Based on Low Power Wide Area Networks

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Abstract. We describe an innovative system to support the care network of older adults that live autonomously at home, as well as monitoring their daily activities in the living environments. The novel system is based on two ICT infrastructures: (a) a new open access regional Low Power Wide Area Network (LPWA) based on LoraWAN\textsuperscript{R} technology, and (b) an open regional big-data platform for sensor networks, called SensorNET. The system has been co-developed by Lepida Scpa (a local public owned tech-company) and AIAS WeCareMore Centre (an association of people with disabilities specialized in assistive technologies). The first prototype of the system is currently being tested involving residents of sheltered apartments (Novi Care Residence) and their caregiver. The ultimate goal for the system is to foster the integration of the local care and social networks with a view to allow older adults to stay longer and live independently and safe in their homes.

Keywords: Telemonitoring · Telecare · Older adults · LPWA · Sheltered apartments · Care residence

1 Introduction

In a social context where there is an increasing need for public services and policies designed for a growing number of people in the “silver age”, the role of public services and public owned tech-companies is not marginal at all. The diffusion and capillarity of information and communication technologies are now mature to a point that most people, even the older ones, feel comfortable with them. Smartphones are ubiquitous devices and ‘smart & cheap’ connected objects can populate every home, now even in absence of a home-based-wifi connection, thanks to the new open access network-backbones like LoraWAN\textsuperscript{R}. Technology
has finally come to an appreciable “calm” degree, as Weiser and Brown intended in 1995 [1]. Even networks’ neutrality has grown to a strategic point that could drive public choices to new investments.

Lepida Scpa, an Emilia-Romagna region strategic public-owned company, is focused on technology networks and solutions for innovative and more efficient local public administrations. It has recently realized an Internet-of-Things public Network, based on LoraWAN® technology, with a native integration with the WAN ultra-broad band fiber-optic network called Lepida, with the purpose to create an open network where citizens, companies and public administrations can integrate their own sensors and devices. Called “RetePA-IoT”, this network has the aim to collect and transport data from multiple sensors in order to make them available both to the owners themselves and to everyone (public bodies, citizens and communities), for institutional and public interest purposes.

In Emilia-Romagna region this virtuous territorial synergy between devices, networks and sensors has given the possibility of realizing an innovative project in the field of Digital Welfare. The Municipality of Novi di Modena and his public owned institution for social services, ASP Terre d’Argine, have made available to Lepida Scpa and his partner AIAS (a non profit organization with a long term expertise in supporting disabled and older adults with innovative assistive technologies) a location called “Care Residence”, a new building designed for the needs of older people who wants to live in autonomy, but in a context where caring and social interactions are easily available.

Lepida Scpa, in his role of supporting local administrations in promoting public policies for social inclusion and active ageing through innovative technologies, have realized not only a LoraWAN® wireless backbone (with a base station situated in the center of the town of Novi di Modena) but even an open and big-data platform for sensor networks, called SensorNET.

Thanks to these key infrastructural elements, Lepida Scpa and his partner AIAS have designed a solution that match the needs of Novi Care Residence managers and is able to help nurses to monitor the behavior of roomers to prevent inactivity, wrong habits and emergency situations.

ASP Terre d’Argine has given the possibility to deploy LoraWAN® sensors in a number of apartments in complete transparency with roomers and in compliance with privacy rules and normatives, in order to display and experiment “calm” technology services toward a real digital welfare ecosystem.

2 Context

2.1 Social Context

Within Europe, Italy has the largest proportion of older adults per population [2]. Among the 60.6 million Italian inhabitants in 2015, 13.4 million (22%) were aged 65 and older [3]. In the Emilia-Romagna Region, one in four persons are over 65 (23.8% of the total population of 4.4 million), with a peak in the municipality of Bologna (24.4%). In Bologna, demographic studies estimate that the group of
so-called “older-old” (over 80 years old) in 2030 will be about 41,000, representing
more than 10% of the total regional population [4].

This rising ageing demographic has led to a higher incidence of chronic diseases and a greater demand for long-term care. According to the “Piano della Cronicità” (Chronicity Plan) from the Italian Ministry of Health, the percentage of people aged 65–74 in 2013 that suffered from at least two chronic diseases was 48.7%, rising to 68.1% for those aged 75 years and older. In Emilia-Romagna, 60% (610,000 persons) of the population over the age of 64 years report having at least one chronic disease and 50% of those aged over 64 report having one or two chronic diseases, while 9% report having three or more chronic conditions [5]. Concerning technology use among the Italian older population, the use of digital devices and access to online services seems to lag behind other European countries. As of 2017, for instance, only an estimated 31% of people in the 65–74 age range accessed the internet against an EU average of 54.6% [6].

2.2 Technological Context

“Ambient Intelligence is a vision of the future information society stemming from
the convergence of ubiquitous computing, ubiquitous communication and intelli-
gent user-friendly interfaces [...]. It puts the emphasis on user-friendliness, user-
empowerment and support for human interactions.” [16]. Closely linked to this
concept is the spread of the Internet of Things, as a widely available technology in
different life contexts. According to Sadiku [17], IoT allows people and devices to
interact each other involving different areas of life: transportation (i.e. parking or
management, logistics, emergency services), community (i.e. smart metering, fac-
tory, retail) and mostly home (i.e. entertainment, utilities, security and health).
Among the most widespread devices in the field of IoT applied to health care we
can find blood pressure monitor, pulse oximeter, activity trackers, and more in gen-
eral devices binded to some vital measurement. However, it is also possible to use
devices created for the detection of environmental data in the healthcare sector.
As shown by Malavasi [13], data collected relating to presence and movement in a
room can be useful to monitor some specific behavior (i.e. how many times a user
goes to bathroom at night); data relating to the air quality in an indoor environ-
ment and the comparison of the same with data relating to the external environ-
ment can be used to suggest to the user a change of habit (e.g.: open/close windows
more often); finally, the data collected by a smart camera capable of recognizing
faces can be used to detect the sociability of a fragile person who lives alone (i.e.
how many people visit him/her in a month). IoT devices can use different commu-
nication protocols and different technologies to communicate. The most common
are [17]: RFID and near-field communication, QRCode, Bluetooth low energy and
Wireless. [13]. A new technology low power is LoraWAN®. An example of appli-
cation of LoraWAN® in the field of IoT and healthcare is shown by Mdhaffar [14].
This work proposes a health based system based on the LoraWAN® communica-
tion network mainly focused on the detection of vital parameters (pressure, blood
sugar and body temperature). The peculiarity of this solution consists in propos-
ing a module that uses e-health sensors connected to a LoRa end node module,
which collects the data acquired by the sensors and sends them to a LoRaWAN® Gateway, then send to a server. Another interesting work that uses sensors and LoRaWAN® network for telemonitoring for elderly people who need assistance is the SOCIAL platform, proposed by [15]. Both [13] and [14] implement a dashboard to show the measured data to caregivers.

3 Methodology

3.1 A Co-design Based Multicycle Development and Testing Approach

The Contatto (internal code name) project main goal is to develop and test a system that can be effective in supporting the caregiver network of older people that live alone in their homes, making it possible to remain continuously “in contact” with them in a non invasive way.

A full co-design approach was considered a main priority in designing and implementing the system and these are the main operational steps of the project:

- Users’ (caregivers) needs analysis
- Preliminary design (architectural definition and sensors selection)
- Multicycle co-design activities
- Prototype development
- Friendly trials
- Multistep deployment with user involvement
- Prototype preliminary testing

4 System Development

4.1 Why LoRaWAN®?

Over the last five years, the possibility to implement new networks with wide geographic coverage and low power consumption (the Low Power Wide Area Networks - LPWAN - operating in the band around the 868 MHz in Europe and 915 MHz in the USA) are emerging in a worldwide scenario. An example of this type of network is the one implemented by SIGFOX [7], an operator dedicated to the internet of things (IoT - Internet of Things), which, based in France, is extending its coverage to Russia and other European countries, also including, from 2015, Italy. A technology that fits into this trend, but that can be used in private and local applications (that is, without necessarily requiring the presence of an operator), is the LoRaTM of Semtech technology [8]. As the name LPWAN suggests, these new technologies have two major strengths:

- data transfer rates are very low, to maintain as low as possible the energy consumption of the connected devices;
- their architecture, based on star topologies and characterized by long range connections, allows the coverage of large areas.
These new technologies can be considered the actual innovation in the IoT world as they extend by a factor of ten the coverage range of the de facto standards such as ZigBee, becoming an infrastructure enabler for new and different application areas, related to the topic of monitoring and, in general, to the smart-cities paradigm. In 2019, in Italy, 76.1% of families had access to the Internet and 74.7% had a broadband connection. There remains a strong digital divide between families, mainly due to generational and cultural factors. Almost all families with at least one underage member have a broadband connection (95.1%); among families made up exclusively of people over 65, this share falls to 34.0% [9]. Most households without internet access at home indicate lack of capacity as their main reason (56.4%) and 25.5% do not consider the internet a useful and interesting tool. There are economic reasons linked to the high cost of connections or necessary tools (13.8%) [9]. Digital services, especially in health and social care, need to emancipate from digital divide problems and the presence of an open access network-backbone like the LPWAN used in the project, can address the connectivity challenges of traditional Internet of Things platforms, laying the foundations for a new smart services scenario.

4.2 Sensors and Data

To choose which were the best sensors for experimentation, several co-design cycles were carried out, alternating focus groups and friendly trials. The focus groups involved specialists from the LoraWAN® network, home automation and telecommunication engineers, caregivers and experts in the social sector and were focused on trying to understand which were the most interesting and most useful data to be collected for the end user. The friendly trials focused on scouting the sensors available on the market and directly testing selected sensors. Based on the feedback of the potential end users involved in the co-design activities, it was decided to collect the following data:

- **Motion detection**: detect movement during the night, can be an indicator that the user is awake and doing some activity;

- **Temperature and humidity**: temperature/humidity when is too low/high compared to the external environment may indicate that the user has forgotten window open or to make a correct change of air;

- **Brightness**: the detection of a very bright environment during the night hours can be an indicator of some nocturnal activities, or indicate the fact that the user has forgotten a light or television on.

LoraWAN® devices cover very different areas of smart monitoring applications from outdoor (smart agriculture and smart environment i.e.) to indoor (smart home and smart metering i.e.). The sensors used for the testing phase were chosen from a selected list of devices, which includes those ready to be integrated into the regional network. Among the other specifications, priority was assigned to a very easy installation (i.e. on a shelf), minimal invasiveness in home environment, low maintenance need and extremely long battery life (from 2 to 5 years). The final sensors selected are described in Table 1.
Table 1. List of sensors

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>Main features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascoell</td>
<td>Infrared passive sensor for indoor apps.</td>
<td>- 16m coverage area</td>
</tr>
<tr>
<td>IR868LR</td>
<td></td>
<td>- three IR Beams</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 3.6V 2700 mAh battery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 868 Mhz LoraWAN® radio module</td>
</tr>
<tr>
<td>Ewattch</td>
<td>Sensor for indoor apps:</td>
<td>- Temperature measurement range: −40 °C to 60 °C</td>
</tr>
<tr>
<td>ATRS0016</td>
<td></td>
<td>- Relative humidity measurement range: 0 to 100%</td>
</tr>
<tr>
<td>Ambiance</td>
<td></td>
<td>- Presence detection distance: 5 m/130° angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Luminosity measurement: 0 to 65535 Lux</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 3.6 V 2700 mAh battery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 868 Mhz LoraWAN® radio module</td>
</tr>
</tbody>
</table>

4.3 System Architecture

![System Architecture Diagram](image)

Figure 1. This picture represents the system architecture.

Figure 1 shows the architecture of the implemented system. In particular, the LoraWAN® sensors were installed inside the Care Residence apartment in Novi. The Lepida Scpa platform, composed of RetePA-IoT and SensorNET, is responsible for processing the payload received from the sensors, extracting, collecting
and analyzing the measurements taken. It also provides some APIs to allow third-party software to receive data. The APIs support HTTP and MQTT protocols. The dashboard, developed with the Ionic\[12\] framework, makes HTTP requests to the Lepida platform, analyzes the data received and makes them readable to the end user (caregiver). In the next paragraph some implementation choices in the development of the dashboard will be discussed.

4.4 The Dashboard: A Simple User Interface to Support the Caregiver Network

The philosophy of Design Thinking [11] underlines the importance of involving the end-user from the earliest stages of project development, in order to realize inclusive tools based on real user needs.

For the scopes of the current project, we first involved health and social care professionals working within the premises of the care residence in Novi. Such professionals included nurses and educators, whose working day is often marked by activities to be organized or carried out, with often very tight work rhythms. For these reasons, they do not have much time to spend in data consultation. Furthermore, one cannot ignore the fact that not all operators may have the necessary skills to correctly read and interpret data interpolated on a graph. In some cases, thinking of older workers, there may be some barriers related to the use of complex IT tools and technologies. Based on this first analysis, it is clear that something new was needed, capable on the one hand of exploiting the potential of a solid and powerful structure such as RetePA-IoT and Sensornet, and on the other hand capable of making the information collected by the sensors as simple and accessible as possible. The added value of this new application consists exactly in providing an accessible interface tailored to the user needs. Let’s now describe the user’s needs, starting from the analysis of a typical working day. Caregivers are at the care residence usually from 8:00 to 18:00. During this period of time they interact daily with the older adults who live in the care residence. There are also daily checkups in the morning and in the evening before leaving the facility. Therefore their request is to have a tool that allows to detect any abnormal behavior during the time slot in which no operator is present, i.e. in the evening and at night. It should be noted that operators are not expected to be contacted during the night, consequently the operators do not need to remotely control what happens in the care residence from home. The goal is to have a tool that allows to check at the beginning of the work shift, what happened during the night, in order to identify any anomaly. It should be noted that the detection of data during the night is not in itself an indicator of an issue. It is up to the operator to give meaning to the data on the basis of his knowledge of the user and an eventual interview. For these reasons, a monitoring system has been created to provide an overview of the
night activities of the various apartments. This system consists of two main sections: the first one contains a general overview of the state of the apartments, with an interface that allows the caregiver to understand at a glance whether the apartment is in a potentially “risky” situation or not; the second shows the detailed status of each apartment, it contains measurements and graphs relating to daily and weekly data. To help the caregiver in the interpretation of data, a semaphore-like system has been created, as you can see in Fig. 2. Each color corresponds with a certain degree of risk:

- **Green**: means that everything is ok;
- **Yellow**: means that there has been a slight variation from the established thresholds;
- **Red**: means that there has been a marked variation from the established thresholds

To establish whether or not a measure belongs to a certain color, reference thresholds have been defined. The range of each threshold that determines the band change is fixed and established a priori, for example as regards the temperature, the guidelines of the WHO have been followed [10]. At this stage, no artificial intelligence has been implemented to adapt to user behavior.

![Fig. 2. Screenshot of the monitoring system. The figure a shows an overview of the system. The figure b shows the data group by measure.](image)
4.5 Helping Caregivers: An Easy Way to Interpret Data

Fig. 3. This flowchart represents the process that a caregiver should follow in order to give proper meaning to the data shown by the dashboard.

Before showing up the preliminary results of this experimentation, it is necessary to make a dutiful premise regarding the interpretation of the data shown by the Dashboard. In fact, until now, we have described a tool that shows data through a graphical interface, that renders colored indicators based on some parameters. How important are these data in the process of identifying any nocturnal problem? How can the caregiver properly analyze the data? An important reminder is that this tool is not a medical system and it does not have the ultimate goal of becoming one. In particular, the dashboard is a tool that acts as a mediator between the experiences of caregivers. The data shown by the Dashboard makes sense only when they are contextualized with the environment from which they are extracted. These assumptions were the starting points in data interpretation.

As regards the specific context of Novi, the data considered most important by the operators of the care residence are those detected by the sensors from 00:00 am to 5:59 am. Evening and night correspond to the period of time in which operators are away from the care residence. Among all the data detected by the sensors during this time slot, particular attention was paid to the calculation of
the movements made by the user during the night, to detect any strange situation. Thinking carefully, it is easy to imagine situations in which moving from one room to another during the night is a perfectly plausible action, that is, going to the bathroom, watching TV or reading late until inviting some friends. The key factor for the interpretation and analysis of the data is the user’s awareness of making movements. To better understand why user’s awareness is crucial in the process of giving meaning to data, a flowchart diagram has been prepared, as shown on Fig. 3.

Once movement is detected, the first thing the caregiver needs to check is whether the person is actually aware of his movements during the night. This approach allows immediately to exclude a fair range of hypotheses from the reasons of the movement, (i.e. sleepwalking, wandering), without however making the collected data useless. Speaking with a person who is aware of making those movements allows the caregiver to collect additional information relating to the causes of the movements themselves: if the movements occur in certain circumstances (after a heavy dinner, an illness, needs) or if they happen by choice (reading, watching tv). Based on the analysis carried out together with the person, the caregiver will be able to establish whether it will be necessary to make some in-depth visits or not. On the other hand, if the person is not at all aware of the movements carried out during the night, the caregiver can use the information as an indicator to evaluate the presence of some disease, probable but not certain, like sleep disorder, sleepwalking or simply cognitive impairment.

5 Preliminary Results

5.1 Pilot Test

This pilot test involved three stages:

- **Friendly trials:** the research and development team has become familiar with the LoraWAN® sensors and how they work. Based on the results of these trials, the sensors to be installed in the apartments were chosen;
- **First installation:** in order to test the behavior of the sensors in the care residence, a prototype kit was installed in one apartment inhabited by a person with very regular habits. This person together with the caregiver had the daily task of compiling a table to mark the hours in which the person woke up and the time in which he went to sleep. This phase was used to evaluate the correspondence between the values returned by the sensors and those gathered by users;
- **Second installation:** during this phase additional kits were installed in three apartments, based on the suggestions of the caregivers. During this phase, the operators began to become familiar with the dashboard.

As regards to the phase of friendly trials, the measures considered most important at the end of the behavioral survey were chosen. During this phase, the end users of the system stressed the importance of having reliable sensors
An Innovative Telemonitoring System

that would give an indication of the movement of users inside the apartment and this led to the choice already extensively discussed in Sect. 4.2. The first installation was mainly used to test the coverage of the LoraWan network in the care residence and to make some considerations regarding the positioning of the sensor in the apartment. For this reason, a “safe” apartment was identified, i.e. inhabited by an elderly person without cognitive difficulties; for two weeks she and her caregiver were asked to write down on a time sheet when she fell asleep and the time in which she woke up. In this way it was possible both to verify the reliability of the data returned by the sensor and to increase user confidence in the technology. As for the positioning of the sensor in the room, we must make a premise regarding the conformation of the apartments. All the apartments of the care residence consist of two rooms (a living room and a bedroom) connected by an anteroom which leads to the bathroom door. During the first installation it was decided to position the intrusion sensor so that it could detect both the movements in the hall and in the anteroom (Fig. 4). However, this approach has shown some structural limitations, as with a single sensor it is impossible to understand whether the absence of movement indicates with certainty that the user is in the room or if he has left the house. Therefore, in the second installation it was chosen to use two intrusion sensors, one positioned in the bedroom and one in the living room. At the end of the first installation, the prototype of the dashboard was also shown to the caregivers and a focus group was carried out to collect impressions, feedback and think about possible improvements.

During the second installation, 4 other apartments of the care residence were chosen. This time, the caregivers expressed the need to specific monitor two apartments because they had long suspected possible night wandering episodes.

Fig. 4. This figure shows an example of positioning a sensor intrusion detector in the care residence apartment
For this reason it was decided to add a sensor also in the bedroom at least in the apartments inhabited by users considered “at risk”. In this way it is possible to have an overall picture of the user’s movements in the apartment. During this installation a new version of the dashboard was provided to caregivers and training sessions were carried out on the tool, including the assessments made in Sect. 4.5. After a week of evaluation by the caregivers, it actually emerged that at least one of the participants was moving around a lot during the night. This fact was essential for assessing the impact of our IoT system in social-context.

6 Discussion and Conclusion

From the experiments carried out it emerged that the technology developed and integrated in the social assistance context has proved to be a valid support tool for the caregivers. Moreover it’s been underlined the fact that it was essential to involve the user from the beginning of the design, in order to adapt a general purpose technology like LPWA technology to the real needs and requirements of the end user. An aspect much appreciated by the users who live in the apartment was the fact that the existence of the system and the installation of the sensors did not in any way change their lifestyle (e.g. the sensor battery does not need to be recharged, they do not require on-site configuration, they are small and do not take up much space in the apartment). The modularity of the system allows you to possibly add other sensors that also measure other parameters.

For example, during the focus group carried out after the end of the second installation, emerged the need to also have sensors that indicate the opening and closing of the doors. Moreover, the fact that the technology is widespread and low cost allows with little investment to expand the field of action, laying the foundations for building a service at regional level for remote monitoring, involving not only protected residential structures, but also private apartments.

References

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Tele-Monitoring and Tele-Rehabilitation of the Hand in Hemiplegic Patients: A Preliminary Study

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Abstract. Hemiplegia after stroke, one of the consequences of the acute loss of focal brain functions, is a syndrome clinically characterized by a deficit of voluntary motor activity in one-half of the body. Many studies highlight the benefits of rehabilitation treatments on the partial recovery of motor function and how the effects of these treatments are not lasting unless frequently stimulated by maintenance activities. This study describes a methodological approach, based on non-invasive technologies, to the quantitative evaluation of motor tasks defined in the MESUPES-Hand section, which could allow targeted and monitored stimulation of patients in a home environment, reducing or diluting new hospitalizations and further traditional rehabilitation treatments over time, and the reduction of healthcare costs. In particular, a 3D vision system is proposed, based on RGB-Depth optical sensors and Computer Vision techniques, to capture the trajectories of the fine movements of the hand and fingers during the execution of the motor tasks defined in the MESUPES-Hand section. From the 3D trajectories collected in real-time, the system estimates groups of specific functional parameters for each task to characterize the hand motor performance quantitatively and automatically assign objective scores as required by the standard evaluation criteria indicated by the MESUPES scale. Preliminary results suggest that the system detects quantitative and qualitative differences between hemiplegic and healthy hands: this is the necessary first step to automatically assess the hand motor function, progress, and changes, even in home environments jointly to remote rehabilitation programs.

Keywords: Post stroke · Home monitoring · Hand rehabilitation · RGB-Depth cameras · Computer vision · Artificial intelligence
1 Introduction

Hemiplegia after stroke, one of the consequences of the acute loss of focal brain functions, is a syndrome that is clinically characterized by a deficit of voluntary motor activity in one-half of the body. It is one of the leading causes of death in the world.

Post-stroke tele-rehabilitation has proven to be a promising intervention for the assessment and rehabilitation with remote supervision of physical, occupational, language, and other therapies to improve the motor, cognitive and psychological deficits consequent to stroke events.

The systematic analysis performed in several studies and reviews [1–4] on the effectiveness of tele-rehabilitation interventions for recovery from the motor, cognitive and psychological dysfunctions in post-stroke has found that tele-rehabilitation approaches were associated with significant improvements of the general condition in post-stroke subjects. In particular, the design of exergames or ecological exercises aims to allow more intensive training and rehabilitation activities with lower costs for the health system. Another advantage is the opportunity to be carried out in home environments, therefore continuing the rehabilitation treatments at home with minor discomfort.

The most remarkable advantage of an exercise defined as ecological, which refers to the behaviours of everyday life, is to try to rehabilitate those functions possessed before the stroke event working on everyday situations that the patient knows and recognizes. This strategy facilitates the acceptance of motor, cognitive, psychological, and motivational stimuli to make the rehabilitation more effective. A 2016 randomized control trial (RCT) [5], for example, found that this rehabilitation strategy was significant for global cognitive functioning, attention, memory, visuospatial abilities, executive and emotional functions, and for general recovery of patients’ abilities.

So the choice of combining tele-rehabilitation with ecological exercises could prove to be a winning choice from a clinical and economic point of view.

However, the first step is to reliably assess the patient performance against validated clinical measurement scales [6]. One of the primary disabilities after stroke affects the upper limb and, in particular, it is associated with the loss of dexterity, causing enormous difficulties in carrying out daily activities. Residual dysfunctions could affect hands and fingers for many years after the stroke event, negatively impacting the quality of life. For this reason, we have focused this study on evaluating the hand performance [7] according to the MESUPES Hand scale [8, 9]: the recovery of the manual dexterity is, in fact, a primary objective of rehabilitation treatments to improve the patient’s autonomy in daily life. Furthermore, the possibility of automatically analysing hand movements could allow a qualitative examination, similar to the clinical evaluation, and quantitative assessment aimed at continuous monitoring of the patient even outside hospital context.

In recent years, several technological solutions have been proposed for the analysis of motor function in post-stroke. The accelerometers, for example, were used for the analysis of gait symmetry [10]; inertial sensors for the analysis of the mobility of upper limbs [11]; textile-based sensors to estimate angular measurements of legs, arms, and trunk [12]. As for less invasive approaches, computer vision methods and RGB-Depth cameras were used to objectively quantify the motor performance of the arms using kinematic parameters in rehabilitation exercises [13]. The same approach was used to verify
the accuracy of RGB-Depth sensors in estimating upper limbs and trunk angular measurements [14]. Many studies deal with motor rehabilitation using virtual environments, serious games, and exergames [15]. In contrast, only a few studies have focused on fine movements related to hand and finger recovery [16–19], and some employ cumbersome solutions based on wearable sensors [20–22].

A low-cost and non-invasive solution for the quantitative and objective assessment of hand and fingers mobility is presented in this study. The aim is to measure motor performance through functional parameters that could allow the continuous and over-time monitoring of the improvement or worsening of the hand motor function. In particular, this may be suitable for monitoring the hand performance in unsupervised settings and for evaluating the effects of motor stimuli and rehabilitation programs provided at home. Estimating functional parameters using simple and non-invasive technologies could be a straightforward method to monitor the subtle alteration or improvement of hand dexterity in post-stroke subjects, especially in home environments, to ensure a more frequent assessment of motor functions. To this end, this study addresses also the comparison between clinical and system scores, to evaluate the reliability of the RGB-Depth solution to assess the hand motor performance. In addition, a quantitative approach using functional parameters can provide objective, easy comparable and complete information about the hand motor performance than coarse and qualitative standard clinical rating scale. This solution could represent a fundamental preliminary step for an accurate and contactless quantitative analysis of the hand motor function, usable to build rehabilitation programs that can contribute to train and maintain the neurocognitive and motor level recovered by hemiplegic patients after intensive hospitalization by optimizing in this way both rehabilitation treatments and economic resources.

2 Material and Methods

2.1 The MESUPES Scale

MESUPES is the most common clinical rating scale for assessing the motor function of upper limbs in stroke subjects [8]. It consists of 17 motor tasks divided into two sections: the MESUPES-Arm section, which has the purpose of evaluating the functionality of the arm (8 motor tasks), and the MESUPES-Hand section to evaluate hand functionality (nine motor tasks) in terms of Range of Motion (the first six tasks) and Orientation (the last three tasks). In this study, only the MESUPES-Hand section was considered since the main focus was assessing the fine movements of the hand: Fig. 1 shows the list of the motor tasks for the MESUPES-Hand section.

The motor tasks of the MESUPES-Hand section have to be performed in sitting position, with the arm resting on a table: for this reason, they can only be administered to subjects who have regained the ability to stay seated. The tasks related to orientation involve some small objects with which to interact to complete the task correctly. In clinical practice, the therapist instructs subjects to perform the motor tasks by themselves: even if not explicitly required by the MESUPES scale, the therapist could ask the patient to use the healthy hand first, thus verifying the correct understanding of motor tasks.

Then, the therapist supervises the execution of the task and assigns a score according to the criteria provided by the MESUPES-Hand section. For Range of Motion tasks, the
score is assigned according to the following criteria: 0 points if no movement; 1 point for movement less than 2 cm; 2 points for movement greater than 2 cm. For Orientation tasks, the score is assigned according to the following criteria: 0 points if no movement or movement with abnormal orientation is detected; 1 point for normal orientation; 2 points for whole correct execution.

According to the MESUPES-Hand evaluation criteria, each task is evaluated separately by the therapist: at the end of the test session, the therapist calculates the partial and total scores, based on the motor tasks that the patient was able to perform. The maximum partial score achievable for the Range of Motion tasks is 12 points; the maximum partial score for the Orientation tasks is 6 points; the maximum total score for the MESUPES-Hand section is 18 points.

![Fig. 1. List of the motor tasks defined by the MESUPES-Hand scale.](image)

### 2.2 The Motion Capture System

A non-invasive vision-based system is proposed to capture the movements of hands and fingers in real-time. It consists of an RGB-Depth optical sensor connected to the processing unit (such as a laptop, desktop, or mini-PC running Windows® 10 equipped with at minimum an Intel® i5 processor and 8 Gb of memory). The optical sensor supplies synchronized color and depth streams (minimum resolution: 640 × 480 pixels for RGB and DEPTH streams) at a rate of at least 30 frames per second, thus allowing the reconstruction of 3D movements in real-time. The RGB-Depth sensor used for this study is Microsoft Kinect® v1. However, it is important to consider that the core of the proposed solution is the hand tracking algorithm that also works with other optical devices such as Intel Real Sense SR300® (as in our work on Parkinson’s disease [23]) or Orbbec Astra® that has the same performance and operative functions of Microsoft Kinect® v1. The RGB-Depth sensor firmware was updated with the last available version before starting the study.
The motion capture system also includes a user aid, i.e., a pair of lightweight passive gloves with colored markers. The use of gloves guarantees the uniform color of the hands, avoiding problems related to complexion and skin tones. In contrast to the black color of gloves, five different colors have been imprinted for each fingertip to identify areas of interest on the hand (Fig. 2). An additional white marker on the palm or back of the glove is present for the future fine-tuning of the system’s automatic system configuration and calibration procedures.

An ad-hoc hand tracking algorithm is used to recognize markers and trace the corresponding real-time 3D trajectories of the hand and fingers involved in each of the nine motor tasks defined by the MESUPES-Hand section. The hand tracking algorithm, based on Computer Vision methods and the fusion of color and depth streams, was developed in a previous study for the automatic assessment of motor performance in Parkinson’s disease: the robustness and accuracy of the hand tracking algorithm in more dynamic motor tasks was previously validated against a gold reference (i.e., an optoelectronic system, BTS SMART DX400©, 8 TVC, 100–300 fps) and other commercial devices [23], among which Leap Motion®.

Unlike [23], the RGB-Depth camera is mounted on a tripod and points downwards, framing the table on which the motor tasks are performed. The view above the table is preferable in this case, as it guarantees the best view of the hands (therefore the visibility of colored markers) during the required movements; the reliability of depth images in close range mode (i.e., at a distance between 70 cm and 1 m) and the accurate reconstruction of the 3D hand movements; a wide enough working volume to perform the motor tasks within the field of view of the camera even in the case of uncontrolled movements of the upper limbs, common conditions in subjects with hemiparesis. This solution presents several advantages over the Leap Motion© device, one of the most used for hand tracking. First of all, it ensures greater working volume than the Leap Motion© device, allowing to capture also uncontrolled movements of the upper limbs. In addition, the dexterity tasks of the MESUPES-Hand scale require keeping the hand in contact with the table. In this case, the only possible configuration is with a top view. The Leap Motion© hand tracking algorithm achieves maximum accuracy and robustness when positioned under the hand at approximately 30 cm. So, it is not applicable in this context unless an arm support structure is available, making the solution more expensive and less practical.

The software component, running on the processing unit, consists of C++ procedures to access the camera streams; provide a simple graphical user interface (GUI) from which the therapist activates and ends the acquisition of each task; estimate the 3D trajectories of color markers through the hand tracking algorithm. At the end of the acquisition session, the analysis of each motor task is performed automatically using dedicated MATLAB scripts that extract some functional parameters from the 3D trajectories of the captured hand performance. Videos and data of each performance are then stored in the patient’s folder to be subsequently supervised by the therapist who may verify the compliance of the performed task.
2.3 Participants and Experimental Protocol

Ten patients with hemiparesis on one side of the body, in post-acute or subacute stroke, with minor disability of the upper limbs and lower limbs (possibility of walking) were recruited for this preliminary study. They were enrolled at the San Giuseppe Hospital, Istituto Auxologico Italiano, Piancavallo (Verbania), Italy. It was their first intensive rehabilitation hospitalization.

The exclusion criterion was cognitive impairment with Mini-Mental State Examination (MMSE) < 26. No exclusion criteria regarding age, sex, side, dominance or therapy in place. Table 1 shows the demographic and clinical features of the participants.

According to the experimental protocol, participants wore gloves with color markers and performed the sequence of motor tasks following the therapist’s instructions, first with the healthy and then with the hemiparetic one. As indicated by the MESUPES-Hand section, motor tasks must be performed in a sitting position and with the hands resting on the table.

The therapist instructed patients on how to perform each motor task: although the MESUPES-Hand section does not require to evaluate the performance of the healthy side, in the experimental protocol, we chose to have each motor task performed even with the healthy hand to verify the patient’s understanding of the therapist’s instructions. In case of excessive difficulty or fatigue in carrying out a particular task or continuing the sequence of tasks, the therapist may decide to interrupt the acquisition session to avoid a negative emotional and psychological impact on the patient.

2.4 Analysis of Motor Performance

The hand tracking algorithm implements Computer Vision methods applied to each pair of color and depth synchronized images generated by the RGB-Depth sensor: for this purpose, the OpenCV library [24] was used. The goal is to estimate the 3D trajectories of the hand and fingers. The initial position of the hand is determined using the color
Table 1. Demographic and clinical characteristics of participants.

<table>
<thead>
<tr>
<th>Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>10</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>7/3</td>
</tr>
<tr>
<td>Side with hemiparesis (left/right)</td>
<td>4/6</td>
</tr>
<tr>
<td>Age (mean ± standard deviation)</td>
<td>61.3 ± 13.4</td>
</tr>
<tr>
<td>Mini-mental examination state</td>
<td>&gt;26</td>
</tr>
<tr>
<td>Ability to walk</td>
<td>YES</td>
</tr>
</tbody>
</table>

segmentation technique: it allows the detection of color blobs on the glove that meets predefined color thresholds (defined as minimum and maximum values for each color component) based on the lighting conditions. The HSV color space was preferred for its robustness to changes in lighting conditions typical of uncontrolled environments, such as might occur in the patient’s home. The 2D pixels that identify the gloved hand are then converted to 3D positions, using the corresponding depth information, from which it was possible to estimate the 3D centroid and the hand bounding box.

The same method was then applied on each successive pair of color and depth images to continuously update the 3D position of the hand centroid and bounding box. The color segmentation technique was also used to detect color blobs within the bounding box corresponding to color markers: for each color, triplets of color thresholds were previously identified to recognize and trace each marker and the corresponding fingertip. In this way, each 3D marker centroid was estimated and trace during the execution of motor tasks, as shown in Fig. 3.

For the 8th and 9th motor tasks, which involve the use of a die as shown in Fig. 3, additional Computer Vision methods were applied on the color images (e.g., binary masks, thresholding techniques, morphological filters, connected components) to detect points on the die face, at the beginning and end of the performance, and the die rotations to provide additional information on performing the motor task.

Groups of functional parameters are then extracted from the estimated 3D trajectories and color image processing to provide an overall quantitative characterization of motor performance. The estimation of functional parameters is the starting point for immediate and objective comparison between performance, for example, of healthy hand and hand with hemiplegia; or “pre” and “post” rehabilitation treatment; or “post” rehabilitation treatment and the follow-up after a few months.

Furthermore, the objective analysis allows to verify the compliance of each motor task and automatically assign scores to the motor function as indicated by the evaluation criteria of the MESUPES-Hand section. Finally, the availability of several quantitative measures provides a more complete and precise indication about the hand functionality to support clinical assessments.
2.5 Statistical Analysis

The trials related to complete tasks for each participant were analyzed to estimate the corresponding functional parameters and perform the statistical analysis.

The Wilcoxon test was used to verify the statistical difference between the scores assigned by the therapist and the system. The initial hypothesis was that no statistical difference exists between them, confirming the congruency of the automatic and clinical scores. In addition, we used Spearman’s correlation coefficients to verify the correlation between the total MESUPES-Hand score assigned by the therapist and the automatic total score assigned by the system. In this case, the initial hypothesis was a high direct correlation (i.e., positive correlation) between the total scores.

3 Experimental Results

3.1 Analysis of 3D Trajectories and Kinematic Parameters

For the first six motor tasks of the MESUPES-Hand section, a clinical score is assigned based on the range of motion, between zero (no or feeble movement) and two points (more significant movement, over 2 cm for each finger involved in the motor task). The same criteria were adopted to assign the automatic score to the motor performance,
estimating the maximum movement of the fingers involved in each motor task. For the last three activities, involving small objects, additional criteria refer to the ability to picking up and lifting a bottle (Task 7) and rotating the die (Task 8 and Task 9). Moreover, the system may provide additional functional parameters for a complete characterization of the motor performance: this could be particularly useful in case of comparisons over time.

Examples of 3D trajectories of hand and fingers movements are shown in Fig. 4 and Fig. 5, while Table 2 shows the list of functional parameters estimated from the 3D trajectories. It is important to note that the defined functional parameters are the same for almost all motor tasks, but they need to be interpreted differently based on the individual motor task.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thumb visibility (%)</td>
<td>Percentage of visibility of thumb finger marker during task</td>
</tr>
<tr>
<td>Index visibility (%)</td>
<td>Percentage of visibility of index finger marker during task</td>
</tr>
<tr>
<td>Middle visibility (%)</td>
<td>Percentage of visibility of middle finger marker during task</td>
</tr>
<tr>
<td>Ring visibility (%)</td>
<td>Percentage of visibility of ring finger marker during task</td>
</tr>
<tr>
<td>Little visibility (%)</td>
<td>Percentage of visibility of little finger marker during task</td>
</tr>
<tr>
<td>Thumb-index distance (cm)</td>
<td>Distance between thumb and index fingers</td>
</tr>
<tr>
<td>Thumb-index variability (-)</td>
<td>Variability of distance between thumb and index fingers</td>
</tr>
<tr>
<td>Max thumb (cm)</td>
<td>Maximum movement of thumb finger</td>
</tr>
<tr>
<td>Max index (cm)</td>
<td>Maximum movement of index finger</td>
</tr>
<tr>
<td>Max middle (cm)</td>
<td>Maximum movement of middle finger</td>
</tr>
<tr>
<td>Max ring (cm)</td>
<td>Maximum movement of ring finger</td>
</tr>
<tr>
<td>Max little (cm)</td>
<td>Maximum movement of little finger</td>
</tr>
<tr>
<td>Max hand LR (cm)</td>
<td>Maximum movement of hand (left-right direction)</td>
</tr>
<tr>
<td>Max hand FB (cm)</td>
<td>Maximum movement of hand (forward-backward direction)</td>
</tr>
<tr>
<td>Max hand UP (cm)</td>
<td>Maximum movement of hand (up-down direction)</td>
</tr>
<tr>
<td>Hand LR variability (-)</td>
<td>Variability of hand (left-right direction)</td>
</tr>
<tr>
<td>Hand FB variability (-)</td>
<td>Variability of hand (forward-backward direction)</td>
</tr>
<tr>
<td>Hand UD variability (-)</td>
<td>Variability of hand (up-down direction)</td>
</tr>
</tbody>
</table>

The functional parameters related to visibility may highlight some difficulties in motor control. For example, it is expected that all fingers are almost always visible (percentage very close to 100%) when performing specific motor tasks (e.g., Task 2, Task 4, Task 5, and Task 6): lower percentages probably indicate the inability to control the fingers correctly. The same is valid for parameters relating to hand movements along with one of the three main directions. In the first six motor tasks, it is necessary to keep
the hand still while performing the finger movements: the detection of hand movements in one of the three directions probably indicates the inability to properly control the arm during the execution of the motor tasks, as shown in Fig. 5 where unexpected movements of the hemiplegic hand were detected. Considering these parameters as a whole may provide much more information on motor function than single parameters analyzed individually.

The images of Fig. 4(a) refer to Task 1: the system automatically assigned two points to motor performance since the maximum movement of the two fingers (thumb and index finger) was over 2 cm. Although these measurements are sufficient to assign points according to the MESUPES-Hand evaluation criteria, the graph on the left indicates the variation in the 3D distance between the two fingers and the regularity of the movement performed.

The images of Fig. 4(b) refer to Task 4: the system automatically assigned two points to motor performance since the maximum movement of the middle finger was over 2 cm. Although this measure is sufficient to award points according to the MESUPES-Hand evaluation criteria, the graph on the left indicates that the 3D distance between thumb and index finger was constant during the task. In addition, the graph on the right indicates that the other fingers did not move (in practice, only movements of the middle finger were detected as required by the motor task).

The images of Fig. 4(c) refer to Task 2: the system automatically assigned two points to motor performance as the maximum movement of all fingers was over 2 cm. Although these measures are sufficient to award points according to the MESUPES-Hand evaluation criteria, the graph on the left indicates that the 3D distance between thumb and index finger was relatively constant during the task. In addition, the graph on the right indicates that all the fingers moved at the same time, smoothly and with approximately the same range of motion.

Finally, Fig. 6 shows the detection of the points on the die face: this allows to evaluate if the subject was able to take and rotate the die as required by the motor task. The points marked by the die are detected with Computer Vision techniques at the beginning and the end of the motor task: if no rotations have occurred, the points marked by the die will be the same. The 3D trajectories of fingers involved (i.e., thumb, index, and middle) also provide a qualitative indication of the rotations performed. To correctly analyze the points marker by the die, the die face to be analyzed must be completely visible: at the moment, this is the most critical aspect of the analysis and may require manual intervention by the therapist to place the die in a favorable position, especially at the end of the motor task. Two patients have shown excessive fatigue during the test session, so the therapist interrupted the ninth motor task, so no performance was analyzed. Instead, one patient could not perform any task with the hemiplegic hand, so the assigned total score by the therapist and the system was 0.

3.2 Automatic Assessment of Hand Motor Function

The performance of the participants were acquired during the execution of each motor task and scored by the therapist according to the MESUPES-Hand evaluation criteria. Then each complete performance was automatically analyzed and scored by the system on the basis of the defined functional parameters.
The scores assigned to each task were then grouped considering the two parts of the MESUPES-Hand section, as occurs in clinical practice: range of motion (task 1–6) and orientation (task 7–9). Finally, the total score was calculated by adding the two partial scores obtained. This procedure was repeated for both the healthy and hemiplegic hands for all the participants. As an example, the scores assigned by the system to one of the participants (Patient #6) are shown in Table 3, which highlights where the performance of the two hands is different. In addition, partial and total scores related to the same subject are shown in Table 4: this allows a direct comparison between the total scores assigned by the therapist and the system.

The statistical analysis was performed on the performance of all the participants to compare the automatic scores to the ones assigned by the therapist, verifying their agreement. Table 5 shows the average scores with standard deviation for each of the tasks assigned by the system and the therapist.

The results show the association between the automatic and the therapist-assigned scores, both for single tasks, partial and total scores. The differences are because the automatic scores consider not only sharp distance measurement but all the kinematic
of the hand performance. The most remarkable differences ($p < 0.05$) are found in motor tasks 2 and 5 because two subjects did not perform the task as indicated by the MESUPES-Hand scale. In particular, for task 2, the hand was lifted from the table: the system assigned an automatic 0 points (i.e., test not performed correctly) while the therapist rewarded the patients’ effort by assigning 2 points. For task 5, patients did not perform the movement of the second and third fingers while keeping the other fingers still; again, the system assigned 0 points while the therapist rewarded the patients’ effort by assigning two points.

In addition, considering the total MESUPES-Hand scores of the 10 participants, the correlation between the automatic and clinical scores was evaluated using Spearman’s correlation [25]: the Spearman’s coefficient indicates a value of 0.97 ($p < 0.001$), confirming the agreement between the total assigned clinical scores and those estimated through the automatic and objective analysis of the hand motor function.
Fig. 6. Detection of points on die face to evaluate rotations for Task 8 and 9: points detected at the beginning (on the left) and at the end of the task (on the right). The rotations of the die are also highlighted by the variation of the 3D distance between thumb and index.

<table>
<thead>
<tr>
<th>MESUPES-Hand</th>
<th>Healthy hand score</th>
<th>Hand with hemiparesis score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Task 2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Task 3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Task 4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Task 5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Task 6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Task 7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Task 8</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Task 9</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3. Example of automatic scores assigned by the system to each motor task (Patient #6).

Preliminary results indicate that the system may objectively capture and characterize the differences between the healthy hand and the hand with hemiplegia, and to assess the hand motor performance according to the MESUPES-Hand evaluation criteria and in agreement to therapists, but providing more objective information on the kinematic hand performance.
Table 4. Comparison between clinical and automatic scores (Patient #6).

<table>
<thead>
<tr>
<th>Scores</th>
<th>Tasks</th>
<th>Healthy hand</th>
<th>Hand with hemiparesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>System scores</td>
<td>Tasks 1–6</td>
<td>12/12</td>
<td>11/12</td>
</tr>
<tr>
<td></td>
<td>Tasks 7–9</td>
<td>6/6</td>
<td>2/6</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>18/18</strong></td>
<td><strong>13/18</strong></td>
</tr>
<tr>
<td>Clinical scores</td>
<td>Tasks 1–6</td>
<td>12/12</td>
<td>10/12</td>
</tr>
<tr>
<td></td>
<td>Tasks 7–9</td>
<td>6/6</td>
<td>3/6</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>18/18</strong></td>
<td><strong>13/18</strong></td>
</tr>
</tbody>
</table>

Table 5. Average scores with standard deviation on 10 participants assigned by the system and by the therapist

<table>
<thead>
<tr>
<th>MESUPES-Hand task</th>
<th>Therapist score (mean ± dev. st.)</th>
<th>System score (mean ± dev. st.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>1.56 ± 0.81</td>
<td>1.50 ± 0.89</td>
</tr>
<tr>
<td>Task 2</td>
<td>1.53 ± 0.83</td>
<td>1.33 ± 0.98</td>
</tr>
<tr>
<td>Task 3</td>
<td>1.47 ± 0.92</td>
<td>1.47 ± 0.92</td>
</tr>
<tr>
<td>Task 4</td>
<td>1.44 ± 0.89</td>
<td>1.38 ± 0.96</td>
</tr>
<tr>
<td>Task 5</td>
<td>1.47 ± 0.83</td>
<td>1.07 ± 0.80</td>
</tr>
<tr>
<td>Task 6</td>
<td>1.57 ± 0.85</td>
<td>1.57 ± 0.85</td>
</tr>
<tr>
<td>Task 7</td>
<td>1.27 ± 0.93</td>
<td>1.33 ± 0.90</td>
</tr>
<tr>
<td>Task 8</td>
<td>1.19 ± 0.98</td>
<td>1.19 ± 0.98</td>
</tr>
<tr>
<td>Task 9</td>
<td>1.25 ± 0.97</td>
<td>1.25 ± 0.97</td>
</tr>
<tr>
<td>Partial score (Tasks 1–6)</td>
<td>8.56 ± 4.99</td>
<td>7.88 ± 4.99</td>
</tr>
<tr>
<td>Partial score (Tasks 7–9)</td>
<td>3.31 ± 2.60</td>
<td>3.38 ± 2.53</td>
</tr>
<tr>
<td>Total score (Tasks 1–9)</td>
<td>11.88 ± 7.20</td>
<td>11.25 ± 7.11</td>
</tr>
</tbody>
</table>

4 Conclusions

The activity carried out has made it possible to assess the feasibility of an objective assessment of the MESUPES-Hand scale in subjects with stroke consequences. A non-invasive and low-cost motion capture system and hand tracking algorithm, based on Computer Vision methods and RGB-Depth sensors, have been proposed to accurately track the hand and fingers movements during the execution of the motor tasks defined in the MESUPES-Hand section.
The preliminary results make us embark on a path of rehabilitation and evaluation at home capable of maintaining a functional standard and preventing the risk of functional decline. Future work will concern the extension of the analysis to a more significant number of subjects, to confirm the preliminary results. Furthermore, the possibility of integrating more parameters will be investigated in order to produce an overall evaluation using Machine Learning and Artificial Intelligence approaches and to appreciate the improvement or worsening of the hand motor function. Finally, the use in home settings will be considered as part of remote monitoring and rehabilitation programs.

This study is part of a long-term project (REHOME Project, Piedmont Region – POR FESR 2014-2020). An integrated platform for the remote monitoring and rehabilitation of post-stroke patients will be implemented to stimulate and automatically analyze the evolution of the upper limb motor performance. Further work will be necessary to make the system easily usable in the home. In particular, it will be necessary to equip the system with a human-machine interface to guide the patient in the self-management of the proposed system and perform the motor tasks autonomously. In addition, functional parameters and scores assigned by the system will be automatically sent to a data collection platform after each evaluation session to promote the remote monitoring and supervision of the hand performance by clinicians and therapists. Finally, the same hand tracking algorithm may be used to implement specific hand rehabilitation exergames in virtual reality, with the aim of training and stimulating hand movement and dexterity and promote the recovery of hand functions while having fun. In this context, functional parameters could be used to analyze the hand movement, characterize it objectively, and evaluate the effectiveness of the treatment and the progress in functional recovery. This improvement could make the proposed solution a complete system for treating motor disabilities of the upper limb, not only for post-stroke patients but also in other pathologies. The integration of rehabilitative motor tasks aimed at functional recovery monitorable through specific evaluation motor tasks (i.e., diagnostic motor tasks) could represent one of the most innovative aspects of a solution based on non-invasive optical RGB-Depth devices.

In conclusion, the preliminary study shows the possibility of integrating a better therapeutic rehabilitation proposal, with frequent evaluation and monitoring of the hand motor function, to reduce healthcare costs due to long-term rehabilitation needs.

References

Cognition and Technologies
Comparison of Computerized Testing Versus Paper-Based Testing in the Neurocognitive Assessment of Seniors at Risk of Dementia

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Abstract. In subjects affected by neurocognitive disorders, mild neuropsychological disturbances may be detected even years before overt dementia. With advancing age, it is therefore important to perform early testing and repeat them over time to assess any variation in cognitive performance, which may allow for early diagnosis and care. The choice of tests and the interpretation of responses need to be tailored to the characteristics of the subjects and involve the presence and validation of an experienced specialist, while the wording of the instructions, the presentation of the items and the recording of the responses should be maximally objective and impersonal. In our study we evaluate the possibility to employ a Digitized Battery, based on traditional paper-based tests and equipped with a voice assistant and a speech-to-text engine, to provide standardized administration of neuropsychological tools. The automation of these aspects, which allows a remote evaluation, even at home, of the patient and maximizes the opportunity for the evaluator to observe the psycho-emotional and behavioral state of the subjects, therefore constitute a thorough advancement in dementia assessment.

Keywords: Mild cognitive impairment · Neurocognitive disorders · Computerized testing · Neuropsychological assessment · Early diagnosis

1 Introduction

Neurocognitive disorders (NCD) are the leading cause of disability and dependence in the elderly population and represent a heavy economic and societal burden [1]. The diagnosis of NCD is mainly based on the patient’s history, examination, and appropriate objective assessments, according to standard criteria [2]. Brain imaging and other biomarkers allow for the early identification of neuropathological changes, which may precede the overt clinical manifestations by many years [3] and for differential diagnosis. Major NCD, which is commonly known as dementia, is typically diagnosed when
acquired cognitive impairment has become severe enough to compromise social or occupational functioning. However, people affected by NCD in initial phases may show no symptoms, or present a Subjective Cognitive Decline (SCD), or a Mild Cognitive Impairment (MCI) – with essentially preserved functional abilities and a mild deterioration of memory, attention, or other cognitive domains which is detectable with a standard neuropsychological assessment [4]. There are currently no disease-modifying drugs for dementia, therefore, the early diagnosis is one of the main objectives of medicine. However, to date, according to a recent meta-analysis, the proportion of undetected dementia exceeds 60%, and it is even higher in younger and milder seniors [5]. In this view, the possibility of applying technology to early and widely detect people at risk is particularly desirable.

Traditional testing present undeniable advantages, including the clinical sensitivity of the examiner in selecting appropriate tests, in identifying conditions which could affect performance beyond cognitive impairment (such as anxiety), and in observing any small difficulties that would be difficult to detect in an exclusively quantitative evaluation. However, it suffers from some limitations. These include the high cost, in terms of money, resources and time, of carrying out repeated follow-up at short time lapses [6]; the tendency – for some clinicians – to help the patient more than allowed by the scale administration criteria; the subjectivity of the evaluators in interpreting some potentially ambiguous answers, which may affect the calculation of the test scores; the inability to precisely control the timing of presentation of stimuli and to precisely record the accuracy of any motor responses, the impossibility of precisely quantifying additional information related to test execution strategies [7]. Although some of these limits can be overcome through in-depth training of the evaluators, others, such as costs and precision in controlling administration and response times, are inevitably affected by the human factor. Furthermore, substantially, in-depth training requires the administration of the tests – i.e. the wording of the instructions, the presentation of the items and the recording of the responses – to be maximally objective, impersonal and identical between different subjects.

Consequently, while the selection of tests and the interpretation of responses need to be tailored to the characteristics of the subjects and involve the presence and validation of an experienced specialist, the digitized administration of cognitive tests, which would allow a possible controlled fruition directly from the examinee’s home or the general practitioner’s surgery, would benefit from digitized testing. Digitized testing would achieve the goals of maximum objectivity, impersonality, standardization, cost and time savings, thus representing an opportunity to early detect the presence of NCD in a larger number of people at risk [8].

Several clinical information technology (IT) tools have recently been developed to assess cognitive performances in self-administered way and/or directly at home [9–11]. However, to date, digitized testing appear difficult to implement, since many seniors do not have the IT tools, the familiarity or the willingness to use computerized systems. Moreover, no computerized assessment tool for the early detection of MCI, has to date been validated with a large controlled study [12]. Nonetheless, there are indications, albeit weak, to support the fact that a digitized neurocognitive assessment may prove promising in the early detection of NCD [13, 14].
The aim of our project was to develop a computerized battery of neurocognitive tests which can be easily self-administered on a tablet or PC by seniors with normal cognition, SCD or MCI, under the supervision of an experienced specialist. Compared to the current state-of-the-art, our digitized battery implements a voice assistant and a speech-to-text engine, that allow the examinee’s voice interaction with the IT system. Moreover, it collects the audio recordings and written interactions of the user with the IT system, and makes them available to the specialist, for increased diagnostic accuracy.

2 Materials and Methods

2.1 Overall Structure of the Project

The study involved five phases. As a first step, a battery of paper-based neurocognitive tests (which will be briefly described in the next paragraphs) aimed at the investigation of the performances of seniors in different cognitive domains was selected by clinical experts. Tests that were not covered by copyrights were preferred, to ensure that the Digitized Battery might, in the future, be used by a wide number of specialists without violating any copyrights.

The next phase was to create a computerized version of each domain-specific test meeting the following requirements:

- Every feature of each digitized test (DT), including the administration of instructions, the type of response exerted, the possibility to provide prompts and suggestions, the recording of the answers, and the calculation of the scores are identical or as similar as possible to that of the corresponding paper-based test (PT).
- The instructions/delivery of each DT are provided by a voice assistant (VA), and the examinee’s verbal responses are translated by a speech-to-text engine (STT), to allow easy interaction with the IT system.
- For each test, the audio recordings, or graphic signs (i.e. written answers or drawings of the subject), or any other kind of interactions of the subject with the system are recorded, collected, and made available to the examiner.
- The scores are calculated automatically, but the examiner has the option to change them, as well as the faculty to amend any translation errors made by the STT.
- The system is developed to administer the whole battery automatically and independently from the examiner, who in any case could intervene to interrupt the DTs, provide clarifications, correct any errors, or rectify the participant’s scores.

The third phase involved the enrolment of a sample of aged participants with SCD, MCI and mild global cognitive decline according to diagnostic criteria [4, 15] and Mini-Mental State Examination [16] scores. Seniors who at the paper-based cognitive evaluation corresponded to the inclusion criteria were invited to perform the computerized evaluation the following week. The experimental sessions were conducted individually, under the supervision of a clinician specifically trained to use the application. Participants performed the DTs seated, using a tablet placed on the desk, with the screen facing upwards. Short practice sessions were performed before the execution of almost all the DTs, in which the clinician could intervene with suggestions or helping the subject to
carry out the task correctly. The examiner’s intervention was instead thought to be absent or minimal during the automated administration of the DTs.

The fourth step envisaged two sub-phases: (a) a between-subjects analysis to compare the socio-demographic characteristics and performance in the PTs between the subjects who performed the DTs and those who – for heterogeneous reasons – did not; (b) the within-subjects comparison of the performances in DTs and PTs (gold standard) with appropriate statistical analyses. We had planned to optimize the computerized tool based on the data which were gradually collected with our participants, regarding their performances, and any indications/suggestions or difficulties related to the use of the digitized battery. The COVID-19 pandemic and the imposed restrictive measures resulted in the interruption of the project during this phase, after the enrolment of a subsample of participants. Due to the study interruption, this phase was therefore conducted only on a subsample of enrolled participants.

The fifth phase would have involved the creation of numerous alternative versions of digitized tests, aimed at their use for cognitive training, and the evaluation of their effectiveness by comparing the scores in PTs and DTs before and after the training within a group of treated participants and between treated subjects and a control group of seniors, undergoing standard paper-based cognitive training. This phase was not carried out, because, before the interruption of the study, it was observed that the digitized battery needed several improvements before being easily used by seniors both as a diagnostic and as a rehabilitation tool.

2.2 Study Procedure

As previously stated, the project was interrupted in the middle of phase 4, because of the supervening epidemic COVID-19, after the enrolment of a subsample of seniors with subjective or mild objective cognitive decline, some of whom performed both PTs and DTs, while the remainder were evaluated only with PTs.

In next paragraphs, the study methods and results obtained in phases 1–4 will be described in detail.

2.3 Assessment Tools

Demographic, Clinical, Functional and Behavioral Variables. Socio-demographic and clinical information (sex, age, education, drug treatment, presence of comorbidities such as diabetes, obesity, hypertension, hypercholesterolemia, thyroid dysfunctions, cardiovascular diseases, cancer, other diseases, hospitalizations or first aid recovery in the last year) was collected through an in-depth anamnestic interview. The Functional Activities Questionnaire (FAQ) [17] and the Basic and Instrumental Activities of Daily Living [18] were used for the functional assessment. Depression, apathy and psychosis were evaluated with the Geriatric Depression Scale (GDS) [19], the Apathy Evaluation Scale (AES) [20] and the screening questions for psychosis of the Structured Clinical Interview 1 (SCID-I) [21].

Paper-Based Neuropsychological Test Battery (Phase 1). Global cognitive performance was evaluated with the Addenbrooke’s Cognitive Examination-Revised (ACE-R) [22, 23], a brief cognitive test battery for dementia screening including all MMSE
Comparison of Computerized Testing Versus Paper-Based Testing

items and additional questions allowing the fast evaluation of specific domains. Verbal short-term and working memory were assessed with the Digit Span Forward (DF) and Backward (DB) test [24]. The Rey Auditory Verbal Learning Test [25] was used to assess immediate (RAVLT-I) and delayed (RAVLT-D) verbal recall. Constructional Praxis and visuo-spatial memory were evaluated with the copy and the delayed recall of the Rey-Osterrieth Complex Figure Test (ROCFT) [26]. Visuo-spatial attention was assessed with the Multiple Feature Target Cancellation (MFTC) [27] and the Trail Making Test (TMT) sub-test B (TMT-A) [28]. The TMT sub-test B (TMT-B) [28], the Short Stroop Test (SST) [29] and Elithorn Perceptual Maze Test (EPMT) [30] were used to assess executive functions, specifically cognitive flexibility, environmental interference and planning. Language was evaluated with the Phonemic (PF) and Semantic (SF) Verbal Fluency Tests [31] and with Naming from Description test (ND) [32].

The main features of each domain-specific PT and of its derived DT are briefly described in Table 1. For a more detailed description of each PT, the reader is referred to their cited bibliographic references.

Computerized Neuropsychological Test Battery (Phase 2). The computerized battery was developed to include the digitized version of all PTs listed in the previous paragraph, with the exception of the ACE-R, of which, due to copyright laws, only the space-time orientation questions (STO) and the clock-drawing task (CDT) were developed. Indeed, since we realized that the drawing area was too small to allow the reproduction of the ROCFT, the digitized evaluation of visual-constructive skills was modified in the first phases of the battery development and replaced with the computerized version of the Copy of Drawings (CD) from the Mental Deterioration Battery, which consists in the copy of three less complex stylized figures (house, wind rose, parallelepiped) [25]. The CD scores were compared to that obtained in the copy of drawings from the ACE-R.

Digitized versions of the Corsi Block-Tapping Test Forward and Backward (CF, CB) [24] and of the Visuo-spatial Learning Test (VL) [30] were also developed, in order to inquire visuo-spatial memory abilities. In the computerized versions of these tests, blocks were replaced by light-bulbs that turned on and off sequentially, one at a time (Table 1).

Table 1 shows the main characteristics of the paper-based and computerized versions of each test. Unless otherwise indicated, the methods of administration and scoring are identical for each PTs and its corresponding DTs.

Computerized Platform. The Digitized Battery was implemented on the OMNIACARE platform. It is a multifunctional, modular ICT system designed specifically for the social welfare and healthcare sector. Each module is developed to perform some specific functions, to adapt precisely and dynamically to different situations. It is therefore possible to implement a greater or lesser number of functionalities, using or not the specific elements, without compromising the general functioning of the whole system. This architecture is therefore open to potential developments, through the addition of new modules. As regards the specific aims of this study, a Learning Management System was developed, i.e. a multiplatform system capable of delivering exercises in multimedia mode to make the learning process pleasant, usable and effective. At the same time, it
Table 1. Description of all digitized tests developed, with reference to the corresponding paper-based tests, and their limits. PT: Paper-based test. DT: Digitized test. VA: Vocal Assistant. S.: subject. E.: evaluator.

<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial-Temporal orientation</td>
<td>Test instructions and 10 spatial-temporal orientation questions are read by the e. [23]. The s. responds orally. No preliminary training questions, aids or suggestions are allowed. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the number of correct responses.</td>
<td>Test instructions and 10 spatial-temporal orientation questions [23] are read by the VA. The s. responds orally or using the keyboard/notepad keypad. No preliminary training questions, aids or suggestions are allowed. The application records, collects and transcribes the answers and evaluates their correctness by comparing them to the answers pre-set by the e. Test score corresponds to the number of correct responses. The e. has the possibility of having the s. listen to the instructions again, if they have not been correctly received, to rectify incorrectly transcribed or incomplete answers and to correct the score automatically assigned.</td>
<td>The system requires high-speed internet connection. In its absence, or in case of imperfect pronunciation or low voice, the answers were not logged or incorrectly transcribed. Transcription errors were partially addressed by asking the s. to answer in writing. However this implies a difference in the modality of the response between PT and DT.</td>
</tr>
</tbody>
</table>

(continued)
### Table 1. (continued)

<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal short-term memory</td>
<td>The s. has to repeat numerical sequences of increasing length in the same order as read aloud by the e. [24]. A preliminary training session with 2 digits is provided for training and to evaluate test executability. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the maximum number of digits that the s. is able to repeat correctly.</td>
<td>Test instructions and numerical sequences of increasing length are read by the VA. At the end of each, a sound alerts the s. that it is his/her turn to answer. The s. answers orally after pressing a virtual button on the application, which enables the microphone. A preliminary session with 2 digits is provided for training and to evaluate test executability. The application records, collects and transcribes the answers and evaluates their correctness by comparing them to the exact sequence. The type of errors (omissions, insertions, translocations, inversions, perseverations) are also coded. Test score corresponds to the maximum number of digits that the s. is able to repeat correctly. The e. can rectify incorrectly transcribed or incomplete answers and correct the score automatically assigned.</td>
<td>Most participants did not remember to enable the microphone before answering, preventing their answers from being recorded. This action also created interference, diverting the s.'s attention from the task, and favoring the forgetting of the sequence. This issue was partially addressed by having the e. to enable the microphone. The system requires high-speed internet connection. In its absence, or in case of imperfect pronunciation or low voice, the answers were not logged or incorrectly transcribed. The SST was sometimes inaccurate or transcribed words phonetically similar to some digits (e.g., 8 = “föto”). All these errors implied the need for the e. to rectify almost each sequence, making it impossible to administer the test at this stage of the study.</td>
</tr>
<tr>
<td>Verbal working memory</td>
<td>The s. is required to repeat numerical sequences of increasing in reverse order of that read aloud by the e. [24]. A preliminary training session with 2 digits is provided for training and to evaluate test executability. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the maximum number of digits that the s. is able to repeat correctly.</td>
<td>(see above)</td>
<td>(see above)</td>
</tr>
<tr>
<td>Cognitive function</td>
<td>Paper-based test (PT)</td>
<td>Digitized test (DT)</td>
<td>Limits of the DT</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Visuo-spatial short -term memory</td>
<td>Nine blocks are arranged randomly on a board. The s. has to imitate the precise sequence of blocks, with progressively increasing length, tapped by the e. [24]. A preliminary training session with 2 blocks is provided for training and to evaluate test executability. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the maximum number of blocks that the s. is able to tap correctly. This test was not administered in its paper-based version.</td>
<td>Nine light-bulbs are randomly arranged on the screen. They flashes, one at a time, in sequences of increasing length. The test requires the s. to tap (or tap backward) the bulbs accordingly. Test instructions are read by the VA. At the end of each sequence, a sound alerts the s. that it is his/her turn to act. Each bulb lights up when and as long as it is touched by the s., in order to provide visual feedback. A preliminary training session with 2 bulbs enlightening is provided for training and to evaluate test executability. The application records, collects and transcribes the answers and evaluates their correctness by comparing them to the exact sequence. Test scores corresponds to the number of bulbs in the longest sequence that the patient had correctly tapped. The type of errors (omissions, insertions, translocations, inversions, perseverations) are also coded. The e. can correct the score automatically assigned.</td>
<td>The system was sometimes insensitive to the touch of the finger /digital pen, possibly due to the absence of high-speed internet connection in the at the test site. For the same reasons, delays could happen, in returning the feedback to the s., with the bulbs turning on after some time from having been touched. Even when the responses were recorded correctly, this issue created interference, diverting the s.’s attention from the task, and favoring the forgetting of the sequence.</td>
</tr>
</tbody>
</table>

(continued)
| Cognitive function                      | Paper-based test (PT)                                                                                                                                                                                                 | Digitized test (DT)                                                                                                                                                                                                 | Limits of the DT   |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| Visuo-spatial working memory            | Nine blocks are arranged randomly on a board. The s. has to tap backward the precise sequence of blocks, with progressively increasing length, tapped by the e. [24]. A preliminary training session with 2 blocks is provided for training and to evaluate test executability. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the maximum number of blocks that the s. is able to tap correctly. This test was not administered in its paper-based version. | *(see above)*                                                                                                                                  | *(see above)* |
| Visuo-spatial learning                  | Nine blocks are arranged randomly on a board. The s. has to imitate the precise sequence of 8 blocks tapped by the e. The sequence is presented until the learning criterion is reached (3 exact consecutive repetitions) or up to a maximum of 18 trials. The e. transcribes the answers and evaluates their correctness according to the test rules. Test scores are calculated on the basis of the number and combinations of blocks that are tapped at any attempt [30] | Nine light-bulbs are randomly arranged on the screen. Each of them flashes, one at a time. The s. is allowed 10 attempts to learn to correctly imitate the sequence of 9 bulbs. Test scores correspond to the number of bulbs in the longest sequence that the patient had correctly tapped in his/her last attempt. *(see above for the system’s characteristics)* | *(see above)* |

*(continued)*
Table 1. (continued)

<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal learning and immediate recall</td>
<td>A list of 15 unrelated words is read aloud for 5 times by the e. At the end of each presentation, the s. is asked to recall as many words as possible, without order constraints [25]. The e. records the words in the order in which they were recalled and any intrusions (words not belonging to the list). The test score corresponds to the number of words that the s. is able to recall correctly in 5 repetitions. Primacy and recency effects and learning over trials are also computable.</td>
<td>Test instructions and a list of 10 unrelated words are read aloud for 3 times by the VA. At the end of each presentation, a sound alerts the s. that it is his/her turn to answer. The s. has to recall as many words as possible, without order constraints, via microphone. The system records the words in the order in which they were recalled and any intrusions (words not belonging to the list). Test scores correspond to the number of words that the s. is able to recall correctly in 3 repetitions. Primacy and recency effects and learning over trials are also computable. The e. can rectify incorrectly transcribed or incomplete answers and to correct the score automatically assigned.</td>
<td>Most s. did not remember to enable the microphone before answering, preventing their answers from being recorded. This action also created interference, diverting the s.’s attention from the task, and favoring the forgetting of the sequence. This issue, was partially addressed by having the e. to enable the microphone. The system requires high-speed internet connection. In its absence, or in case of imperfect pronunciation or low voice, the answers were not logged or incorrectly transcribed. All these errors implied the need for the e. to rectify almost each word, making it impossible to administer the test at this stage of the study.</td>
</tr>
</tbody>
</table>

Verbal long-term memory

| After a 20-min delay from the end of the verbal immediate recall task, in which the s. was engaged in non-verbal tasks, he/she is required to recall as many words as possible from the above-mentioned 15-words list, without order constraints. The e. records the words in the order in which they were recalled and any intrusions (words not belonging to the list) [25]. The test score corresponds to the number of words recalled correctly. |
| After a 10-min delay from the end of the verbal learning task, in which he/she was engaged in non-verbal tasks, the s. is required to recall as many words as possible from the above-mentioned 10-words list, without order constraints. The system records the words in the order in which they were recalled and any intrusions (words not belonging to the list). The test score corresponds to the number of words that the s. is able to recall correctly. The e. can rectify incorrectly transcribed or incomplete answers and to correct the score automatically assigned. |
| Most s. did not remember to enable the microphone before answering, preventing their answers from being recorded. This action also created interference, diverting the s.’s attention from the task, and favoring the forgetting of the sequence. This issue, was partially addressed by having the e. to enable the microphone. The system requires high-speed internet connection. In its absence, or in case of imperfect pronunciation or low voice, the answers were not logged or incorrectly transcribed. All these errors implied the need for the e. to rectify almost each word, making it impossible to administer the test at this stage of the study. |

(continued)
<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual-constructional abilities</td>
<td>The s. is asked to copy 3 stylized figures (a house, a parallelepiped, a compass rose) which are shown at the top of a sheet of paper, in a central position [25]. The e. looks at the drawings created by the s. and assigns scores based on the test rules.</td>
<td>The s. is asked by the VA to copy 3 stylized figures (a house, a parallelepiped, a compass rose), which are shown at the top of the screen, in a central position, with his/her finger or the digital pen. The e. looks at the drawings created by the s. and assigns scores based on the corresponding PT rules [25].</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in omissions, delays or errors in line drawings. This issue created interference, diverting the s.’s attention from the task, to the detriment of test performance. The scores were assigned by the e. on the basis of what observed, and not of the basis of the final drawings produced by the system.</td>
</tr>
<tr>
<td>Multiple domains, general cognition</td>
<td>The s. is required to draw the face of a round clock, with all numbers and hands pointing to ten past eleven [23]. The e. looks at the drawings created by the s. and assigns the scores based on the test rules.</td>
<td>The s. is required by the VA to draw the face of a round clock, with all numbers and hands pointing to ten past eleven. The e. looks at the drawings created by the s. and assigns the scores based on the corresponding PT rules [REF ACE-R]. The e. can rectify the score automatically assigned.</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in omissions, delays or errors in line drawings. This issue created interference, diverting the s.’s attention from the task, to the detriment of test performance. The drawing area, as developed in this stage of the study, is too small, and it is not possible to write all the numbers. All these issues made the DT not administrable.</td>
</tr>
<tr>
<td>Attention (visual search)</td>
<td>The s. is required to identify and circle 13 squared target items that are presented in an array among distractors. The time (seconds) required for completion and the number of identified targets and false alarms are registered. The accuracy in visual search is also evaluated with a mathematical formula that combines correct identifications and false alarms [27].</td>
<td>The s. is required by the VA to tap 10 squared target items that are presented in an array among distractors. Fewer stimuli than those of the corresponding PT were used. The time (seconds) required for completion and the number of identified targets and false alarms are registered. The accuracy in visual search is also evaluated with a mathematical formula that combines correct identification and false alarms. The e. can rectify the score automatically assigned.</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in omissions or delays in providing visual feedbacks. This issue created interference, diverting the s.’s attention from the task, to the detriment of test performance. The scores were assigned by the e. on the basis of what observed.</td>
</tr>
</tbody>
</table>

(continued)
### Table 1. (continued)

<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention and cognitive flexibility</td>
<td>Two sub-tests, to be performed as quickly as possible are presented to the s. [28]: 1) to connect in sequential order a series of circles containing numbers from 1 to 25, which are drawn in random order on a sheet. A preliminary training session with 5 stimuli is provided for training and to evaluate test executability. 2) To connect a series of circles containing numbers from 1 to 13 and letters from A to M, alternating in sequential order by numbers and letters. A preliminary training session with 10 stimuli is provided for training and to evaluate test executability. Each of the 2 sub-test’s scores correspond to the time (seconds) spent to complete the test. Another test score is also computed by subtracting the two sub-tests’ scores. During both tasks, in the event of an error, the e. intervenes to bring the s. back to the last item correctly identified.</td>
<td>Two sub-tests, to be performed as quickly as possible are presented to the s. by the VA: 1) to connect in sequential order a series of circles containing numbers from 1 to 25, which are randomly displayed on the screen. A preliminary training session with 5 stimuli is provided for training and to evaluate test executability. 2) To connect a series of circles containing numbers from 1 to 13 and letters from A to M, alternating in sequential order by numbers and letters. A preliminary training session with 10 stimuli is provided for training and to evaluate test executability. Each of the 2 sub-test’s scores correspond to the time (seconds) spent to complete the test. Another test score is also computed by subtracting the two sub-tests’ scores. During both tasks, in the event of an error, an auditory feedback is provided: the e. intervenes to bring the s. back to the last item correctly identified. The e. can rectify the scores automatically assigned.</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in omissions, delays or errors in line drawings. This issue created interference, diverting the s.'s attention from the task, to the detriment of test performance. Moreover, 25 stimuli were too numerous for the drawing area, i.e., too small and too close to each other. Therefore they were easily inadvertently touched (and thus scored as touched) when they were next to another item that the s. intended to correctly reach. These issues, together with the need of intervention of the e. in case of error, made the DT untestable.</td>
</tr>
</tbody>
</table>

(continued)
### Table 1. (continued)

<table>
<thead>
<tr>
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<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental interference</td>
<td>Three sub-tests, to be performed as quickly as possible are presented to the s.: 1) to read a series of 30 words (color names) printed in black; 2) to name the ink color of a series of 30 colored dots; 3) to name the ink color of a series of words (color names), while word meaning and font color are incongruent, in the third one. Preliminary sessions with three stimuli are provided for training and to evaluate each sub-test executability. For each sub-test, the e. records the time and any errors. A “time (seconds)” score and an “errors (count)” score are calculated through formulas that subtracts the average of the first two sub-tests from the performance in the third [29].</td>
<td>Three sub-tests, introduced by the VA, have to be performed as quickly as possible: 1) For 30 times, a word (“red”, “green”, or “blue”) printed in black is presented at the top of the screen, in a central position; the s. has to tap, among three buttons presented at the bottom of the screen and colored red, green or blue, the one corresponding to the meaning of the word. After the choice, the screen refreshes and a new word appears. 2) For 30 times, a dot printed in red green or blue is presented at the top of the screen, in a central position: the s. has to tap, among three colored buttons presented at the bottom of the screen, the one corresponding to the color of the dot. After the choice, the screen refreshes and a new dot appears. 3) For 30 times, a word (“red”, “green”, or “blue”), printed in red, green or blue, is presented at the top of the screen, in a central position. The word meaning and the ink color are incongruous: the s. has to tap, among three colored buttons presented at the bottom of the screen, the one corresponding to the ink color of the word. After the choice, the screen refreshes, and a new word appears. Preliminary sessions with three stimuli are provided for training and to evaluate each sub-test executability. For each sub-test, the system records the time and any errors. A “time (seconds)” score and an “errors (count)” score are calculated through formulas that subtracts the average of the first two sub-tests from the performance in the third.</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in delays in the screen refresh.</td>
</tr>
</tbody>
</table>
Table 1. (continued)

<table>
<thead>
<tr>
<th>Cognitive function</th>
<th>Paper-based test (PT)</th>
<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visuo-spatial planning</td>
<td>Eight patterns of criss-crossing straight lines resembling fishing nets are presented, one at a time, on a sheet, with large black dots at some of the line intersections. The s. is requested to draw a route from one end of the maze to the other, in order to connect as many dots as possible, moving along the meshes of the net and without turning back [30]. A preliminary sessions with 4 nets is provided for training and to evaluate each sub-test executability. The task involves the administration of 8 mazes. Test scores are assigned based on errors and execution times.</td>
<td>Eight patterns of criss-crossing straight lines resembling fishing nets are presented, on a time, on the screen, with large black dots at some of the line intersections. The s. is requested to draw a route from one end of the maze to the opposite one, in order to connect as many dots as possible, moving along the meshes of the net and without turning back. A preliminary sessions with 4 nets is provided for training and to evaluate each sub-test executability, during which the e. can intervene to correct or help the s. The task involves the administration of 8 mazes. Test scores are automatically assigned based on the number of solved mazes, but the e. has the option to edit them.</td>
<td>The system was sometimes insensitive to the touch of the finger/digital pen, possibly due to internet connection problems. This resulted in omissions, delays or errors in line drawings. This issue created interference, diverting the s.’s attention from the task, to the detriment of test performance. The scores were assigned by the e. on the basis of what observed, and not of the basis of the final drawings produced by the system.</td>
</tr>
<tr>
<td>Phonologic Fluency</td>
<td>The s. is required to pronounce as many words as possible in a minute, beginning with a given letter [31]. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the number of correctly pronounced words, excluding repetitions, words sharing the same root and proper names.</td>
<td>The s. is required to pronounce as many words as possible in a minute, beginning with a given letter. The application reads the instructions aloud, gives some examples (referring to a letter different from the one used in the test), and produce a sound which alerts the s. that it is his/her turn to answer. The s. answers orally after pressing a virtual button, on the screen, which enables the microphone. The application records and transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the number of correctly pronounced words, excluding repetitions, words sharing the same root and proper names.</td>
<td>The phoneme-grapheme converter is not always accurate and sometimes reports phonologically similar words. The test requires a high-speed internet connection to run correctly; therefore, it was impossible to perform the trial due to the connection problems encountered during execution.</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Cognitive function</th>
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<th>Digitized test (DT)</th>
<th>Limits of the DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic Fluency</td>
<td>the s. is required to pronounce as many words as possible in a minute, pertaining to a given semantic category. The e. transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the number of correctly pronounced words, excluding repetitions, words sharing the same root and proper names [31].</td>
<td>The s. is required to pronounce as many words as possible in a minute, pertaining to a given semantic category. The application reads the instructions aloud, and produce a sound which alerts the s. that it is his/her turn to answer. The s. answers orally after pressing a virtual button, on the screen, which enables the microphone. The application records and transcribes the answers and evaluates their correctness according to the test rules. Test score corresponds to the number of correctly pronounced words, excluding repetitions, words sharing the same root and proper names. The e. can rectify incorrectly transcribed or incomplete answers and correct the score automatically assigned.</td>
<td>The phoneme-grapheme converter is not always accurate and sometimes reports phonologically similar words. The test requires a high-speed internet connection to run correctly; therefore, it was impossible to perform the trial due to the connection problems encountered during execution.</td>
</tr>
<tr>
<td>Oral Naming</td>
<td>A verbal description of 38 words, belonging to the categories of concrete living /non-living and abstract concepts, is read aloud by the e., one at a time [32]. S. are instructed to listen to each definition and to provide the name of the described concept. For each item, the s. obtains a score of 1 if he/she autonomously provides the correct answer, a score of 0.5 if he/she is able to identify it among 3 alternatives and a score of 0 if no/wrong answer is provided. The overall score is calculated by summing the scores per-item.</td>
<td>Test instructions and a verbal description of each of 20 words, belonging to the categories of concrete living /non-living and abstract concepts, is read aloud by the VA. S. are instructed to listen to each definition and to provide the name of the described concept. For each item, the s. obtains a score of 1 if he/she autonomously provides the correct answer, a score of 0.5 if he/she is able to identify it among 3 alternatives and a score of 0 if no/wrong answer is provided. The overall score is calculated by summing the scores per-item. The e. can rectify incorrectly transcribed or incomplete answers and correct the score automatically assigned.</td>
<td>The phoneme-grapheme converter is not always accurate and sometimes reports phonologically similar words. The test requires a high-speed internet connection to run correctly; therefore, it was impossible to perform the trial due to the connection problems encountered during execution.</td>
</tr>
</tbody>
</table>
is able to record feedback and responses to allow, therapists and practitioners to receive a complete assessment of the participant’s abilities [33].

After the definition of the test battery, which is described in the next sub-paragraph, a design activity based on parametric templates was carried out to proceed with its implementation on the OMNICARE platform, in order to build the interfaces to administer the DTs and the modules for data transmission related to their execution. The design of the parametric templates was oriented towards the possibility of creating exercises with personalized contents for each user and of being able to constantly insert new contents for each template. This will also allow, in the future, to enrich the system with new exercises, and to insert specific contents for each individual user.

The software consists of a frontend application (FE) for three different environments – Android tablet, Windows application and web application – which communicates with the OMNICARE backend server (BE), containing the user profile and his/her associated data. It is possible to create customized profiles, selecting specific DTs and their order, for each user. However, for the purposes of the present study, an identical battery of DTs was administered to all participants, in the same order. The FE downloads the DTs from the BE, generates and runs each DT based on specific parametric models (so the FE downloads the test configuration data from the server and generates each test based on the related model), sends and saves the data related to the DT execution on the BE, where the test evaluation takes place. The Communication between the FE and the BE server takes place via specific Web Services.

For each DT the BE sends a “mandate” (assignment) consisting of a text or an image showing the DT rules, which are displayed in the FE and which are read by the VA. Where the DT rules allow it, the mandate may be displayed on the screen for the entire duration of the task or for a pre-determined amount of time.

To evaluate the correctness of the examinee’s answers, a computed metric called “distance” is used. It checks letter by letter or word by word if the “distance” of the definition matches the correct answer (like a corrector). Also, it checks if there is removal, insertion or substitution of elements. Speech recognition is also configured in such a way that it asks if what is being spoken is the same (or close to) a given text. For example, it is useful to recognize words/strings back to front.

It is also possible, via a button on the FE, to abort the execution of each DT or to suspend and then resume it from the point of interruption. The number and duration of the breaks is also recorded.

2.4 Inclusion and Exclusion Criteria for Enrolment (Phase 3)

Seniors aged 65 or over to be assessed with the paper-based and computerized batteries were enrolled at the “Guardia di Finanza” Ambulatory of Rome. Inclusion criteria were: normal objective neurological examination; diagnosis of MCI [4] or SCD [15]; MMSE [16] score ≥ 20; FAQ score [17] ≤ 9. The ability to express written informed consent was the essential prerequisite for participation.

The exclusion criteria were: age or test scores outside the inclusion ranges; cerebral damage; epilepsy; severe psychiatric disorders; drugs or alcohol abuse history; sensory-motor deficits severe enough to prevent digitized testing.
2.5 Statistical Analyses (Phase 4)

All data was entered into a Microsoft™ Excel worksheet, while the analyses were performed using IBM™ Statistical Package for the Social Sciences (SPSS) for Windows, version 21.0. Participant characteristics were presented as absolute frequencies and percentages when categorical, as means ± standard deviations when continuous. The CHI-2 test and T-test for independent samples were used for between-subjects analyses, to compare the demographic, cognitive, functional and behavioral characteristics of the subjects who underwent the evaluation with the DTs compared to the people who did not accept the computerized evaluation or did not perform it due to study interruption. Pearson’s correlation was used in within-subjects analyses to evaluate the association between each DT and MMSE scores and between each DT and the corresponding PT. Due to the limitations encountered during the administration of the initial versions of some DTs (described in Table 1), which will be dealt with in future developments of the platform, it was not possible to administer the whole computerized battery. Therefore, these statistical analyses were carried out only with respect of a sub-group of DTs, that we were able to administer to almost everyone who undergo the computerized assessment.

3 Results

Due to the COVID-19 pandemic, the study was interrupted after the paper-based neuropsychological assessment of 38 subjects, of which 15 (39.5%) females. The mean age was 72.29 ± 8.47 years and the mean education was 11.00 ± 4.64 years. Twenty-one (55.3%) of them were re-evaluated the following week with the computerized battery (Fig. 1).

Of the remainder, 12 refused the second evaluation with DTs (31.6%), 3 resulted too cognitively impaired in the paper-based assessment, according to MMSE criteria, to undergo digitized evaluation (7.9%), 1 interrupted the computerized assessment, complaining about visual difficulties which made tests involving visuospatial functions not administrable (2.6%), 1 was not re-evaluated, due to the start of the lockdown a few days after paper-based assessment (Fig. 1).

![Fig. 1. Distribution of study participants who underwent / did not undergo the digitized evaluation, and causes of non-participation in computerized assessment](image-url)
As shown in Table 2, with the exception of apathy, non-significant differences in socio-demographic, cognitive, functional and behavioral characteristics were observed between the seniors who underwent the digitized assessment and those who did not undergo it, with the exception of AES scores, which resulted higher in people who did not carry out the computerized evaluation ($T, 32 = 2.06; p < 0.05$).

**Table 2.** Socio-demographic, cognitive, functional and behavioral characteristics of the screened subjects, and divided by participation (yes/no) to the computerized assessment. MMSE: Mini Mental State Examination; FAQ: Frontal Assessment Questionnaire; GDS: Geriatric Depression Scale; AES: Apathy Evaluation Scale.

<table>
<thead>
<tr>
<th>Digitized assessment performed</th>
<th>Yes</th>
<th>No</th>
<th>All screened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>73.95 ± 6.68</td>
<td>70.24 ± 10.09</td>
<td>72.29 ± 8.47</td>
</tr>
<tr>
<td>Schooling (years)</td>
<td>11.24 ± 4.57</td>
<td>10.71 ± 4.86</td>
<td>11.00 ± 4.64</td>
</tr>
<tr>
<td>MMSE</td>
<td>26.00 ± 2.76</td>
<td>26.28 ± 3.66</td>
<td>26.12 ± 3.15</td>
</tr>
<tr>
<td>FAQ</td>
<td>1.62 ± 2.50</td>
<td>3.44 ± 6.49</td>
<td>2.41 ± 4.68</td>
</tr>
<tr>
<td>GDS</td>
<td>6.38 ± 5.52</td>
<td>9.77 ± 8.15</td>
<td>7.68 ± 6.74</td>
</tr>
<tr>
<td>AES</td>
<td>27.52 ± 6.49*</td>
<td>32.31 ± 6.73*</td>
<td>29.35 ± 6.90</td>
</tr>
</tbody>
</table>

*: significant differences with $p$-value $< 0.05$

In Table 1, the principal limitations of each DT, at the present level of development of the computerized battery, are described in detail. Briefly, the system, especially in case of connection problems, failed to record or recorded incorrectly the answers that were typed or pronounced by the senior. Having to push a button to enable the microphone implied a non-user-friendly and forgettable interaction with the system, which almost always needed the intervention of the examiner. The drawing area resulted too small to allow the execution of some DTs. System errors and delays in returning feedback created interference, diverting the participant’s attention from the task, and favouring the forgetting of the task, to the detriment of performance. These problems also resulted in the impossibility of administering some tests or the unreliability of the scores as automatically computed by the system (Table 1).

The results of the correlation analyses between each DT and MMSE scores and between each DT and the corresponding PT are summarized in Table 3. A significant and moderately strong correlation was observed between MMSE scores and the digitized versions of TSO (Table 3). The MMSE also showed a moderate positive association with the computerized versions of EPMT and CD, and a moderate negative correlation with the number of errors in the digitized SST, and with the times of execution and errors in the computerized MFTC (Table 3).

A significant and moderately strong correlation was observed between the paper-based and the digitized versions of TSO and CD (Table 3). A moderate positive association was also identified between the paper-based and the computerized versions of the
Table 3. Results of the correlation analyses between each Digitized Test scores and Mini-Mental State Examination scores and between each Digitized Test scores and the corresponding Paper-based Test scores.


<table>
<thead>
<tr>
<th>DT</th>
<th>Association with MMSE</th>
<th>Association with the PT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (p-val)</td>
<td>PT</td>
</tr>
<tr>
<td>Digitized STO</td>
<td>0.622 (0.003)**</td>
<td>ACE-R STO</td>
</tr>
<tr>
<td>Digitized CF°</td>
<td>0.323 (0.164)</td>
<td>DF</td>
</tr>
<tr>
<td>Digitized CB</td>
<td>0.385 (0.104)</td>
<td>DB</td>
</tr>
<tr>
<td>Digitized CD</td>
<td>0.452 (0.040)*</td>
<td>ACE-R CD</td>
</tr>
<tr>
<td>Digitized MFTC</td>
<td>Time: −0.481 (0.032)*</td>
<td>MFTC</td>
</tr>
<tr>
<td></td>
<td>Errors: −0.483 (0.031)*</td>
<td></td>
</tr>
<tr>
<td>Digitized SST</td>
<td>Time: −0.027 (0.913)</td>
<td>SST</td>
</tr>
<tr>
<td></td>
<td>Errors: −0.555 (0.009)**</td>
<td></td>
</tr>
<tr>
<td>Digitized EPMT</td>
<td>0.545 (0.013)*</td>
<td>EPMT</td>
</tr>
</tbody>
</table>

*: significant association with p-value < 0.05.
**: significant association with p-value < 0.01.

test evaluating short-term memory and visuo-spatial planning, and in times of execution of paper-based and digitized SST.

4 Discussion

The developments and dissemination of Information and Communication Technology in the field of health and in everyday life, led to the development of the computerized versions of many neuropsychological tests [7, 34–36], however, as far as we know, we are among the first to be developing a complete digitized battery which can be selfadministered by the patient with mild cognitive decline under the supervision of a trained clinician, allowing easy and intuitive interaction (through the VA and STT services). Our computerized neuropsychological battery also has the advantage of not requiring any installation by the elderly examined, being able to work on common web browsers in windows and android environments.

The results of our analyses reveal that the self-administered and automated computerized assessment we developed is promising in detecting early cognitive decline in subjects at risk, if conducted under the supervision of a psychologist who may help the examinee to acquire familiarity with the digital tool or intervene in the event of problems.

Despite the numerous limitations that need to be addressed in the future, most of the digitized tests we developed showed significant and at-least moderate correlations with
the MMSE. This means that their administration, already at this early stage of development, is able to provide some measure of the person’s global cognition and that, once optimized and validated on a larger population, they could be used, together with or in place of standard neuropsychological tests, for the assessment of the cognitive functions of the elderly. In addition, most digitized tests showed moderate to moderately strong correlations with performance on paper-based tests that explore the same cognitive functions. Specifically, moderately strong associations were observed between paper-based and computerized versions of test evaluating visuo-constructive abilities and orientation in space and time. Moreover, if the TSO questions were identical between paper-based and digitized versions of the test, the stimuli of the drawing tests and the methods for scores calculation were different between ACE-R CD and computerized CD. This means that the computerized assessment of visuo-constructional praxis may provide a reliable evaluation of the patient’s constructive capabilities.

Moderate associations were also detected between domain-specific digital tests and paper-based tests exploring short-term memory, environmental interference, visual research and visuo-spatial planning. The lower association detected could be, at least in part, explained by the limitations that emerged during the execution of some digital tests, such as the lack of sensitivity of the tool, latency times, connection difficulties and errors made by the system in recording the subjects’ responses.

A really important limitation of this study was not being able to perform some of the DTs from the digital neuropsychological battery which were initially foreseen, and the lack of participation in the computerized assessment by a consistent percentage of seniors assessed with the PTs. However, it should be noted that, with the exception of AES scores, those who did not undergo the digitized assessment had demographics and cognitive/functional scores that were substantially overlapping to those of the seniors who carried out the computerized evaluation. This means that there was no self-selection bias for the participation in the study related to age, sex, cognitive or functional characteristics, and that, plausibly, apathy was the main responsible for not participating to the second evaluation. However, like other psychiatric symptoms, apathy represent a risk factor for rapid cognitive decline or dementia in elderly people and in seniors with MCI [37, 38]. Therefore we may have lost the elderly who will show a more rapid evolution of diseases in the future. Nevertheless, apathy is related to dysfunctions in the frontal and prefrontal circuits [39] which are implied in higher-order cognitive functions, like judgement skills, and this may partly explain why more apathetic patients did not perform the task. On the other hand, it is possible to hypothesize that the lack of motivation alone influenced the choice of some apathetic subjects not to further participate the study.

Some improvements are mandatory to optimize the execution of the DTs, in order to make the participants as free as possible to focus exclusively on their cognitive performance. Among the main ones, the drawing area should be mentioned, which is too small in size to be easily usable at present, especially by participants who are not digitally skilled. Moreover, our system requires a fully functional fast internet connection to work properly. A slow and/or unstable connection invariably resulted in the incorrect or failed recording of the subjects’ responses. This represents a problem in rural areas, in people who use mobile wifi tethering or, especially, in seniors, who are more likely to use outdated connection methods compared to younger people. This issue
might be solved by introducing a local cache for data collection, however the study was interrupted before this functionality and other improvements were implemented. Finally, especially in relation to the COVID-19 pandemic and the possibility of making health-services not requiring the physical presence of the examiner / examiner to be administered remotely, it would be important to make the program accessible directly from home, with personalized access.

5 Conclusions

The results of this study contribute to increase the knowledge currently available in scientific literature on the use of computerized tools in the clinical and diagnostic field, although it is necessary to reflect on some limitations that could make this approach less more challenging than the traditional paper-based one. In conclusion, the supervised computerized battery is a promising usable tool in bridging the gap between the appearance of the first insidious symptoms of cognitive decline in people with MCI and the first specialist clinical evaluation.

By enrolling a greater number of seniors with and without initial cognitive impairment in a multicentre study, it would be possible to create a real standardization of the battery, making it usable as a rapid diagnostic screening tool in the Italian Centres for the assessment of cognitive decline. Future studies and a slight modification of the instrument may allow for remote administration, at the person’s home, under the supervision of the specialist via an external videoconference platform or a videoconference service to be implemented in the digitized battery. The benefits in terms of time, costs and personnel would be certain: the computerized assessment could be used, in a first phase, to measure the cognitive performances of the subjects. Parallel versions of each DT may also be used to provide multiple cognitive assessment at pre-defined intervals of time (quarterly, for example) and multiple versions of each DT may be developed to provide cognitive training. By creating numerous parallel versions of the proposed exercises - for example new lists of words to be memorized, new drawings to be copied, new sequences to be repeated, and so on - it would be possible to further extend this study and assess the effective potential to use this system, which is now just a promising diagnostic tool, also as a valid rehabilitation tool. This would also make it possible to verify whether the patient is able to learn how to perform new procedures, and how many tests they need to improve their performance, while providing a further assessment of their mnemonic/cognitive abilities, in order to get a comparison between the performances obtained over time and monitor any improvement.

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References


Clinical Decision Support System for Multisensory Stimulation Therapy in Dementia: A Preliminary Study

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Abstract. Worldwide around 50 million people are affected by Dementia, causing a growing public health problem with significant impact not only on individuals but also on caregivers, families, and communities. The first-line therapy is pharmacological, based on the use of a few drugs with effects on brain neurotransmitters. Nevertheless, these therapies are contraindicated in some subjects, offer few results and associated side-effects are not negligible. Among various available non-pharmacological treatments, the Snoezelen one (i.e., multisensory stimulation) is particularly interesting, since its main goal is the reduction of pressure and tension experienced by the patient in the housing groups. However, there is no clear evidence right now that such non-pharmacological interventions are effective in subjects with dementia. The aim of this study is to design and prototype a Clinical Decision Support System (CDSS) that collects patient's neurovegetative parameters during stimulation sessions, and searches for patterns that are predictive of behavioral state change (e.g., from agitated to relaxed, or from apathetic to activated), allowing therapists to decide with greater reliability the best stimulation combination for a patient. The proposed algorithmic framework was evaluated using publicly available data, also in perturbed form to investigate more challenging patterns. The compared predictive approaches (i.e., multivariate time series classification) achieved accuracy rates greater than 85% with original data, and greater than 83% when complex combinations of both shape and temporal perturbations were present. Instead, in the case of only one kind of perturbation, either shape or temporal, the achieved accuracy was greater than 90%.

Keywords: Clinical Decision Support System · Dementia · Multisensory stimulation · Snoezelen therapy · Multivariate physiological time series · Multivariate time series classification

1 Introduction

Dementia syndrome (DS) is a public health problem with a growing incidence. There are about 50 million people affected around the world, and every year there are nearly
10 million new cases. And, to make matters worse, this trend is set to triple by 2050. In addition, the disease carries a high economic burden on societies, since the costs of caring for people with DS are estimated to rise to US$ 2 trillion annually by 2030 [1]. Indeed, DS is recognized as a major cause of disability and dependency among older adults, with the potential to devastate the lives of affected individuals, as well as of their families and caregivers.

However, it is important to note that DS is not a single disease but a group of disorders characterized by degenerative changes in the brain, causing a decline from a previously attained cognitive level, affecting both activities of daily living (ADLs) and social functioning [2]. The primary and most common types of DS include Alzheimer’s disease (AD), vascular dementia, dementia with Lewy bodies, and frontotemporal dementia (FTD) [1].

The current first-line therapy, focusing on brain degenerative processes, consists of a few drugs which act on some brain neurotransmitters involved in the pathogenesis, such as cholinergic and glutamatergic neurotransmissions [3–5]. Nonetheless, such pharmacological therapies are contraindicated in some subjects, offer limited results, and associated side-effects are in general not negligible [6, 7].

Several non-pharmacological interventions have been proposed, even if not to resolve severe clinical conditions, but at least to help in the management of patients with DS, such as Cognitive Training, Cognitive Rehabilitation, Cognitive Stimulation Therapy, Snoezelen/Multisensory Stimulation, Reality Orientation, Reminiscence Therapy, Validation Therapy, Physical Activity, Light Therapy, Music Therapy, Aromatherapy, Animal Assisted Therapy, Doll Therapy [8].

Among all proposed non-pharmacological methodologies, the Snoezelen method is particularly interesting. In this methodology, developed in the Netherlands in the 70s, multiple objectives can be met, the most important of which is to promote relaxation and reduce behavioral disorders, in particular psychomotor agitation episodes. To this end, Snoezelen takes place in a specially equipped room, where the patient can leave everything behind and find complete relaxation, stimulated by sounds, light effects, fine vibrations, pleasant scents, etc., on the basis of the principle that “nothing has to be done, everything is allowed” [9].

Regarding the available literature, studies on the efficacy of multisensory stimulation interventions with the Snoezelen method in subjects with dementia are not conclusive, although some of them reported very interesting results. Furthermore, a Cochrane review report concluded that no evidence exists for efficacy of this methodology [10].

Aiming to improve the efficacy of multisensory stimulation with Snoezelen, the present study proposes the use of an innovative technological support during stimulation therapy sessions. At this purpose, a series of miniaturized sensors located on the patient’s body, without annoying him/her in any manner, measure various neurovegetative parameters in real-time. Hence, a Clinical Decision Support System (CDSS) is specially designed to find predictive patterns in multivariate neurovegetative time series (i.e., able to anticipate behavioral reactions induced by therapy stimuli), and thus to provide useful hints to the therapist in selecting the most effective stimulation.

The remaining of the paper is organized as follows. Section 2 presents the current state-of-the-art and briefly provides some theoretical background related to Snoezelen
interventions, neurological basis of multisensory stimulation, sensory impairments in DS patients and multivariate time series classification. Section 3 describes the research materials and methods used to design a CDSS for multisensory stimulation therapy and to validate it with publicly available data in original and perturbed configurations. In Sect. 4, the preliminary findings of the present research, obtained with both original and perturbed data, are presented and discussed. Then, in Sect. 5, some conclusions are drawn.

2 Background and Related Work

2.1 Snoezelen-Based Multisensory Stimulation Interventions

The Snoezelen method takes place in a dedicated space, known as multisensory room, where therapists practice the sensory stimulation, i.e., stimulate the senses of the patient through different modalities (e.g., visual, auditory, olfactory, tactile, or multi-modal), in order to promote various functions/objectives such as relaxation, self-confidence, creative activities, exploratory activities, leisure activities, reduction of challenging behaviors, and so on [11, 12].

Duchi et al. [13] developed a “Multisensory Black Room” equipped with different sensory stimulus, aiming to improve the cognitive-functional abilities of older adults with neurodegenerative diseases and cognitive impairments. The implemented stimulation elements included both visual (i.e., virtual reality glasses, fiber optic shower, stair of colors, star curtain, interactive lighting system) and auditory (i.e., sound therapy) modalities. They evaluated their room with older adults randomized in two groups: one group performing room stimulation (12 weeks, 5 days a week, 30 min each day), and a control group without room stimulation. The results indicated reduction of aggression patterns, and improvements in fine/gross motor skills, in focus of attention, and in the relationship with their social and personal environment.

Maseda et al. [14] explored the effects on mood, behavior, and biomedical parameters of two non-pharmacological interventions, namely multisensory stimulation in Snoezelen room and individual music sessions, in institutionalized older adults with severe dementia. They randomized 21 patients aged over 65 years in two groups: one group underwent to multisensory stimulation sessions, and the other one to individual music sessions (in both cases, interventions were administered for 12 weeks, two days a week, 30 min each session). The authors concluded that both interventions were effective in managing mood (participants were more happy, enjoyed themselves, less bored/inactive) and behavioral disturbances (more attentive to/focused on their environment, more relaxed/content, talked more spontaneously) and at improving physiological rates (decrease in heart rate and increase in oxygen saturation were observed). In a previous research, Maseda et al. [15] conducted a controlled longitudinal study to assess long-term effects of multisensory stimulation with Snoezelen on older adults with dementia. They randomized 30 patients in 3 groups: multisensory stimulation environment (MSSE) group, activity group (i.e., one-to-one activity sessions), and control group (i.e., any of the mentioned activities). The authors reported an improvement in physically non-aggressive behavior scores (i.e., agitation) in the MSSE group in comparison with the activity group. Both groups also exhibited an improvement in the mood
scores during intervention, which however was not statistically significant and worsened for both groups in the follow-up period. Concerning the cognitive level and functional Status in ADL (assessed with Barthel ADL score), they found no significant effects in the MSSE group and no significant differences between the activity and control groups.

Singh et al. [16] investigated the effects of Snoezelen-based multisensory stimulation on aggressive and self-injurious behaviors in adults with severe or profound mental retardation and mental illness. Participants were rotated in three groups: Snoezelen, ADL-skill training, and vocational-skill training. They reported reduction of both aggression and self-injury levels when were in a Snoezelen room. However, the reported difference in aggression levels, before and after Snoezelen, was not statistically significant.

Kragt et al. [17] investigated the effects of the multisensory stimulation in Snoezelen room on the well-being of older adults in a very advanced stage of dementia. The presence of behavioral problems, registered by video cameras and analyzed by means of specific sub-scales, was used as measure of the well-being. Their results indicated a higher degree of well-being (i.e., less behavioral problems) during the Snoezelen therapy with respect to when the participants remained in the living room. But their results also indicated the need for a large-scale study including additional outcome parameters.

Bailly and Pointereau [18] evaluated the effects of Snoezelen therapy on eighteen women with dementia. They reported a significant change in the physiological measurement immediately after the sessions, not present however between sessions. Further measurements revealed an increase in self-esteem up to a week after the last session. They concluded that Snoezelen can have a beneficial effect in dementia, but also pointed out that further research with appropriate control groups was needed. Furthermore, in earlier research, Baillon et al. [19] assessed the effects of Snoezelen therapy on agitated behavior of older adults with dementia in comparison to reminiscence therapy. Although they concluded that people with severe dementia might gain more benefit from Snoezelen than reminiscence therapy, nevertheless their research data were of insufficient power to provide conclusive evidence and thus further research should be carried out.

An important contribution was the work of van Weert who published relevant researches on the effectiveness of Snoezelen on the behavior and mood of demented nursing patients [20], as well as on the communication of nursing assistants and demented nursing patients during morning care [21]. In both research studies, van Weert and colleagues reported positive effects and improvement of investigated symptoms, concluding in favor of Snoezelen as added value for the quality of care.

In spite of the many studies suggesting that the use of Snoezelen-based multisensory stimulation into daily care activities can be beneficial for reducing agitated behaviors, promoting mood, and encouraging interaction, a milestone Cochrane review of Chung and Lai [10] pointed out that such benefits are non-significant, since they are referred to symptoms and not to overall performance. Thus, the authors concluded, there were no strong evidence favoring the efficacy or benefit of Snoezelen on behaviors, mood, and interaction with dementia adults.

As the above review of literature on Snoezelen-based multisensory stimulation suggests, despite its popular use in dementia care, the clinical application needs to be supported by strong scientific evidence, i.e., there is a need for more reliable research-based evidences to justify the use of Snoezelen in dementia care.
Regarding the acquisition of physiological parameters during multisensory stimulation, which is the focus of the present paper, it is important to highlight that some research studies measured neurovegetative signals during interventions [14, 18, 75, 76], aiming in such a way to produce more clinical evidence on the effect of Snoezelen. Nevertheless, they too concluded that further empirical studies, with adequate numbers of subjects and appropriate controls, were needed to confirm the benefits of the Snoezelen method compared to other types of interventions. Moreover, in other studies, physiological signals were also measured but to recognize emotions [29], to detect stress [30, 31] and agitation [28, 32, 33], outside the context of both dementia and multisensory stimulation.

On the other hand, no previous studies, to the best of the authors’ knowledge, have aimed to investigate the prediction of patient’s behavioral state changes from physiological neurovegetative parameters to support therapeutic decisions in real-time. Such an opportunity and related studies are discussed in the remaining of this section.

2.2 Physiological Neurovegetative Parameters

The aim of this subsection is to highlight the importance of neurovegetative parameters in predicting behavioral changes of patients underwent to multisensory stimulation treatment, and how such parameters were exploited in earlier studies.

Both behavioral and non-behavioral reactions are induced by endogenous and exogenous stimuli. Behavioral reactions, such as expressing aggressiveness, facial emotions, etc., can be inhibited by voluntary control to some extent. Instead, non-behavioral reactions, as neurovegetative manifestations, are not under the influence of the cerebral cortex and thus are very difficult (if not impossible at all) to control voluntarily [22, 23]. Furthermore, neurovegetative responses (physiological parameters), in terms of ergotropic and trophotropic reactions, can be considered as anticipatory of some behavioral reactions such as activation and relaxation [24–26].

The involuntary behavior is related to autonomic nervous system (ANS) functions such as sympathetic and parasympathetic activities: stressful or relaxing situations cause dynamic changes in ANS. More specifically, the sympathetic nervous system (SNS) dominates during stressful event, whereas the parasympathetic nervous system (PNS) dominates during resting behavior [27]. These concepts have been exploited in several studies to investigate symptoms of stress, e.g., agitation, anger, fear and frustration, by measuring physiological neurovegetative parameters, since many of them are regulated by SNS and PNS, such as heart rate, galvanic skin response, blood pressure, and so on [28, 29].

As studies have shown [30, 31], skin temperature and galvanic skin response are indicator of stress level, i.e., high levels of stress are related to: 1) low levels of skin temperature due to contraction of blood vessels, and 2) low levels of skin resistance due to an increase of the body moisture. Sakr et al. [28, 32, 33] investigated a supervised multi-sensor system for detection of agitation in dementia patients. To this end, they monitored three neurovegetative parameters: heart rate, galvanic skin response and skin temperature. They used multi-level Support Vector Machines (SVMs) to fuse the three neurovegetative parameters and detect agitation. Their results demonstrated a strong
correlation between the monitored physiological signals and the emotional states of the patients.

2.3 Sensory Impairments in DS Patients

In the past few years, several studies have reported that sensory impairments are associated with dementia risk [50–53] and, furthermore, that the risk increases with the number of impaired sensory functions [50, 51]. Other researchers investigated the sensory processing in dementia (especially focusing on somatosensory functions) [54–56], as well as the emergence of changed behaviors related to various sensory functions [57], such as sensitivity to brightness, loudness, food texture (i.e., hypersensitivity), and attention to details (i.e., sensitivity). Moreover, hearing loss [52, 58, 59], retinal thinning [60, 61], decreased visual contrast sensitivity [62, 63] and reduced pupillary response [64, 65] have been correlated with disease onset in people with DS.

Braak and Del Tredici [66] suggested the involvement of the locus coeruleus (i.e., an olfactory processing area that projects to the olfactory bulb) at the early stage of DS, explaining the exceptional vulnerability of the olfactory function. On the other hand, it was well established by Waldton’s pioneering studies [67] and more recently confirmed by several works [68–71] that the odor identification, i.e., detection and recognition of previously smelled odors, is profoundly impaired in people with DS. What that makes this function particularly sensitive to the DS neuropathology probably is the concurrent involvement of olfactory cortex, orbital frontal cortex, and mesial temporal structures. Moreover, Murphy et al. [72] reported that processing tasks responsible of combining odor naming with odor memory are lateralized in the left hemisphere.

The association between retinal thinning and DS neuropathology has been reported by Iseri et al. [60] and Beshira et al. [61], who examined the thickness of retinal nerve fiber and ganglion cell layers, and the macular volume through optical coherence tomography in spectral domain. Although Gilmore et al. [62] observed contrast sensitivity impairment in people with DS, nonetheless Risacher et al. [63] observed sensitivity impairment also in people with mild cognitive impairment and with cognitive complaint not showing performance deficits. However, in general, increasing the visual contrast compensates deficits in contrast sensitivity, enhancing the performance on visual-dependent tests (i.e., letter identification, word reading, and so on). But, as pointed out by Toner et al. [73], this does not happen in the case of people with DS, who continue to exhibit poor performance regardless of visual contrast level, suggesting that their deficit has a cognitive nature. The abnormal pupillary responses of patients with DS prompted Granholm et al. [64] to suggest the pupil dilation to ocular administration of topicamide (i.e., acetylcholine blocker) as a possible biomarker of DS. Furthermore, they observed that the difference in the pupillary light reflex after treatment with tropicamide were significantly lower (1.01 mm) in DS patients than in healthy controls (1.42 mm).

2.4 Multivariate Time Series Classification

Since stress or agitation symptoms become more evident as time progresses, normally physiological signals are continuously monitored. Hence, to deal with huge data obtained in such a way, measurement signals are firstly segmented and then suitable features are
extracted [48]. This approach of features extraction from signal segments is effective for detecting a state that has already manifested itself at the current moment (e.g., stress, agitation, mood, etc.), but it is not as effective when it is needed to detect predictive indicators or markers of states that have not yet manifested (e.g., future changes in the patient’s behavioral state). In the latter case, indeed, the signal evolution over time (i.e., shapes and temporal collocations) should be considered. For that reason, it is more convenient to formulate the problem in terms of multivariate time series (MTS) classification. In the following, the most popular algorithms for (multivariate) time series classification, which can be roughly subdivided into instance-based and feature-based approaches, are briefly reviewed.

In the case of instance-based approach, a similarity measure is used to test instances of time series. Although both Euclidean distance and dynamic time warping (DTW) have been successfully used [34, 35], the Euclidean distance not always allows to achieve high classification performance [36]. Keogh and Ratanamahatana [37] addressed the problem of exact indexing of DTW, introducing a new method without false dismissals. In the same work, they pointed out that k-nearest neighbor (K-NN) in combination with DTW was a strong solution for univariate time series classification, since DTW provided a measure of similarity invariant to certain nonlinear time variations (i.e., time translations/dilations between signal patterns). Later, Górecki and Łuczak [38] introduced a new parametric distance measure obtained from regular DTW and from its derivative version, demonstrating its superior classification performance with MTS.

An advantage of the feature-based approaches is that they are generally faster. In the literature, the feature selection step, acting on dimensionality reduction and comprehensibility enhancing, has been usefully applied to improve classification accuracy [39, 40]. After that step, normally, standard classifiers are adopted [41]. On the other hand, a disadvantage of the feature-based approaches is its potentially high domain-specific quality. To overcome this issue, Rodríguez et al. [42] suggested generic temporal features and extracted them from intervals of time series, whereas Kadous and Sammut [43] suggested a general method to define problem-specific meta-features. Unfortunately, however, the main limitation of interval features lies in the assumption that patterns are entirely included in the same time interval, while on the contrary certain patterns may be anywhere in time.

3 Materials and Methods

The purpose of the CDSS presented in this paper is to provide the operator (e.g., therapist, caregiver, clinician, etc.) with a series of useful indications to support him/her towards the choice of the most appropriate stimulation for the patient. The focus of the preliminary study presented here is on design and initially validate the algorithmic framework for real-time collecting and analyzing patient’s neurovegetative parameters, such as heart rate (HR), breathing rate (BR), skin temperature (ST), body movement rate (BMR), and so on, during multisensory stimulation sessions with Snoezelen equipment, in order to predict eventual changes in the patient’s behavior status induced by the current stimulation.

As explained in Sect. 2, the rationale behind is that stimuli induce both neurovegetative and behavioral manifestations, where the former cannot be voluntarily inhibited.
and may be considered as anticipatory of the latter. The principle of such a process is schematized in Fig. 1.

It is only fair to note that, given the nature of the system in question (decision “support” system), every decision regarding the type of sensory stimulation rests solely with the operator: the CDSS must not force the operator, whose choices are based on variations in the patient’s neurovegetative parameters and in the patient’s behavioral state (BS). It is also important to note that the neurovegetative variations may be predictive of BS changes, but misalignment between neurovegetative parameters may be present during monitoring. However, the predictive power of neurovegetative parameters is outside the scope of this study and it will be included in specific evaluation within further research.

3.1 Overview of the Clinical Decision Support System

During each multisensory stimulation session, given the patient’s clinical conditions, the operator sets a goal that can be “relaxation” (e.g., in case of agitated behavior) or “activation” (e.g., in case of apathetic behavior) of the patient, and consequently he/she chooses the stimulation sequence deemed more suitable. The CDSS, based on the patient’s neurovegetative parameters collected during the stimulation sessions, provides the operator with useful information for conducting the therapy session.

![Fig. 1. During the multisensory stimulation, the patient’s physiological parameters are continuously monitored and analyzed by the CDSS to predict future patient’s behavioral state (BS).](image)

It is as well to emphasize the importance of evidence of autonomic parameters, of their real-time recording and of the time variable on behavior. Indeed, in the method under development, unlike the classic one, the ultimate goal of recording and analysis neurovegetative parameters in real-time is to predict and anticipate the patient’s BS in order to support and guide the operator in the choice of stimulation sequences and to make effective the therapy session and the full therapeutic path.
Concerning the indications provided by the CDSS to the operator, it is useful to distinguish two operating modes: transitory and operational. The transitory mode refers to the first N sessions, when the training of the decision model is not yet completed, thus the CDSS can provide only statistical information about the adhesion/deviation of the neurovegetative parameters with respect to the baseline values (collected before starting the stimulation session). Statistical information can be provided in a summary form, referring to both the current session and the history of previous sessions. With the progress of stimulation sessions for a specific patient, the decision-making model is strengthened and the CDSS gradually enters in the operational mode, during which it can not only provide statistical indications (e.g., deviation from the baseline of the neurovegetative parameters) but also hints about the opportunity to maintain or discontinue specific stimulations for a specific patient on the basis of previous experience (i.e., trained models).

For this to be possible, it is necessary that, during the stimulation and at the end of the session, the operator informs the CDSS about the decision he/she has made about: 1) the effectiveness of the current stimulation, and 2) the achievement (or not) of the session goal. The former feedback is needed to train the predictive model (i.e., prediction of patient’s BS), the latter is needed to close the loop of the decision model (i.e., statistical reports).

The assumptions made up to now are summarized below:

1) Each stimulation session has a goal, set by the operator, which can be to activate or relax the patient.
2) Each stimulation session includes one or more stimulations, giving place to a stimulation sequence.
3) During a stimulation session, the operator provides to the CDSS the following inputs:
   a. When the session starts, the operator defines the session goal as activation or relaxation.
   b. During stimulation, the operator observes the patient and, every time that the patient’s BS changes, assesses the effectiveness of the stimulation. More specifically, the effectiveness of the stimulation is rated by choosing a value between $+2$, $+1$, 0, $-1$, $-2$; where the value 0 indicates a neutral situation or that the stimulation has had no effect on the patient, the positive values indicate gradually increasing beneficial effects (i.e., compliance with the session objective), and negative values indicate various levels of adverse effects.
   c. At the end of the session, the operator rates the achievement of the session goal by choosing a value between 0, $+1$, $+2$; where the value 0 indicates the total failure, $+1$ indicates a partial success and $+2$ the full success of the session.

In Fig. 2, the modus operandi of the CDSS described above is represented, for more clarity, in terms of flow chart. The region bounded with dashed line is cyclically repeated for each stimulation applied in a session. During each stimulation, the system provides statistical indications about deviation/adherence of current neurovegetative parameters to the baseline values (collected in absence of stimulation). If the number of stimulation sessions already done is enough to complete the model training, then the system can also
provide hints about the effectiveness of the current stimulation based on the prediction of the patient’s BS. During each stimulation, the operator observes the evolution of the patient’s BS, and when it changes the operator reports this circumstance to the system by rating the efficacy of the current stimulation, and providing an input value ranging between $-2$ and $+2$. At the end of the entire session, the operator rates the whole session with respect to the session goal, set at the start of the session, inputting a value between 0 and 2.

It should be noted in particular that, to achieve the final goal, that is the prediction and anticipation of the patient’s BS through real-time recording of neurovegetative parameters, the operator’s inputs are recorded and timestamped not only at the end of a session but every time the operator observes a change in the patient’s BS, so that such change can be associated with the evolution of the patient’s neurovegetative parameters.

![Overall flow chart diagram of the CDSS. The region surrounded with dashed line represents the information flow of a therapy session.](image)

**Fig. 2.** Overall flow chart diagram of the CDSS. The region surrounded with dashed line represents the information flow of a therapy session.

### 3.2 Multivariate Physiological Time Series Analysis

Given an MTS of neurovegetative parameters, a series of samples are obtained using a sliding-window technique. The window size is chosen later, in learning phase (parameter tuning), by using the cross-validation (i.e., leave-one-out) method on learning data set. Hence, MTS samples are classified by pursuing and comparing two different approaches: instance-based and feature-based.

In the case of instance-based approach, a multidimensional dynamic time warping (DTW) is used as distance metric [44], and the nearest neighbor method (NN) is used for the classification process. This approach is referred as PDDTW-NN in the followings. A parametric derivative DTW distance is defined as linear combination of the multidimensional DTW and of its derivative DDTW [38]. As the windows size, also the parameter
defining the linear combination is chosen during learning phase. Both parameters are chosen in correspondence of the smallest error with the NN classifier.

In the case of feature-based approach, interval-based predicates are used to extract statistical features (SF) on which a support vector machine (SVM) is trained [41, 45]. This approach is referred as SF-SVM in the followings. In this case, a series of statistical features are calculated for each window sample, such as normalized mean and variance, minimum, maximum, and normalized power spectrum (Welch’s periodogram method [46]).

For the sake of the completeness of the discussion, some details are provided about how spatial and temporal variations are estimated in the two approaches mentioned above. In the instance-based approach, the MTS samples are compared (i.e., comparing here means estimating variations among MTS sequences) by using the DDTW distance which is defined as discussed in the following. Let \( P \) and \( Q \) be two MTS, they can be represented as 1-dimensional trajectories in an \( m \)-dimensional Euclidean space as follows:

\[
P = \{ P(i) = (p_1(i), p_2(i), \ldots, p_m(i)) \in \mathbb{R}^m : i = 1, 2, \ldots, n \}, \tag{1}
\]

\[
Q = \{ Q(i) = (q_1(i), q_2(i), \ldots, q_m(i)) \in \mathbb{R}^m : i = 1, 2, \ldots, n \}. \tag{2}
\]

Using the above notations, the DTW distance between \( P \) and \( Q \) is defined by using the distance matrix \( D \) (cost function) whose elements are defined as follows:

\[
D(P(i), Q(j)) = \sum_{k=1}^{m} (p_k(i) - q_k(j))^2. \tag{3}
\]

The DTW distance can, then, be computed in standard way, i.e., by minimizing the path cost from point \( D(1, 1) \) to point \( D(n, n) \), through the warping path \( W = \{ w_1, w_2, \ldots, w_K \} \) of elements in \( D \), constrained by the three conditions: (i) boundary, (ii) continuity, (iii) monotonicity. Thus, the DTW distance is given by

\[
DTW(P, Q) = \min_W \left\{ \sum_{k=1}^{K} w_k \right\} \tag{4}
\]

Finally, defined the derivative of \( P \) and \( Q \) as \( P' = \{ P'(i) : i = 1, 2, \ldots, n \} \) and \( Q' = \{ Q'(i) : i = 1, 2, \ldots, n \} \), the DDTW distance is given as follows:

\[
DDTW(P, Q) = DTW(P', Q'). \tag{5}
\]

In the feature-based approach, instead, the samples are compared by using point-based predicates defined as follows:

- **point\(_\leq\)(\( S \), \( P \), \( t \), \( th \)):** For each MTS sample \( S \), this predicate is true if the time series \( P \) at the time \( t \) is less or equal then threshold \( th \).
- **mean\(_\leq\)(\( S \), \( P \), \( t_0 \), \( t_1 \), \( th \)):** For each MTS sample \( S \), this predicate is true if the mean of the values of the time series \( P \) evaluated in the interval given by \( t_0 \) and \( t_1 \) is less or equal than threshold \( th \).

The above example given for the mean holds also for, *mutatis mutandis*, the variance, minimum, maximum, and power spectrum, as well.
3.3 Experimental Setup

For this preliminary evaluation, the publicly available data set of physiological parameters, namely the Driver Stress Data (DSD), published by Healey and Picard [47] was used to conduct experiments. This choice was done since, at the present stage of the research, physiological data related to multisensory stimulation were not yet available and, on the other hand, there was not publicly available data sets of this kind. Although the physiological response of drivers cannot be compared with that of patients with DS, nevertheless the variability of physiological data in the DSD data set is more than enough for the purpose of this study, i.e., to develop and preliminarily validate algorithms for prediction of patient’s BS.

The data set includes four kinds of physiological sensor data, i.e., electrocardiogram, galvanic skin response, and respiration (i.e., chest cavity expansion), measured to detect driver’s stress levels in a real environment. The considered data set includes 17 useful sessions (i.e., drive runs) of physiological parameters collected from nine different subjects. Each session is divided into 15 drive events, of which the first and the last are resting periods (used as baseline in this study), whereas during the other events (from 2 to 16) the subject’s stress levels ranged through low, medium and high. For the purposes of the present study, the physiological time series are taken up from the inter-event transition intervals, in order to train and test the models for predicting the subsequent stress levels.

In addition, from the DSD data set other three additional data sets were derived by perturbing the baseline signals (i.e., resting periods) to simulate various kinds of MTS pattern combinations, as suggested by Saito and Coifman [49]. The first data set includes only shape perturbations (SP), the second one includes only temporal perturbations (TP), and the third one both shape and temporal perturbations (STP). The first two data sets are exampled in Fig. 3 and Fig. 4, respectively.

4 Experimental Results and Discussion

The experimental results reported in Table 1 and Table 2, reveal the ability of the CDSS to predict a change of the patient’s BS. At this purpose, the following BSs are considered: relaxed, neutral, activated, which are matched with the stress levels of the DSD data set. The prediction performance is evaluated in terms of sensitivity (SEN), specificity (SPE) and accuracy (ACC), defined as follows:

\[
SEN = \frac{TP}{TP + FN},
\]

\[
SPE = \frac{TN}{TN + FP},
\]

\[
ACC = \frac{(TP + TN)}{(TP + TN + FP + FN)}.
\]

From the original DSD data set (i.e., without perturbation), 200 time series instances were taken out of which 50% used for model training and 50% for testing. Instead, in the case of perturbed data sets, the considered instances were fifteen times more. In
DSD data set, electrocardiogram signal was sampled at 496 Hz, galvanic skin response and respiration signals were sampled both at 31 Hz. The heart rate metric was estimated from the electrocardiogram signal, i.e., by considering the R–R intervals, using the same sample rate of the respiration signal.

In the case of the original DSD data set, the better prediction performance was achieved with the SF-SVM approach with 85.5% accuracy against 75% of PDDTW-NN. However, in presence of more complicated spatial and temporal cues, performance measures behaved very differently. When only spatial perturbations were present, SF-SVM approach still provided good results with 91% accuracy, but it dropped off significantly with temporal perturbations and combination of both spatial and temporal perturbations, achieving 69.0% and 80.0% accuracy, respectively.

![Baseline values](image)

**Fig. 3.** Perturbations of the baseline (uppermost plot) obtained from three different shapes. For this example, the heart rate signal is considered.

In the case of SF-SVM, the window size (WS) parameter was set at greater values, since this approach suffers from the limited power of local features. On the other hand, PDDTW-NN turned out to be more sensitive to WS parameter, although achieved better results in presence of complex temporal perturbations. Instead, although also SF-SVM
includes temporal features, it performed worst with complex combination of temporal cues.

### Table 1. Classification performance of the PDDTW-NN approach.

<table>
<thead>
<tr>
<th>Data sets</th>
<th>SEN%</th>
<th>SPE%</th>
<th>ACC%</th>
<th>WS (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSD</td>
<td>77.78</td>
<td>72.73</td>
<td>75.00</td>
<td>180</td>
</tr>
<tr>
<td>SP</td>
<td>76.53</td>
<td>75.49</td>
<td>76.00</td>
<td>180</td>
</tr>
<tr>
<td>TP</td>
<td>92.63</td>
<td>88.57</td>
<td>90.50</td>
<td>45</td>
</tr>
<tr>
<td>STP</td>
<td>84.54</td>
<td>82.52</td>
<td>83.50</td>
<td>65</td>
</tr>
</tbody>
</table>

Fig. 4. Perturbations of the baseline values (uppermost plots) obtained from three types of temporal cues. Temp 1: shift of ending instants. Temp 2: shift of starting instants. Temp 3: duration changes (stretch/tighten). For this example, heart rate and galvanic skin response signals are represented.

The better performance of SF-SVM with original DSD data set may be due to the absence of critical combinations of temporal cues, but more investigation is needed.
Table 2. Classification performance of the SF-SVM approach.

<table>
<thead>
<tr>
<th>Data sets</th>
<th>SEN%</th>
<th>SPE%</th>
<th>ACC%</th>
<th>WS (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSD</td>
<td>85.86</td>
<td>85.15</td>
<td>85.50</td>
<td>310</td>
</tr>
<tr>
<td>SP</td>
<td>90.20</td>
<td>91.84</td>
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<td>308</td>
</tr>
<tr>
<td>TP</td>
<td>70.65</td>
<td>67.59</td>
<td>69.00</td>
<td>124</td>
</tr>
<tr>
<td>STP</td>
<td>80.61</td>
<td>79.41</td>
<td>80.00</td>
<td>210</td>
</tr>
</tbody>
</table>

Conversely, the poor performance of PDDTW-NN with original DSD data set may be due to signal shapes having different extensions, preventing to optimally define the WS parameter.

Although physiological parameters have been used in emotion (or mood) recognition [74], such processing task differs from BS change prediction, which is the focus of this study. Indeed, the aim of emotion recognition is to identify different types of physiological patterns belonging to certain emotional-state classes. On the contrary, the aim of behavioral state change detection is to identify variations in physiological patterns which can be associated with future changes in patient’s BS. For that reason, it is not meaningful to compare results of this study with those achieved in studies on emotion/mood recognition.

In this study, DSD data set (i.e., physiological data from drivers) was used, due to the lack of more specific data sets publicly available. This choice was not supported by the presence of close similarities between the physiological responses of drivers and patients with DS. Instead, the rationale of this choice has been that the DSD data set includes an amount of variability in physiological signals deemed sufficient to test algorithms predicting patient’s BS changes, and furthermore the variability was increased by generating additional data sets (i.e., SP, TP and STP). Moreover, it is important to keep in mind that the scope of this study is limited to the design and validation of the CDSS which will be used in the subsequent experimental phase of the research, after which it will be possible to determine the real patient’s physiological response to multisensory stimulation.

The clinical studies using physiological parameters [14, 18, 75, 76], among other elements (i.e., observed behavior, mood, etc.), to assess the effects of the Snoezelen method are limited. Although the results of these studies showed an improvement in physiological parameters (e.g., mean heart rate decrease, mean SpO2 increase, and so on) from before to after the stimulation sessions, no significant differences were reported in comparison to control groups that had received other types of interventions. In these studies, the physiological parameters were recorded before and after the stimulation sessions, but in some of them also during sessions, with sampling rates generally ranging between one and five minutes per sample.

The present study, unlike the aforementioned ones, has based the data analysis on statistical features more advanced than the simple mean and standard deviation, as well as on instance-type features, extracted from physiological data collected with much higher sampling rates. This suggests a greater capacity of the proposed approach in recognizing...
patterns of variability of physiological parameters that are more complex than the simple change of mean values.

Furthermore, the physiological parameters included in the DSD data set show a progressive variability corresponding to time intervals characterized by different stress levels. This made it possible to simulate the onset of a change in the physiological parameters anticipating a future subject’s state, regardless of whether it is stressful or behavioral. For these reasons, the authors are very confident that the proposed methodology will be able to detect physiological patterns, even complex ones, able to anticipate changes in patient’s BS in order to provide more evidence on the effectiveness of the Snoezelen method during the experimental phase.

5 Conclusions

In this paper, preliminary results on the study of patient’s BS change prediction during multisensory stimulation therapy are presented. The BS change is predicted from multivariate physiological time series, investigating the two most popular approaches, instance-based and feature-based, respectively. Since, at this stage of the research, real patient’s data sets are not yet available (currently, the Snoezelen room is under construction, and the patients’ recruitment process is in progress), the DSD publicly available data set was considered. To make the DSD data set more adherent to the problem at hand, a series of shape and temporal perturbation were also applied to original data. The achieved results show the ability to classify time series instances into pattern class representative of some BS changes. However, the investigated techniques, i.e., SF-SVM and PDDTW-NN, exhibit some limitations which should be further evaluated with real data or more realistic ones.

Ongoing and future research efforts include systematic data collection, in both academic and clinical setups, aiming to identify predictive indicators in patient’s neurovegetative parameters measured during multisensory stimulation sessions. Furthermore, on the basis of collected (quasi-)real data sets, it will be evaluated if the predictive approaches here presented are enough or more power ones should be investigated (e.g., representation learning for MTS).

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References


A Sensing Platform to Monitor Sleep Efficiency

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Abstract. Sleep plays a fundamental role in the human life. Sleep research is mainly focused on the understanding of the sleep patterns, stages and duration. An accurate sleep monitoring can detect early signs of sleep deprivation and insomnia consequentially implementing mechanisms for preventing and overcoming these problems. Recently, sleep monitoring has been achieved using wearable technologies, able to analyse also the body movements, but old people can encounter some difficulties in using and maintaining these devices. In this paper, we propose an unobtrusive sensing platform able to analyze body movements, infer sleep duration and awakenings occurred along the night, and evaluating the sleep efficiency index. To prove the feasibility of the suggested method we did a pilot trial in which several healthy users have been involved. The sensors were installed within the bed and, on each day, each user was administered with the Groningen Sleep Quality Scale questionnaire to evaluate the user’s perceived sleep quality. Finally, we show potential correlation between a perceived evaluation with an objective index as the sleep efficiency.

Keywords: Sleep monitoring · Sleep quality · Unobtrusive systems

1 Introduction

Intelligent systems provide solutions to improve the health management, especially of older adults or chronically sick people, providing both short and long term monitoring. Within an aging society, interventions to preserve health, and tools to assist people, are urgently needed. It is worth noting that people experience changes, both in mental and physical aspects, especially as they grow old.
As a consequence, people deal with life-changing problems. One of these problems generally affects the characteristics of the sleep habits: changes in sleep architecture, sleep duration, and quality [1]. Elderly people exhibit difficulty in falling asleep, sleep fragmentation and maintaining sleep. According to [2], sleep disturbances increases of 50% for people over 65 years old. As a conclusion, a better quality of life in elderly people may be achieved by increasing sleep quality as well as promoting good sleep [3].

In past years, several innovative systems consisting of devices for activity tracking, wearable devices and smart devices for well-being have been introduced in the market and they are daily used from a growing number of people. Sleep assessment and the related evaluation research has grown steadily [4,5] as well. An important aspect to consider is that despite younger people’s perceptions, seniors’ use of technology is the rule rather than the exception. As reported in [6], seniors (aged 65 to 75) report an average of 19 to 31 interactions per day with their daily appliance, including computers and devices. Elderly users are considered less inclined to accept new technology than younger people. Typically, if they are motivated to use new technological solutions – because the benefits are clearly perceived – this inclination changes. As a consequence, in order to increase the acceptability, devices equipped with long-life batteries or, in general, devices easy to install and which require low effort for maintaining and interacting have been proposed. The system proposed in this paper is composed by several force-sensing resistor placed as a grid between the mattress and the slats. It can be easily deployed in a home setting and, most important, according to the motivations introduced above, performs its evaluation in an unobtrusive way. The scope of the proposed system is monitoring the sleep in order to evaluate the sleep efficiency (SE). In fact, SE is commonly defined as the ratio of total sleep time (TST) to time in bed (TIB) and it plays a fundamental role in sleep research [7,8]. We have deployed our system in a real world setting within a bigger sleep study held at the ETH, Zurich. Finally, we compared the objective measurements performed by the proposed system with the Groningen Sleep Quality Scale (GSQS) questionnaires to evaluate the correlation between the objective SE index and the perceived sleep quality collected through the questionnaires.

2 Related Work

An accurate sleep monitoring is fundamental in order to detect early signs of sleep deprivation and insomnia, evaluating sleeping habits, and consequentially implementing mechanisms and systems for preventing and overcoming sleep problems [9].

Tracking the sleep can be achieved by also analysing the body movements. The key idea comes from the observation that movements, generally, reduce during the resting periods with respect to active ones [10]. For the purpose of the sleep monitoring, the body movements are analyzed not only to infer when a subject is resting or not, but also to measure some sleep variables like: total sleep time, bedtime and rise time [11]. In order to record sleep sessions on an
extended period in a home setting more efforts should be spent to find reliable sleep monitoring system able to monitor the human sleep and its characteristics.

Fortunately, technological advances have allowed the development of non-invasive, long-life, battery powered, wearable devices equipped with tri-axial accelerometers (i.e., actigraphy) able to monitor and collect data generated by movements. Some devices exploit a piezo–electric mechanism to detect movements, along two or three axes, and to digitally count the accumulated movements across pre–designed epoch intervals (e.g. 1 min), storing them in an internal memory.

Wearable devices for actigraphy, and in particular wrist-worn actigraphy devices measuring sleep parameters [12] have been validated through the comparison with polysomnography which is considered the gold-standard method [5,13]. In general, longer actigraphy-based monitoring may correlate better with gold-standard method. The strengths of actigraphy-based systems are the low impact on maintaining for the users and their low cost. However, the major weakness of this method is the limitation in distinguishing activity from motionless while users are awake or being asleep.

Despite the main strength of actigraphy lies in the ability of monitoring sleep behaviour and inferring sleep wake patterns over long periods of time at home, actigraphy also has several weaknesses. In [14], the authors report that up to 28% of weekly recordings of children and adolescents were insufficient for the sleep analysis. The main reasons for data loss included patient non-compliance to the pre-defined protocol (inability to complete the diary or log and misplacement of the wearable actigraph device), illness, and technical problems. In [15,16], the use of wearable general purpose sensor technologies to monitor the bed posture of patients is proposed. In order to overcome the issues related to wearable devices, no contact systems based on several technologies (e.g. camera, accelerometers) have recently been proposed. For example, in [17], an unobtrusive system able to infer the bed posture and the breathing signal is presented. The system is based on an expensive technology which employs a sensor, called Kinotex, that was developed by the Canadian Space Agency for tactile robotic sensing. Finally, in [18], an inexpensive system based on placing above the mattress a capacity textile sensing technology is described. However, the authors noticed problems on the reproducibility of the experiments, due to the movement of the textile system, which necessitates a new calibration phase each time.

Another technique to assess sleep quality, exploiting sensors or pads installed under the mattress, is the ballistocardiography (BCG). It is based on the detection of the ballistic forces of the body generated by the pumping of the blood into the circulatory system with each heartbeat and breathing cycles. The forces generated by the human body are used to detect the heart rate, heart rate variability and respiratory rate. Commercial devices based on this principle use both pneumatic pressure sensors (e.g. Withings Sleep Analyzer) or piezoelectric sensors (e.g. TE Sleep Monitoring, Beautyrest Sleeptracker) to detect the movements produced by the body. Although BCG allows to use minimally invasive devices, it has some disadvantages such as potential inaccuracies while measuring the physiological parameters when two or more subjects are on the same
bed, sensitivity reduction due to the bed sheet or blankets and subjectivity of the involved biological markers [19].

The system proposed in this paper is able to merge the inexpensive feature of [17] and the unobtrusive feature of [18], just placing, under the mattress, several FSR, able to report the force pressure generated by the patient over the mattress.

3 The Proposed Sensing Platform

Taking into account both the findings described in the previous section and our former work in this field described in [20–23], we present an improved version of the sleep monitoring system able to generate a synthetic sleep quality index representing the user’s night resting capacity. The system can be easily deployed in every home setting and could also be integrated in wider Ambient Assisted Living scenarios, running side by side with other user’s monitoring platforms to provide multidomain continuous monitoring (e.g. stress analysis, physical exercise, social activity). Thanks to its extremely low intrusiveness, the system can also be deployed in environments involving older people with sleep impairments. Since it is based on the detection of the force applied upon the mattress, should be advised against medical conditions requiring the usage of air anti-bedsore mattress which would heavily hinder the sensing capabilities of our platform.

Our system relies on force-sensing resistors (FSRs), arranged in a grid pattern, placed between the mattress and the slats (Fig. 1).

These sensors consist of a conductive polymer which changes its electrical resistance proportionally with the force applied on the sensor surface. In addition, the sensors are characterized by an extremely low profile (less than 0.5 mm), low cost, a good shock resistance and a low temperature sensitivity with an output variance up to 0.36% per degree C. We use these sensors to detect the distribution of the pressure exerted by the human body lying on the bed. In order to acquire and store the pressure values over time, the sensors are connected to a Raspberry Pi single-board computer by means of analog-to-digital converter units which translates the electrical voltage coming from the sensors to a digital format.

The Raspberry Pi board is able to continuously collect raw pressure data while recording it on permanent storage. At the end of a sleep monitoring session, the logs, stored in a CSV format, can be retrieved and further analyzed. By exploiting the network connection, multiple boards can be combined together to increase the amount of sensing points or integrated with other sleep or environmental monitoring devices to provide automatic data collection and aggregation. From the raw data, consisting in the pressure readings generated by the sensors over time, our algorithm evaluates the frequency and the number of body movements performed by the human body during the night. In particular, we first perform a preprocessing phase by: (i) computing the total pressure exerted by the body over time and (ii) applying a moving window average to the data in order to reduce the impact of the environmental vibrations and the electrical
noise which are mixed up in the signals. Furthermore, we apply an hysteresis thresholding in order to strengthen the detection of the user on the bed. The upper and lower threshold values are customized for each user to match their weight footprints in order to separate the sensor readings matching the empty bed from those matching the loaded bed (Fig. 2).

Besides, to detect the user movements, we compute the amount of variation of the pressure values within a fixed-size moving window; we consider a movement whenever this quantity exceeds a given value, calibrated for each user. Taking into account both the user presence on the bed and the sequence and duration of the user movements (Fig. 3), the algorithm produces a synthetic index, namely Sleep Efficiency index. The index, based on the findings in [19], takes into account the number and the duration of the movement periods during which the user is assumed to be awake, the time taken to sleep as well as the total time spent in bed [24]. In the first place, in order to compute the sleep efficiency index, the following parameters are derived from the pre-processed data:

- Time In Bed (TIB): time elapsed between the first instant the user went on the bed in the evening and the last instant the user got out of bed in the morning; this parameter might include periods during which the user get off the bed during the night.
- Sleep Onset Latency (SOL): time elapsed between the first instant the user went on the bed in the evening and the instant the user is assumed to sleep (no movements detected within a fixed time window).
Fig. 2. Distribution of the pressure values used to determine the lower (red) and upper (green) hysteresis thresholds to detect the user presence on the bed. (Color figure online)

Fig. 3. Detection of the user presence on the bed (green) and his movements (red) based on the total pressure over time (blue). (Color figure online)

– Wakefulness After Sleep Onset (WASO): time the user is assumed awake, i.e. the periods of time during which the user is moving plus the periods of time the user got out of the bed during the night.

From these parameters, the Total Sleep Time ($TST$) is computed as in Eq. 1.

$$TST = TIB - WASO - SOL$$

Eventually, the Sleep Efficiency index is obtained through the formula in Eq. 2.

$$SE = \left( \frac{TST}{TIB} \right) \times 100$$

4 Preliminary Analysis and Discussion

To prove the feasibility of the suggested method we did a pilot trial, conducted in a controlled university environment, within a bigger sleep study [25]. The study
involved university students which were asked to wear the Apnea Link device as well to monitor additional physiological parameters such as oxygen saturation, nasal airflow, and breathing effort. The study protocol was approved by the Ethics Committee of ETH Zurich, no. EK 2015-N-70 and retrospectively registered at https://clinicaltrials.gov, no. NCT04053738. Written informed consent was obtained from all subjects.

Five male participants (age: 25.8 SD: 4.5 years, body mass index: 22.4 SD 2.3 kg/m², Epworth sleepiness scale (ESS) at baseline 6.3 SD: 2.3) out of the group of subjects that were recruited in 2017 were selected for this pre-trial. This subgroup included one participant with an EES above 10 which indicates excessive daytime sleepiness [26].

The sensors were installed within the bed for all four nights. On each day, each user was administered with the Groningen Sleep Quality Scale (GSQS) questionnaire [27] to evaluate the user’s perceived sleep quality.

**Table 1.** Comparison between users’ GSQS scores and the SE indexes. Darker and lighter blue in GSQS and SE columns represents the scores and indexes obtained during the nights with and without the bed moving, respectively.

<table>
<thead>
<tr>
<th>User</th>
<th>GSQS score</th>
<th>Sleep efficiency index</th>
<th>Intraclass correlation</th>
<th>GSQS score σ²</th>
<th>GSQS score σ</th>
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<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>34</td>
<td>-0.98</td>
<td>4.67</td>
<td>2.16</td>
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<td></td>
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<td>-0.06</td>
<td>0.33</td>
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<td>1</td>
<td>91</td>
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</table>
Table 1 shows the GSQS scores (low values indicate a better perceived sleep quality and vice versa) and the SE indexes obtained for each user (the higher the value, the better the computed sleep efficiency). We use the negative intraclass correlation (ICC) as a descriptive statistic to quantitatively measure the correlation between the output of our system and the answers of the same user to the GSQS questionnaire for the four nights. Negative correlation or inverse correlation is a relationship between two variables whereby they move in opposite directions. The degree to which one variable moves in relation to the other is measured by a negative correlation coefficient, which quantifies the strength of the correlation between two variables. The higher the negative correlation between two variables, the closer the correlation coefficient will be to the value $-1$. We used it to describe how strongly our index represents the perceived sleep quality for the same user in their group of nights (ICC close to $-1$ in presence of high correlation and close to 0 or positive values with low or very low correlation). We also show the variance $\sigma^2$ and standard deviation $\sigma$ of the GSQS scores for each group of nights in order to detect the subjective range of possible answers to the questionnaire. Low standard deviation means data are clustered around the mean, while high standard deviation indicates data are more spread out. We believe that groups of nights with high standard deviation in their GSQS score emphasize more the “good” and “bad” nights in terms of sleep quality. We observed that the performance of our systems improves in users showing higher variance in their perceived sleep quality, i.e. having one or more particularly good or bad nights. For user 1, we obtain an intraclass correlation of -0.98, with the user showing a high variance in their GSQS scores. For user 2, instead, we obtained a very low correlation with a positive ICC value, with the user showing a very low variance in their GSQS scores due to very similar nights in terms of perceived sleep quality. This can lead to further investigation of the proposed system as sensitivity measure when used to detect anomalies in the monitored nights related to possible sleep pathologies/diseases.

During the study, in two out of the four nights, interventions in the form of bed movements were provided. Since these interventions could influence our analysis we analyzed the data once considering all nights and once considering only the nights in which the bed did not move. In Table 1, we indicated with darker blue the scores and indexes obtained during the nights with the bed moving, while with lighter blue the ones obtained during nights with no movements of the bed. We observed that the system is robust to this kind of external mechanical perturbations, showing almost the same correlations: overall $r = -0.84$; correlation between nights and GSQS score with the bed moving $r = -0.87$; correlation between nights and GSQS score without the bed moving $r = -0.86$.

For the sake of completeness, we put together all the SE indexes obtained for all the users. This can be useful to see how the proposed system performs without tuning the parameters to the subjective perception of sleep quality of a particular user. The obtained results are shown in the correlation chart in Fig. 4. It shows the regression of the SE indexes over the GSQS scores. The coefficient of
determination $R^2$ provides a measure of how well observed outcomes in terms of GSQS scores are replicated by the proposed system in terms of SE indexes, based on the proportion of the total variations. We obtained a good fitting model with $R^2 = 0.708$ and a low deviation between nights with the bed moving, obtaining $R^2 = 0.74$, and not moving, obtaining $R^2 = 0.76$ (these values are not shown in the figure for a better visualization of the overall performance).

We can conclude that in this pilot trial we were able to show that there is a general correlation between the subjective GSQS and the sleep efficiency index derived with our FSR sensor setup. In the future we will have to show whether we can also find a good correlation to the gold standard polysomnography. Furthermore, it would be interesting to use the system in specific scenarios, like older adults with sleep problems in ambient assisted living environments where invasive monitoring tools are impracticable since they might have an even more negative impact on the sleep quality of the subjects.

References


Are Wearable Sensors Useful to Assess the Psychophysical Fatigue Due to Physical Activity in Elderly People with Mild Cognitive Impairment? A Preliminary Study

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Abstract. Nowadays, wearable biomedical sensors provide a challenging opportunity to measure physiological parameters in an unobtrusive manner; therefore, they can be applied in nearly any scenarios with protocols adapted to the end-user evaluated. Furthermore, the opportunities offered by the new development in the field of Information and Communication Technology (ICT) allow such devices to be checked in real-time by means of a smartphone or tablet, further enhancing their usefulness. Recently, a growing interest in wearables was seen for their application in monitoring the health status of elderly people, which might benefit from a continuous control of their parameters without continuously getting to the General Practitioner (GP).

As such, wearables are also used within scientific research for studying the physiological reactions to particular stimuli. Here, we evaluated the variation in electrocardiogram (ECG) parameters in a cohort of 44 subjects with Mild Cognitive Impairment (MCI), a pre-clinical condition often leading to dementia in a relatively short amount of time. Such parameters, often referred to the activation of the Autonomic Nervous System (ANS), were checked before, during and after a session of light physical activity in two different phases: i) at T0, and ii) after a 7-month treatment consisting of regular sessions of cognitive and physical training and advices about correct lifestyle (T1).

Satisfaction questionnaires, as well as data from wearables were acquired and discussed, reporting an optimal usability for the devices by the MCI population and an effect, both at T0 and T1, for the physical activity on the autonomic parameters.

Keywords: Autonomic Nervous System · Electrocardiography · Mild cognitive impairment · Physical activity · Sensors · Wearables

1 Introduction

Wearables represent one of the most important technological advancements in last decades in terms of the impact they are capable of bringing into the field of healthcare...
and well-being. Their trailblazing success is due to both their capability of acquiring important information about the health and well-being status of an individual and their seamless integration into people’s daily life, nowadays [1].

Through a simple, user-friendly, small and relatively low-cost device, it is possible to measure a wide range of health-related parameters, including physiological and biochemical ones, during the normal routine of an individual’s life. As such, those parameters can be continuously, real-time sent to personal devices, including smartphone and tablet, for their consultation directly by the individual, their caregivers and, ultimately, by the General Practitioner (GP) [2].

Such approach would ultimately carry on several advantages, including a more robust, continuous check of vital parameters with a significant decrease in the need for frequent visits to the GP and to the Emergency Room [3], particularly important during the SARS-CoV-2 pandemic, when the healthcare system is being challenged by an unprecedented excess load worldwide [4]. Within this framework, the application of wearables gains even more importance when dealing with the physiological monitoring of fragile people, including elderly individuals and those with significant clinical comorbidities, being those more at risk for important healthcare challenges and also for severe consequences from the SARS-CoV-2 infection [5, 6].

To date, the most common parameters measured by wearables include the heart rate (HR) and heart rate variability (HRV), body temperature, blood oxygen, saturation, and physical activity, collected by different devices, including electrocardiogram (ECG), ballistocardiogram (BCG), Photoplethysmogram (PPG), actigraphs, etc. [7].

Notably, the physiological parameters eventually extracted studying the ECG signal can be useful to quantitatively assess the involvement of the Autonomic Nervous System (ANS) during daily life and/or particular tasks, with interesting information for studying some features of both the cardiovascular and neurological systems [8–10].

Focusing in particular on the physiological signals to characterize dementia-related ANS changes, just few evidences exist to date dealing with wearables eventually applied in this specific domain. More in depth, recent results confirm the role for smart ICT devices to assess Alzheimer’s Disease (AD)-related physiological changes, notably referring to sleep and ECG data, aimed at monitoring the cognitive changes related to pre-clinical AD [11]. Furthermore, ECG data, particularly those features related to the HRV, were demonstrated to be useful in elderly people with dementia for assessing anxiety, emotions and behavioral features related to a given task or condition [12].

A very important research line, with manifold practical clinical applications is that of monitoring the effects of physical activity on the physiological state of older adults. This domain was mainly studied in healthy individuals, due to their higher compliance and to the ability they have, with respect to patients with dementia, to sustain longer and more high-demanding cognitive tasks, however highlighting an overall positive effect on the cognitive functions brought by the physical exercise in such individuals (see [13] for an overall outlook about the topic). However, the same results were not seen for elderly people with clinical or pre-clinical conditions, including Mild Cognitive Impairment (MCI), where the absence of a general evidence about the positive effect of physical exercise on cognitive functions was highlighted [14]. However, in many cases eventual clinical improvement on the cognitive and physical domains could have been masked by
the heterogeneity of the study protocol or of the study population, since clinical criteria for the MCI diagnosis are sometimes narrow and, in some instances, poorly clear and difficult to be correctly applied [15].

Some years ago, a randomized trial conducted in Italy has demonstrated, in a wide cohort of MCI individuals aged 65 and above, that a non-pharmacological, multicomponent intervention based on cognitive and physical training, as well as music therapy, is capable of improving cognitive status and indicators of brain health in those subjects, based on self-reported questionnaire, cognitive and sensory tests and cardiovascular indicators [16–18].

However, this latter study did not evaluate MCI subjects in terms of their autonomic parameters, still keeping a gap with respect to a complete, 360° assessment of the patients’ health status.

Under this consideration, the present work attempted at evaluating the effect of a light physical activity on the autonomic parameters in a cohort of MCI individuals before and after a mixed cognitive and physical treatment to evaluate: i) the effect of the light, low-demanding physical activity on the ANS of such individuals before the treatment; ii) the effect of the light, low-demanding physical activity on the ANS of such individuals after the treatment. Overall, the impact of the adoption of wearables to assess the physiological variables in elderly subjects with MCI was also evaluated.

2 Materials and Methods

2.1 Study Population

The present study involved 44 participants (21 men, 23 women) with a diagnosis of MCI according to the current clinical guidelines [15], aged 74.2 ± 4.7 years (range 65–89 years old), enrolled through a screening between neurologists, cardiologists and GPs. The subjects involved attended a treatment protocol lasting 7 months, consisting of: i) 3 weekly sessions of cognitive training, with a duration of 2 h per session; ii) 2 weekly sessions of physical training, with a duration of 1 h per session; iii) 1 weekly session of music therapy, with a duration of 1 hour per session.

2.2 Study Protocol

The subjects were assessed using wearable sensors at two different time points: i) at T0 (i.e., before the treatment protocol starting), and ii) at T1 (i.e., after the 7 months protocol).

In those two sessions, the participants were asked to perform a light physical activity protocol, administered through the standardized, well-known Six-Minute Walk Test (6MWT) [19], often employed in the clinical practice to assess the walking ability of a subject and to infer the individual’s activity of daily life (ADL).

Before, during and after the 6MWT, the ECG signal of participants was recorded using the wearable Shimmer2ECG sensor (Shimmer Sensing, Inc., Dublin, Republic of Ireland). The small, lightweight device, embedding electronics for signal conditioning, a Bluetooth Radio and a 2 GB SD card for data storing, was attached to the subject’s body through a fitness-like chest strap (Polar Electro Oy, Kempele, Finland).
The ECG signal acquisition was performed at a sample frequency of 500 Hz, in order to allow for an accurate estimation of HR and HRV [20], during three different sessions, following the same procedure at T0 and T1:

i) Baseline (duration: 3’): the subject is asked to comfortably sit on a chair and relax.

ii) Task (duration 6’): the subject is asked to perform the 6MWT in a dedicated gymnasium.

iii) Recovery (3’): after the 6MWT completion, the subject is asked to comfortably sit on a chair and relax, similarly to the Baseline.

2.3 Signal Analysis

The ECG signal was processed using a dedicated Matlab (The MathWorks, Inc., Natick, MA, USA)-based user interface, properly developed to this extent.

The tool performs the ECG signal analysis starting from the tachogram estimation according to the Pan-Tompkins algorithm [21], allows the user to apply a manual artifact correction and extracts both time- and frequency-domain features, including:

– Time-domain features:

  • Heart Rate (HR): number of heart pounds per unit of time. Measured in beats per minute (bpm), it is usually associated to the sympathetic branch of the ANS [8]
  • Standard Deviation of the normal R-R intervals (SDNN): measured in ms, it is an estimate of the HRV influenced by both the sympathetic and parasympathetic branches of the ANS [8]
  • Percentage of the normal R-R intervals exceeding 50 ms (pNN50): measured in percentage, it is a reliable indicator for the parasympathetic activity of the ANS [8]
  • Cardiac Sympathetic Index (CSI): obtained by the Poincaré Plot, it is employed as a reliable indicator of the sympathetic activity of the ANS [22]
  • Cardiac Vagal Index (CVI): obtained by the Poincaré Plot, it is employed as a reliable indicator of the parasympathetic activity of the ANS [22]

– Frequency-domain features:

  • Low-to-high frequency components ratio (LF/HF): it indicates the overall balance between low (LF, ranging 0.04–0.15 Hz) and high (HF, ranging 0.15–0.4 Hz) frequency components of the ECG signal. A ratio exceeding 1 suggests a sympathetic dominance, whereas for values below 1 parasympathetic nervous system appears to be prevalently activated [8]. It should be stated that the reliability of the LF/HF ratio in quantifying the overall sympathetic/parasympathetic balance is often questioned by several works in the scientific literature, as it is judged less accurate and more affected by artifacts than occurring with time-domain features [23].


2.4 Acceptability Assessment

The individuals enrolled were asked to evaluate the degree of comfort/discomfort due to wearing the sensorized chest strap using a 7-item Likert scale, ranging from −3 (full discomfort) to +3 (full comfort) with 0 as intermediate, neutral value.

2.5 Statistical Analysis

Statistical analysis was performed using the SPSS v.23 software (IBM Corporation, Armonk, NY, USA).

The first assessment was devoted to the evaluation of acceptability for the chest strap. To verify this point, we conducted a one-sample Wilcoxon Signed-Rank Test comparing the scores of the questionnaires to the expected median value.

Then, concerning physiological data, we performed an evaluation aimed at verifying the normality of the data distribution to later decide which approach (whether parametric or not) had to be applied for the statistics, overall. Such analysis was conducted by means of the Shapiro-Wilk Test whereas, based on the results obtained, we adopted a parametric approach (t-test for paired samples) in case of data normally distributed, and a non-parametric approach (two-way Friedman’s ANOVA with post-hoc analysis performed by the Wilcoxon signed-rank Test) with data deviating from the normality. Multiple comparisons were corrected by Bonferroni post-hoc test.

Statistical significance was assumed at $p < 0.05$ for the whole analysis carried out.

3 Results

3.1 Acceptability

The end-users of this protocol positively evaluated the usage of the sensorized chest strap, overall. Of 44 participants, 36 (81.8%) left positive evaluations, 5 (11.4%) were neutral and just 3 (6.8%) reported a discomfort wearing the strap.

With respect to the expected value, the chest strap was well accepted by the participants ($p < 0.001$).

3.2 Statistical Analysis

The Shapiro-Wilk Test revealed a normal distribution for all the ECG-derived parameters, except the HR, whose distribution was assumed to be close to the gaussianity.

Under such considerations, the results obtained from the statistical analysis are resumed in Table 1.

The analysis carried out within the protocol highlighted an increased HR value at Task occurring at both T0 and T1, in both cases followed by a decrease during the Recovery at intermediate values between Baseline and Task.

Similarly, at T0 the value of SDNN increased at Task, without a corresponding significant decrease during the Recovery phase. On the other hand, this trend was not noticed at T1.
<table>
<thead>
<tr>
<th>Feature</th>
<th>B T0</th>
<th>T T0</th>
<th>R T0</th>
<th>B T1</th>
<th>T T1</th>
<th>R T1</th>
<th>B T0 vs. T T0</th>
<th>T T0 vs. R T0</th>
<th>B T1 vs. T T1</th>
<th>T T1 vs. R T1</th>
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</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>67.2 ± 12.9</td>
<td>87.3 ± 10.0</td>
<td>75.1 ± 10.2</td>
<td>68.3 ± 9.4</td>
<td>88.9 ± 12.3</td>
<td>81.2 ± 9.9</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>0.004**</td>
</tr>
<tr>
<td>SDNN (ms)</td>
<td>51.7 ± 41.4</td>
<td>88.7 ± 87.5</td>
<td>73.3 ± 39.5</td>
<td>49.3 ± 28.0</td>
<td>81.9 ± 81.8</td>
<td>78.8 ± 37.8</td>
<td>0.034*</td>
<td>n.s</td>
<td>n.s</td>
<td>n.s</td>
</tr>
<tr>
<td>pNN50 (%)</td>
<td>8.9 ± 16.8</td>
<td>11.6 ± 25.6</td>
<td>6.6 ± 14.5</td>
<td>4.9 ± 8.3</td>
<td>10.5 ± 27.1</td>
<td>2.3 ± 4.0</td>
<td>n.s</td>
<td>n.s</td>
<td>n.s</td>
<td>n.s</td>
</tr>
<tr>
<td>CSI</td>
<td>3.051 ± 1.236</td>
<td>6.074 ± 4.367</td>
<td>6.447 ± 3.442</td>
<td>4.267 ± 1.850</td>
<td>7.288 ± 5.721</td>
<td>8.944 ± 3.267</td>
<td>0.003**</td>
<td>n.s</td>
<td>0.046*</td>
<td>0.042*</td>
</tr>
<tr>
<td>CVI</td>
<td>3.034 ± 0.550</td>
<td>3.083 ± 0.859</td>
<td>3.137 ± 0.473</td>
<td>2.953 ± 0.446</td>
<td>2.978 ± 0.844</td>
<td>3.048 ± 0.434</td>
<td>n.s</td>
<td>0.043*</td>
<td>n.s</td>
<td>0.039*</td>
</tr>
<tr>
<td>LF/HF</td>
<td>2.362 ± 1.930</td>
<td>1.883 ± 1.514</td>
<td>3.004 ± 2.257</td>
<td>2.952 ± 2.483</td>
<td>1.796 ± 1.870</td>
<td>2.145 ± 1.284</td>
<td>0.015*</td>
<td>0.001**</td>
<td>0.003**</td>
<td>n.s</td>
</tr>
</tbody>
</table>

Table 1. Distribution of the ECG-derived variables, expressed as means ± standard deviations, and relative p-values. * p < 0.05, ** p < 0.01. B: Baseline, R: Recovery, T: Task. T0, T1: time points. ns: not-significant.
The CSI values also increased significantly at Task both at T0 and T1, without returning at lower values during the Recovery but continuing to increase, especially at T1, where differences between Task and Recovery were seen as significant.

The CVI also increased at Recovery with respect to the Task at T0 and at T1, without highlighting differences between Baseline and Task in any of the two time points.

Finally, the LF/HF was lower at Task with respect to Baseline and Recovery in both testing sessions.

4 Discussion

The present work aimed at assessing the acceptability of the usage of wearables in monitoring physiological signals of elderly subjects with MCI in a light physical activity session.

The results obtained by the questionnaires administered revealed a positive attitude of the vast majority of subjects with MCI towards technology, yet a “dark side of the moon” despite the continuously increased usage of ICT in dementia and pre-clinical conditions (see [24] for an overall view). Such outcome can represent a milestone in this specific domain, paving the way for a more extensive application of technology in MCI and dementia-like syndromes.

Another aim of the study was to assess the effect of the light, low-demanding physical activity on the ANS of MCI individuals before the treatment. In this regard, the results obtained suggested an increased activation of the whole ANS during the physical activity at T0, probably due to the significant increase in its sympathetic component, as demonstrated by the rise in both the HR and the CSI features, normally related to the activation of this specific branch of the ANS. After the task completion, the decreased HR, together with the slight rise of the CVI suggest a possible parasympathetic activation that, for time scales longer than the 3’ foreseen for the Recovery phase, could have driven the subjects towards a physiological condition comparable to that at Baseline. This phenomenon is in line with that described in literature on healthy individuals, and denotes absence of particularly evident autonomic abnormalities in the MCI population investigated (see [25] for a review). Time needed to MCI individuals to restore their basal framework after this light physical activity obviously depends on personal characteristics, but is generally longer than 3 min and could be more in depth investigated in future works.

Furthermore, the study also aimed at evaluating the effect of the light, low-demanding physical activity on the ANS of MCI individuals after the treatment. According to the data collected and analyzed, at T1 the autonomic response was quite similar to that recorded at T0, with an overall increase of the sympathetic activity due to the 6MWT with respect to the Baseline. However, after the Task, the parasympathetic increase demonstrated by the rise in the CVI already seen at T0 was flanked by a lighter, not previously detected sympathetic rise, as displayed by the CSI. Further comparison between data at T0 and T1, as well as the correlations between autonomic and other cardiovascular features will be the main subject of future research.

Taken together, those results suggest the absence of an evident effect brought by the mixed cognitive/physical training lasting 7 months on the autonomic response to
light physical activity. As we know from the literature, a significant bout of training is commonly associated with a reduction in HR, as well as other sympathetically-dominant features, as observed among competitive athletes [26] or among individuals with different training levels [27]. Therefore, our results probably show the absence of a significant training effect on the whole MCI population.

This could be due to several factors, including: i) a wide inter-personal variability in ANS activity; ii) a relatively short amount of time for the training phase that could have prevented the users from having effective benefits in autonomic terms; iii) the co-existence of a likely physio-cognitive deterioration due to the pre-clinical condition experienced by the MCI cohort that could have masked the differences eventually attributable to the experimental training.

5 Conclusions

The present study sought for assessing the potential usefulness of ICT in the physiological monitoring of elderly people with MCI. The acceptability of such protocol appears to be optimal, possibly suggesting a more extensive application of technology in such specific field of clinical research and beyond. For example, the application of ICT tools in MCI could be foreseen in home settings, where elderly people can be monitored continuously by their GP without requiring frequent ambulatory visits.

Finally, the results obtained by the protocol suggest that a longer training time is needed to bring appreciable differences in the ANS response of MCI subjects with respect to a light physical activity task or to carry on a noticeable training effect on such population. However, such evidence should be confirmed in future research involving a broader cohort, with sub-categories based on clinical MCI subtypes (e.g., amnestic MCI vs. non-amnestic MCI) and matched control groups undergoing treatment-as-usual.

References

Therapeutic Exercise Protocols for People Recovering After Covid-19: A Tele-Health Approach

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Abstract. Post-Covid-19 syndrome occurs in at least half survivors, that claim to suffer from a mild to severe deconditioning syndrome, fatigue, muscle wasting and pain, dizziness, very low tolerance to minimal efforts, depression and anxiety, when they not will suffer from post-critical neurological syndrome and peripheral neuropathies. Telemedicine and telerehabilitation could be decisive solutions to safely take care and follow these patients in the recovery phase, as well as to alleviate the burden of healthcare structures, in order to reach the majority of people and in the presence of the need for social distancing. The study aims at verifying the feasibility and level of users’ satisfaction of a tele-health service that provide therapeutic education protocols for people recovering from Covid-19. An average of 350 accesses per day have been registered on the platform since 31 March to 30 June 2020. 50 people answered the users’ satisfaction questionnaire and declared no side effects and a good effectiveness (median 7.5/10) to manage fatigue and anxiety. Most subjects (66%) were people hospitalized for Covid-9 and discharged home (32,6%,) or exclusively treated at home (27,6%), instead, 11,6% of subjects were still convalescent in hospital. In conclusion, tele-health was appreciated, safe and possibly useful to integrate rehabilitative management of subjects recovering from Covid-19.

Keywords: Covid-19 · Deconditioning syndrome · Telemedicine · Web platform

1 Introduction

The current pandemic due to SARS-COV-2 is characterized by an acute respiratory syndrome (Coronavirus disease-19: Covid-19) that requires hospitalization in about 18.4% cases [1]. According to recent scientific literature, at least half survivors shall suffer from
a mild to severe deconditioning syndrome, fatigue, muscle wasting and pain, dizziness, very low tolerance to minimal efforts, depression and anxiety, or even from post-critical neurological syndrome and peripheral neuropathies [2, 3]. The rehabilitation assistance changes according to the disease phase: in the acute phase, the involvement of the rehabilitation team is invoked by many but the indications are not fully shared and access to facilities is complicated. Subsequently, in relation to the possible high incidence of residual disabling respiratory, cardiovascular and neurological complications, there is the need for resources dedicated to promote the recovery of autonomy and the management of disabilities in the long term. Anyway, COVID-19 pandemic is determining several degrees of confinement that will continue until a SARS-CoV-2 vaccine will be made available for the greatest part of the population. Currently, the pandemic represents a barrier to the implementation of adequate outpatient and home-based care [2, 4]. Rehabilitation providers will serve as an important link in the continuum of care, helping move patients from acute wards back to the community.

Rehabilitation may be effective for recovering from post-Covid-19 syndrome and widespread experience and expert opinions suggest potentiating tele-health systems and home-based care services in order to improve health-care [3, 5, 6] and to overcome the barriers determined by the need for social distancing and reorganization of clinical care. Indeed, recent evidence reports several criticalities and difficulties in providing enough support to patients during the transition from hospital to home [2, 7].

Innovative approaches to care, such as home-based rehabilitation, are likely to become common in this environment [8]. The use of technology for a remote monitoring and telerehabilitation seems desirable to optimize the times of taking charge and facilitate dissemination by reducing the cost/benefit ratio [9].

Telerehabilitation is a branch of telemedicine. Although this field is considerably new, its use has rapidly grown in developed countries during the last ten years. It showed to reduce the costs of both health care providers and patients compared with traditional inpatient or person-to-person rehabilitation [10]. Furthermore, it allows to reach patients who live in remote places or need distancing, where traditional rehabilitation services may not be accessible, and to provide personalized rehabilitation programs, potentially increasing the intensity and efficacy of treatment as well as the patient empowerment [11]. However, certain disadvantages of telerehabilitation, including skepticism on the part of patients due to remote interaction with their physicians or rehabilitators, arose from literature review [10]. The change was forced due to Covid-19 emergency, when telemedicine shows to be a useful resource to be integrated in usual rehabilitation care, to common practice, especially for screening, follow-up and treatment [9]. Technology is ready, using digital biomarkers coming from smartphones, wearable sensors, smart homes and through web platforms.

The study aims to verify the feasibility and level of user satisfaction of a telemedicine service that provides therapeutic exercise protocols for people recovering after Covid-19. Secondly, perception of the improvement of fatigue and anxiety after the training by users who had trained themselves using the platform facilities was also evaluated.

The paper is structured as follows: Sect. 2 describes the telemedicine platform, the educational content, and the clinical metrics adopted for data analysis; Sect. 3 reports study results; Sect. 4 discusses the results and Sect. 5 draws conclusions.
2 Materials and Methods

2.1 The Telemedicine Platform

An original therapeutic education program, available for free in Italian and English language, was published online since March 31, 2020 by a multidisciplinary team. The education program is hosted on a web platform, that is accessible from any device (smartphone, tablet, laptop) and any operating system (Android, Windows, iOS) at the url https://www.rehab-univpm.it/public/#/covid. The web platform was developed as a standard client-server architecture, where the client was implemented as an Angular application and the server through a Microsoft.Net Framework, as shown in Fig. 1. The educational program can be accessed publicly without the need of login or credentials.

Fig. 1. The web platform architecture.

User interfaces and web pages were developed to enhance usability and accessibility, given the wide range of possible users. In particular, Web Content Accessibility Guidelines were followed for a correct design of web pages [12]. Some screenshots about web page and navigation are provided in Fig. 2. The training interface shows the exercises progression within the session of the current day; the user is free to consult the video and pass to the next exercise whenever he/she is ready. A text box is always present to provide a resume of the current exercise together with fundamental notes, important for a correct execution of the exercise itself.

2.2 Users and Educational/Therapeutic Content

The target users are rehabilitation specialists (physiotherapists or clinicians), who are willing to prescribe exercises and people in the recovery phase after Covid-19 that can use the web platform remotely through any device, and subjects who are recovering from Covid-19, and are out of the acute phase of pneumonia. The educational material is composed of a selection of 28 footages displaying as many exercises for the respiratory and limb muscles, with an audio tutorial giving specific instructions on how to perform correct movements. These educational contents are stored on the web platform and organized in 3 different educational courses (scenarios) that users can follow to correctly and effectively train themselves.
The platform provides two type of training protocols (i.e. scenarios), either dedicated to motor and respiratory recovery, each including a series of exercises characterized by progressive intensity and difficulty, to be performed for about 10–15 min twice a day, for 5 days a week for two weeks. The two scenarios differ in intensity and type of exercises to adapt to different clinical and functional conditions. The educational exercise protocols automatically progress forward with the click of the user.

In fact, the scenarios fit different needs on the basis of the Covid-19 severity. In detail, the user can choose among:

- Scenario 1: for people discharged at home after hospitalization in intensive Care unit or other not intensive ward after Covid-19;
- Scenario 2: for people quarantined at home due to mild symptoms of a Covid-19 infection.

In addition, all the 28 exercises (videos) are available from a third page to allow the creation of personalized educational protocols, by clinicians who wish to escape from using the pre-established training protocols. At the beginning of each protocol there are warnings alerting users to take precautions to avoid complications such as falls. It is recommended to use the site following the prescription and under the supervision of a therapist or physician.

Symptoms or signs (i.e. fever) of pneumonia or concomitant diseases contraindicating exercise (ischemic cardiomyopathy; heart attack in the last three months; cardiac arrhythmia; uncontrolled hypertension; heart failure; severe chronic ventilatory failure) must be denied by users.
A booklet, available online on the platform, provides all detailed information about the use of the health system.

Users were asked to use the Borg scale and Barthel’s dyspnea scale before and during training. These measures are only for users to increase safety and allow them to self-monitor their performance. The scores were not registered on the platform, so they cannot be used as a study outcome measure. A detailed description of the two scales and how to use them is available in the booklet.

### 2.3 Assessment Methods

An anonymous questionnaire, built up following the suggestions of Langbecker et al. [13] was uploaded on the telemedicine platform starting from 30 April 2020 in order to acquire data on: feasibility and satisfaction with the project, perception of fatigue and anxiety during the COVID19 pandemic and, possibly, symptom improvement after completing the exercise protocol.

In particular, the survey asks for information on the reason why the platform was visited, what gender (male/female) and age group (<20 years; between 21 and 40; 41–60; 61–80; >80 years) the users belonged; in which region they lived, how did they became aware of platform; whether they were admitted or not to hospital due to COVID19, what severity of anxiety and fatigue had they suffered in the last month (NRS scale from 0 to 10), if they had used the platform to train themselves and how much they felt improved in terms of fatigue or anxiety (NRS scale from 0 to 10) after training; what part of the project they judged as most useful and if they liked it (on a Likert scale ranging from 0 to 5). Finally, the users were free to provide advice or comments as free text.

The link to the questionnaire is displayed on the Covid-19 programs entry page (https://www.rehab-univpm.it/public/#/covid), so that users can fill it whenever they want.

The satisfaction analysis was conducted on the replies received from March 31, 2020 to September 30, 2020.

The primary study outcome measures for each endpoint are as follows:

- feasibility: web platform visits, page views and how many subjects used the web platform to train or train patients with respect to visits to the web platform and pages viewed.
- project satisfaction: average score obtained when asked: What is your level of satisfaction with the contents of the project?

### 3 Results

The web platform registered an average of 220 visits and 623 page views per day from the 31th of March to the 30th of September. The trend of page views and platforms visits is shown in Fig. 3.

The users’ satisfaction questionnaire was answered by 50 people from the 31th of March to the 30th of September: 40% were male, 68% were between 40 and 60 years old. 62,8% used platform to perform the training and 16,3% to recommend
it (physiotherapists); the remaining 20.1% visited our web pages for information or curiosity.

32.6% of the overall sample were people hospitalized for Covid-19 and discharged at home, 11.6% were still convalescent in hospital, 27.6% have been treated at home. Most (70%) people were from northern Italy and got knowledge of the platform browsing the web (47%) or through scientific associations (34%).

80% subjects, who reported a post-Covid-19 syndrome on the questionnaire, complained of fatigue during Activities of Daily Living (ADLs) of a mean level of 6.5 ($\sigma$: 2; Median:7; Range = 1–10) in a 1–10 Numeric Rating Scale (NRS). The perceived improvement after the training was 6.5 ($\sigma$: 2.4; Median 7.5; range: 1–9). About 64% suffered from moderate to severe anxiety symptoms and 54% perceived improvement after training. In a 1–5 NRS, the level of satisfaction with respect to the contents of the project was 4.4 ($\sigma$: 7, median 5, range: 2–5). Some problems with audio emerged and no side effects were reported.

![Average values: 623 page views 220 visits](image)

**Fig. 3.** Trend of web site visits and page views between the end of March and the end of June 2020.

### 4 Discussion

The platform was first published online in March 2020 to cope with consequences of Covid-19 and to overcome the barriers created by the need of social distancing in a pandemic era.

The number of web platform visits and page views demonstrates the importance and usefulness of a tele-health approach to integrate rehabilitative management of subjects recovering by Covid-19. The trend of platform accesses reflects the trend of SARS-Cov-2 contagions and health emergence.

The questionnaire data highlight the persistence of fatigue and anxiety after recovery from Covid-19, as reported by almost 80% and 64% of respondent, respectively [6, 7, 14].
Little is known about the follow-up healthcare needs of patients hospitalized with coronavirus disease 2019 (COVID-19) after hospital discharge. Loerinc et al. showed that the majority of patients were discharged directly home (90.6%). Seventy-five patients (24.2%) required any home service including home health and home oxygen therapy.

Due to the unique circumstances of providing transitional care in a pandemic, post-discharge providers must adapt to specific needs and limitations identified for the care of COVID-19 patients.

The questionnaire responses indicate a perceived and effective usefulness of this tele-education service as indicated by the high percentage of respondents that accessed the platform to follow the educational scenarios as well as the high average perceived improvement reported about the post infection syndrome and the high average satisfaction level.

The platform resulted highly appreciated by users, both care providers and patients. Some limitations exist in this kind of tele-rehabilitation implementation if patients are without a functional diagnosis or severely disabled or lack of monitoring systems.

Finally, specific regulation is warranted to manage privacy issues and face the cybersecurity challenge in an effective way.

5 Conclusion

Tele-health is appreciated, safe and possibly useful to integrate rehabilitative management of subjects recovering from Covid-19. Controlled studies should be implemented to confirm these preliminary results.

Furthermore, a second wave has unfortunately started, followed by a corresponding increase in web platform accesses. In a near future, data collected during this second wave will be evaluated to deepen the effectiveness of the proposed approach.

References


An Edge Ambient Assisted Living Process for Clinical Pathway

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Abstract. The adoption of digital tools in the health sector is a need driven by optimizing processes and improving collaboration between different stakeholders. Exploiting data is the principal activity of the eHealth sector, even vital for some patients’ clinical conditions because its monitoring can help prevent adverse events or disease degeneration. However, the actual use of electronic clinical information to evaluate human decisions against predefined protocols or statistically known evolution patterns is still mostly under-exploited. Clinical Pathway is the primary tool for implementing clinical guidelines and evidence-based medicine. It is used to improve the care processes by monitoring changes in clinical practices to reach the best appropriate care more quickly and reduce the health system’s costs. In this work, we present an Edge architecture for Ambient Assisted Living in the context of home hospitalization. Using process mining techniques helps understand patients’ behaviours, assess their compliance with the corresponding clinical path, and support physicians in making decisions broadly and transparently.

Keywords: Healthcare · Clinical Pathway · Ambient intelligence · Internet of Medical Things · Edge computing · Process mining · Robotics

1 Introduction

One of the objectives of medical science is the so-called personalized or “precision” medicine. It aims to allow differentiated therapeutic paths for each patient based on the biological characteristics of pathology and aspects of their clinical history, their characteristic elements, and the environment in which they live. In this scenario, the Clinical Pathway comes into play as a tool to provide
a standard definition of treatment models and help clinical decision-makers to obtain comparative data relating to the thematic areas on which to make choices [15]. An in-depth analysis of the Clinical Pathway suggests that, considering the clinical path as a process model, it is characterized by two main phases: (i) some activities, or sub-processes, that can be managed by the health personnel of health structures; and (ii) some others that can be managed autonomously by the patient, in a sort of medical-unsupervised manner. Hence, we envision that the latter phase can be processed by an intelligent architecture able to deal with the specific clinical sub-path for the patient at home, check doctor or nurse validation, and guarantee its compliance with the actual medical indications specified in the clinical path.

This idea would benefit patients and caregivers since monitoring patients is a continuous challenge: the ratio between medical personnel and the population is continuously decreasing. Thus, access to medical treatments is slowing even more. Despite the benefits given by its applicability, the research related to Clinical Pathway offers different challenges problems. The Clinical Pathway is complex and multifaceted: it is not just confined at the time of the medical consultation or the diagnostic examination. Still, it extends to a series of steps that the patient must take autonomously without the supervision of anyone. In case of hospitalization, the Clinical Pathways steps would be managed by a nurse who takes care of the patient.

In recent years, in the healthcare system, the theme of Ambient Assisted Living (AAL) has been widely used through “domiciliary hospitalization”, which promotes the assistance of a patient at home [2]. Artificial Intelligence (AI) techniques, Internet of Medical Things (IoMT), and mobile technologies can play a fundamental role in supporting patients at home, constantly monitoring vital parameters, evaluating a potential degradation of health conditions, also requesting the intervention of clinical staff in case of emergency. The wide use of medical, environmental and interactive devices with constrained storage and processing capabilities allows us to state that every single device available in a smart home can convey helpful information to be aggregated, analyzed and processed. For this purpose, healthcare is rapidly moving towards a new direction, which we call an alternative “3-d paradigm”: devices, data and (predictive) diagnostics. Starting from the devices, it is possible to capture all the data processed with Machine Learning (ML) techniques to create predictive diagnostics that would foster, encourage, and adapt to the patient’s usual activities at home.

In this way, the patient’s activities would be checked and compared to the assigned Clinical Pathway, which can be handled as a process model in a Process Mining evaluation phase, such as the Conformance Checking [11].

In this paper, we propose an architecture that, in an AAL fashion, exploits AI and Edge Computing paradigms to unleash the potential of (medical) end-device connectivity. This proposal thus aims to support telemonitoring, systems for clinical decisions, effective management of health emergencies and strict compliance with a Clinical Pathway assigned to a patient at home.

This paper is organized as follows. Section 2 provides an overview of related work and technologies investigated as background knowledge.
Section 3 defines the Edge process creation and describes the Edge architecture, which synergically leverages medical end-devices, edge nodes and cloud nodes to perform AI tasks such as machine learning and Process Mining. Section 4 describes the possible scenarios of application designed explicitly for our approach, such as a cardiovascular failure care pathway and rehabilitation care pathway at home. Finally, Sect. 5 concludes the paper, outlining future works.

2 Background and Related Work

Let us first introduce some terminology. A process consists of a suitable combination of different tasks performed by agents. A task is a generic piece of work to be executed. An activity is the actual execution of a task by an agent. A process model (or workflow) is a formal specification of how a set of tasks can be composed to give rise to valid processes. Allowed compositional schemes include sequential, concurrent, conditional, or iterative execution. A case is a particular execution of activities according to a given workflow. Case traces are lists of events associated with steps (time points). Events of several traces may be collected and interleaved in logs.

In the clinical field, the term compliance describes a patient’s conduct: the adherence to prescriptions, defining to which extent a patient’s behaviour (taking medications, adhering to diets, lifestyle changes) coincides with the doctor’s recommendations. The compliance of the individual clinical procedures represents a problem for the quality of care and the entire health system. For this reason, the Conformance Checking technique provided by Process Mining would help us to identify the analogies and discrepancies between modelled behaviour (the workflow) and observed behaviour (the case traces) [10].

In this respect, AAL systems should exploit contextual information to adapt to user needs and enable tasks independently.

In human routines modelling, specifically in the case of Clinical Pathways, it is essential to consider the flow of human activities. This is why it is common to use workflows as a routine representation tool. As depicted in Fig. 1, a workflow can be seen as a Petri Net [1]. This expressive formalism can represent activities and their flow and allows the development of techniques to handle concurrency. Workflows describe human behaviour, showing the succession of activities carried out by the user. In smart contexts or intelligent environments, this enables to respond to an action with services appropriate to the particular situation.

Therefore, having defined the overlap between workflow and clinical path as the sequence of events that a patient performs, this can be assessed in terms of completeness and correctness to ensure adherence to the physician’s prescriptions (e.g. medicines before meals, measuring blood pressure before/after a walk, etc.).

To improve the performance of the system, at this stage, it is necessary to bring the process evaluation component on-board the edge module.

An example of organizational healthcare processes analysis has been proposed by [13]: the combination of event data and process mining techniques allows
them to analyze the operational processes within a hospital-based on facts, thus providing a solid basis for managing and improving processes within hospitals. In [12] an ontological model for the audit of the Clinical Pathway is proposed to improve the quality of services and reduce hospital costs. While, a methodology to develop a clinical or dynamic treatment path to facilitate the diagnosis and treatment of patients with Heart Failure, relying on machine learning techniques, is in [16].

A literature review proposing a taxonomy of clinical pathway problems and exploring the intersection between Information Systems (IS), Operational Research (OR) and industrial engineering is available in [6]. While in [21], the authors analyze the context-awareness and the adaptivity in executing daily living care pathways in AAL scenarios. The studies conducted in [14,22] were investigated throughout the introduction of Process Mining techniques to analyze, optimize, and improve Clinical Pathways. Authors in [3], instead, provided a formalization of the methodological and technological approach to Clinical Pathway, improving the way patients are monitored.

Due to various challenging issues, such as computational complexity, Edge Computing is a disruptive and promising solution that pushes substantial processing and storage resources from the network core to the network edge, close to mobile devices or sensors. In particular, AI on Edge is emerging as a new paradigm to leverage medical devices and applications connected to remote (and potentially distributed) Hospital Information Systems (HIS) through the Internet. Its pervasive diffusion is promoted by the massive usage of smart and wearable devices and Internet of Things (IoT) communication technologies in the healthcare domain. Authors in [5] showed how AAL is increasingly gaining momentum thanks to the IoT. Edge-Computing would boost AAL success since this kind of architecture promotes a sort of distributed cloud computing at the edges of the IoT network, thus reducing latency and improving reliability. AAL promotes the assistance of patients at home according to their Clinical Pathway, i.e., a set of diagnostic and therapeutic procedures related to the treatment of that specific patient. Authors in [18,20] shed light on the IoT potentiality in the integration and harmonization of data produced by Cyber-Physical

Fig. 1. Example of Clinical path depicted by a Petri Net in which circles represent states and boxes represent transitions between activities (i.e., a, b, c, . . . , and so on).
Systems (CPS) with those already present and generated by classical information systems, thus combining people, processes, data, and things. While, works in [17,19] dealt with a clinical and operational context to develop integrated solutions for seamless care in which AI and IoMT are used at the Edge, with a people-centered approach that adapt to the needs of healthcare providers and that are embedded into their workflows.

Finally, Ardito et al. in [4] present an approach to combine IoT technologies with End-User Development (EUD) paradigms and tools to identify innovative scenarios where end users are directly involved in the creation and customization of the AAL systems they use.

3 Edge Process Approach

3.1 Edge Process Definition

The Clinical Pathway process can be broken down into multiple nodes. These can be represented through the use of a Petri Net, as in Fig. 1.

Using a formal notation, the following definition is proposed.

**Definition 1.** The execution of a process $\sigma$ is described as a sequence of actions $\sigma = \langle a_1, \ldots, a_n \rangle$, where $a_1, \ldots, a_n$ is the sequence of the single activities carried out by the user in a specific and strict order. We denote with $l_\sigma = n$ the length of $\sigma$.

When the patient’s hospital is discharged and return home, the patient’s task is to follow the doctor’s prescription to preserve or improve the clinical situation. The prescription is transformed into a series of steps that make up the patient’s clinical path and must be performed autonomously. When monitoring occurs at home, we introduce a new layer of supervision to replace the medical staff, as shown in Fig. 2.

Patients are equipped with an edge component capable of processing the trend of the patient’s behaviour on-site in a self-consenting and self-assessing way. The portion of the clinical pathway that needs to be supervised at home can be considered a subset of actions that the edge component will have the task of verifying. Formally:
Definition 2. Given an execution process $\sigma$, an execution of a sub-process $\tau$, managed without supervision, is described as a sequence of actions $\tau = \langle b_1, \ldots, b_m \rangle$, with $l_{\tau} = m$, $\tau \subseteq \sigma$ and $l_{\tau} \leq l_{\sigma}$, and where $b_1, \ldots, b_m$ is the sequence of single activities, arbitrarily carried out by the user.

3.2 AI on Edge Architecture

In this section we present the proposed Edge Computing architecture that allows the processing to be done at the devices (i.e., end-nodes), or the gateways (i.e., edge nodes). This will reduce unnecessary data traffic and processing latency, and it is essential for applications such as critical patient monitoring and analysis. In an AAL scenario, we deal with a large number of heterogeneous devices which differ from each other in computational, storage and communication capabilities.

Therefore, the Architecture depicted in Fig. 3 presents a Medical End-Devices Layer and an Ambient Interactive End-Devices:

1. **Medical Devices**: any device intended to be used for medical purposes, such as the diagnosis, prevention, monitoring, treatment, alleviation or compensation of a disease or an injury.
2. **Ambient and Interactive Devices**: any type of mobile or stationary hardware component which enables the interaction between the human being and an application or the environment of the user, characterized by their ability to be perceived at-a-glance, such as smartphones, speech recognition devices, wearable devices, motion sensors, cameras, smoke sensors, etc.

Fig. 3. AAL edge architecture.
A patient is asked to actively or passively interact with these devices: wearable sensors can listen to the body without any particular interaction, environmental sensors remain passive to capture domestic events. In contrast, medical devices for vital signs acquisition may require some interactions. In particular, thanks to a mobile device, such as a smartphone or tablet, some notifications may be sent to the patient to confirm an inferred health status or to remind activities according to the clinical pathway. At the upper level, there is the Edge Layer made of one or more edge nodes which can be a nearby end-device connectable by device-to-device (D2D) communications [9], a server connected to an access point (e.g., WiFi, router, base station), a network gateway, or even a micro-datacenter available to nearby devices. We envision that an Edge node can collect valuable information from medical, ambient and interactive end-devices and process them for a particular purpose. In the Edge Layer, a node is designed to execute Conformance Checking on a predefined sub-process of the Clinical Pathway, another node may be used as an Anomaly Detection Module for the gathered data, and a third node can be adopted as Adaptive ML Module for prediction of clinical risk classes of a continuously monitored patient in a particular condition where a limited number of vital parameters is promptly available.

As depicted in Fig. 3, the edge nodes can communicate with each other and exchange the results of a preliminary edge processing step. For security reasons, the Edge Layer is interconnected through an integration and security layer that allows it to securely convey messages and notifications to hospitals [7]. Finally, the Architecture presents a Cloud Layer in which gathered raw data and processed data (at the Edge) are conveyed to optimize the overall performances and provide a refinement of the clinical pathway in case of patient’s condition degradation. In this way, the Cloud Layer would act as an intermediary, by receiving any request and/or alert sent by the Edge Layer after the measurement of specific vital signs, and by activating specific operating protocol with the hospital or the clinical staff, thus supporting a (remote) complex and adaptive decision making process.

### 3.3 Assessment Methodology

The proposed Edge architecture provides a patient enrollment layer to associate patient types with specific monitoring types (e.g., chronicity). The Edge infrastructure finds the most appropriate Clinical Pathway model by connecting to cloud-based Hospital Information System (HIS) and downloading the clinical sub-pathway as a validated sub-process model. The implementation of the monitoring phase involves the elicitation of a series of medical devices that allow the collection of data. These are sent to the Edge module that transforms them into logs in a standard format (e.g., eXtensible Event Stream, XES), compatible with process mining techniques. The analysis of logs can be performed immediately for each execution of every single step (i.e., measuring pressure, taking a drug, etc.) to verify compliance with the model. Alternatively, in less severe clinical pathways, it can be carried out at the end of the period (e.g., a day) to assess the risk level on single activities or the entire pathway. In case of non-compliance
between the execution instance and the model, the Edge module reports the problem to the medical staff. Figure 4 shows the executions of the Clinical Pathway steps performed by the patient. The translation of these actions into a formal notation makes it possible to use algorithms that check conformance and detect a possible deviation from the model. Proceeding by differences, it is able to highlight missing actions (e.g., forgetting to take a drug) or temporal order that has a clinical value in the treatment path. Therefore, the result is translated into corrective actions that can also be defined to direct executions towards the correct path and provide patients with objective feedback on their behaviour.

### 3.4 Patient Data Security and Reliability

The proposed architecture also aims to address privacy management, which is a challenge in patient telemonitoring: this is the real-time exchange of vital parameters and events triggered by the devices in use in the domestic environment. eHealth services must flow through reliable and low latency services and devices as network problems can cause a critical patient condition. Thanks to edge-based artificial intelligence, our architecture provides the foundation for ensuring data sharing with a high level of security, so patient information is stored and processed locally [8]. Only the less time-consuming datasets can be moved to the cloud, while the rest remain locally, reducing sensitive data transfers [23]. In addition, we have introduced a level of integration and security: based on an Enterprise Service Bus, which allows us to create a secure connection channel between the edge in patients’ homes and the hospital. This channel will enable us to access health information systems using standard interoperability protocols such as the latest version of HL7, namely FHIR (Fast Healthcare Interoperability Resources). It implements a security layer for access, authorization and visibility of sensitive patient data by equipping the architecture with standard protocol for health interoperability.

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**Fig. 4.** Execution of Clinical Pathway steps by the patient.
4 Usage Scenarios

In this section, we present three usage scenarios for clinical pathway handling on Edge. The first one is an IoMT-based scenario, while the other two are based on the use of a Robot.

4.1 Post-heart Failure Clinical Pathway

Heart failure patients will be discharged from the hospital cardiology department after surgery. They are provided with a kit of medical devices and an Edge module. They live alone and have difficulties in managing their illness. They should follow an appropriate diet, take the right amount of drugs and adopt an active lifestyle. The Edge module downloads the patient’s clinical pathway from the cloud and enables the steps that must be activated at the patient’s home. Based on the types of activities to be performed, the appropriate medical devices are involved in detecting and checking different vital parameters. For example, activating the pill dispenser to monitor the intake of drugs; activating the pressure meter to verify the patient’s clinical status. In this way, the patient feels safer because they are monitored and informed about their illness, possible complications, and activities. The healthcare staff at the medical Control Room, through the monitoring system, receives the monitoring data, checks the progress of the clinical pathway and evaluates any health alterations that could require a change of therapy or a possible re-hospitalization. The patient and his relatives are more relaxed and live the discharge from the hospital more serenely as the Edge infrastructure ensure a high degree of surveillance and proactive collaboration.

4.2 Home Hospitalization with Collaborative Robots

We envision creating a smart home environment where a robot has a crucial role. The first scenario consists of the monitoring of the patient in his home. The Medical Devices measure the person’s vital signs, and they send data at the Edge Layer, where algorithms for anomalies detection are executed to identify potentially dangerous situations. If the algorithms observe suspicious values, they can trigger two kinds of alarms:

- **Minor alarm**: the robot reaches the patients to verify their health conditions. With its cameras, the robot analyzes their state of consciousness and observes pain expressions on their face. Moreover, with a dialogue system, the patient can be cognitively stimulated. If the data gathered in this phase show a low level of interaction between the patient and the robot, a major alarm is triggered.
- **Major alarm**: if it has not already been done, the robot, controlled by a remote health professional, reaches the patient. The health professional can verify the patient’s status through the robot cameras and can use its actuators to perform a physical interaction.
The second scenario refers to the execution of physical rehabilitation activities. The robot reminds the scheduled exercise to the patients. If the patients are reluctant, the robot uses persuasion mechanisms to convince them. The robot can also ask the person to wear medical devices to monitor vital signals. During the exercises, the robot monitors the correct execution. Through computer vision algorithms available in the Edge Layer, it is possible to detect if the exercises are correctly executed. The robot’s cameras track the patient’s body joints; their coordinates are sent to the Edge Layer, where the algorithms check the correctness of the exercises. The result is sent back to the robot that possibly, suggests correction or encourages the patient to continue.

5 Conclusion

This work proposed a level of unmanned supervision, based on Edge Computing and AI techniques, which can somehow govern the steps of the Clinical Pathway that the patient should follow autonomously at his home to avoid worsening of his clinical conditions and bring him to a speedy recovery. The paper shed light on formal aspects of executing process mining tasks in an Edge infrastructure, in which activity logs are collected by data coming from medical, mobile, and interactive devices, in the spirit of IoMT perspective. Further aspects focused on the logical structure of the Edge architecture and the communication protocols to be adopted in an AAL scenario. Also, three usage scenarios were described to explain the context in which we rely. Plenty of advantages are obtainable by introducing an edge architecture in the home environment since the possibility of supervising the environment and governing the devices on-site enables a more responsive and effective patient monitoring. The integration of a wide range of devices that collect information of different types allows improving monitoring activities to reduce false positives in alarms. Furthermore, this type of architecture extends the limits of the hospital ward by transforming domestic environments into branches of it. The possibility of understanding the patient’s actions can be considered the first step towards a digital twin model of healthcare personnel to reduce unnecessary travel around the area. Future works will be devoted to the multitude of capabilities and opportunities that the Edge module would address. Investigations will include Recommender Systems to perform a more human-understandable interaction and Robotic Process Automation (RPA) to develop a more fine-grained integration of industrial automation. In particular, we will delve into fundamental aspects of data security at AI on the Edge level. For instance, cognitive security will combine the strengths of AI and human intelligence, learning at each interaction to proactively detect and analyze detected threats and provide the physician with an explanation of the intrusion. In doing so, we will be able to correct the patient’s clinical path immediately. But not only, but the potential of AI and robotics in the diagnostic and therapeutic field will also be revolutionary both in terms of “personalization” of assistance and diagnostic-therapeutic precision.
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References

Author Index

A
Accetta, Luigi, 249
Addante, Filomena, 249
Alloatti, Francesca, 163
Amantea, Ilaria Angela, 163
Amorese, Terry, 85
Andò, Bruno, 37
Andrenelli, Elisa, 355
Apuzzo, Gian Matteo, 102
Ardito, Carmelo, 363
Arimgolo, Michela, 355

B
Bacchin, Davide, 117
Baglio, Salvatore, 37
Becchimanzi, Claudia, 18
Bettelli, Alice, 153
Bianchi, Luca, 102
Biba, Jorilda, 346
Billeci, Lucia, 346
Bisoglio, Paola, 355
Boella, Guido, 163
Bollioli, Andrea, 163
Bonaccorsi, Manuele, 50
Burlando, Francesco, 175
Burzagli, Laura, 129

C
Campagnaro, Valentina, 117, 153
Campana, Gianluca, 117
Capecchi, Marianna, 355
Caroppo, Andrea, 205, 249
Casacci, Paolo, 235, 291
Casiddu, Niccolò, 175
Castorina, Salvatore, 37
Cavallo, Filippo, 18, 50, 73, 85, 216
Ceravolo, Maria Gabriella, 355
Cesario, Lisa, 259
Cesta, Amedeo, 3
Ciccone, Filomena, 50
Ciliberti, Francesco, 249
Cima, Rossella, 355
Cinello, Michela, 102
Cipolletta, Sabrina, 117
Clerici, Daniela, 272
Coccia, Michela, 355
Colcelli, Valentina, 129
Conte, Raffaele, 346
Cordasco, Gennaro, 85
Cortellessa, Gabriella, 3
Crispino, Ruben, 37
Crivello, Antonino, 335
Cuciniello, Marialucia, 85

D
D’Angelo, Gennaro, 346
D’Onofrio, Grazia, 50
Dainese, Giulia, 117, 153
De Benedictis, Riccardo, 3
De Marchi, Fabiola, 163
De Vita, Chiara, 102
Debono, Carl J., 37
Desideri, Lorenzo, 259
Di Girolamo, Marco, 50
Di Noia, Tommaso, 363
Di Nuovo, Alessandro, 216
Di Santo, Simona Gabriella, 291

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Dionisio, Pietro, 50
Diraco, Giovanni, 315

E
Ercolani, Lauredana, 355
Esposito, Anna, 85

F
Fasciano, Corrado, 363
Ferraris, Claudia, 272
Fiorini, Laura, 18, 50, 216
Franchini, Flaminia, 291

G
Gamberini, Luciano, 117, 153
Gambi, Ennio, 189
Gambi, Anna, 355
Geli, Simona, 50
Gherardini, Arianna, 259
Giuliani, Francesca, 50
Giusto, Francesco, 249
Grippaldi, Adriana Zoe, 117

H
Hibel, Margherita, 355

I
Iossa, Antonio, 259

K
Kim, Jaeseok, 73

L
La Rosa, Davide, 335
Lambertucci, Alice, 355
Leone, Alessandro, 205, 249, 315
Loﬁ, Domenico, 363
Loizzo, Federica G. C., 216
Losco, Giuseppe, 139

M
Macchiarulo, Nicola, 363
Malavasi, Massimiliano, 259
Mallardi, Giulio, 363
Manni, Andrea, 205
Mapelli, Daniela, 117
Marletta, Vincenzo, 37
Marsi, Elisa, 102
Mauro, Alessandro, 272

Mazzini, Letizia, 163
Minichielo, Immacolata, 346
Mondini, Sara, 117
Montanari, Carlo, 259
Moro, Tatiana, 153
Motolesi, Maria Rosaria, 259
Muscato, Giovanni, 37

N
Nanni, Stefania, 259
Narne, Edoardo, 153
Nerino, Roberto, 272
Nocentini, Olivia, 73

O
Orso, Valeria, 153

P
Paciotti, Davide, 139
Paggetti, Cristiano, 50
Palumbo, Filippo, 335
Paoli, Antonio, 153
Patrono, Luigi, 249
Pazienza, Andrea, 363
Pepa, Lucia, 355
Pigliapoco, Martina, 355
Pistoia, Massimo, 235, 291
Pistolesi, Mattia, 18
Pluchino, Patrik, 117, 153
Porcaro, Luca, 37
Porfirie, Claudia, 175
Pratali, Lorenza, 346

R
Radi, Lorenzo, 18
Raimondi, Gianfranco, 235
Rescio, Gabriele, 249
Ricciuti, Manola, 189
Rovini, Erika, 18, 50, 216
Russo, Sergio, 50

S
Salupo, Sebastiano, 37
Sancarlo, Daniele, 50, 249
Sancesario, Giuseppe, 291
Sansone, Francesco, 346
Senigagliesi, Linda, 189
Sergi, Ilaria, 249
Siciliano, Pietro, 205, 315
Sorrentino, Alessandra, 18, 216
Sozza, Alberto, 117
Spagnolli, Anna, 117
Spalazzi, Luca, 355
Sulis, Emilio, 163
<table>
<thead>
<tr>
<th>Author</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tagliaferri, Claudia</td>
<td>3</td>
</tr>
<tr>
<td>Tamburini, Elena</td>
<td>50</td>
</tr>
<tr>
<td>Theuma, Nadia</td>
<td>37</td>
</tr>
<tr>
<td>Toccafondi, Lara</td>
<td>50</td>
</tr>
<tr>
<td>Tonacci, Alessandro</td>
<td>346</td>
</tr>
<tr>
<td>Tosi, Francesca</td>
<td>18</td>
</tr>
<tr>
<td>Vacanti, Annapaola</td>
<td>175</td>
</tr>
<tr>
<td>Valori, Tanya</td>
<td>139</td>
</tr>
<tr>
<td>Vignani, Gianna</td>
<td>50</td>
</tr>
<tr>
<td>Vinciarelli, Alessandro</td>
<td>85</td>
</tr>
<tr>
<td>Vismara, Luca</td>
<td>272</td>
</tr>
<tr>
<td>Vitulano, Felice</td>
<td>363</td>
</tr>
<tr>
<td>Votta, Valerio</td>
<td>272</td>
</tr>
<tr>
<td>Wilhelm, Elisabeth</td>
<td>335</td>
</tr>
<tr>
<td>Zamaro, Gianna</td>
<td>102</td>
</tr>
<tr>
<td>Zanchiello, Sara</td>
<td>102</td>
</tr>
<tr>
<td>Zanella, Andrea</td>
<td>117</td>
</tr>
</tbody>
</table>