Brain-inspired computer vision with applications to pattern recognition and computer-aided diagnosis of glaucoma

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Chapter 5

Summary and Outlook

5.1 Summary

In this thesis, I focused on two main research streams. In the first part, I and my collaborators proposed an operator for object recognition, namely the inhibition-augmented trainable COSFIRE filter. Unlike the original COSFIRE filter, which relies on only excitatory input, the proposed filter is augmented with an inhibition mechanism which is qualitatively similar to shape-selective neurons in the IT area of visual cortex. The inclusion of the inhibition mechanism improves the discrimination properties and the performance of COSFIRE filters. Quantitative experiments on three applications demonstrate the effectiveness of the proposed inhibition-augmented COSFIRE filters.

In the second part of the thesis, I and my collaborators proposed a systematic approach to assist ophthalmologists with population-based glaucoma screening. The proposed method automatically detects visual features that are interpretable by ophthalmologists to quantify the risk of glaucoma. We experimented on eight data sets of retinal fundus images and evaluated the performance by comparing the automatically obtained results with those provided by an experienced ophthalmologist. The proposed approach is demonstrated to be effective in delineating the boundaries of the optic discs and achieves better agreement with respect to the manual annotations for large VCDRs, which indicate pathology.

Chapter 2 describes the proposed algorithm for augmenting the excitatory-only COSFIRE filter, which is configured by a single positive prototype pattern, by including a set of negative prototype patterns. The configuration of such a filter comprises selecting given channels of a bank of Gabor filters that provide excitatory or inhibitory inputs and determining certain blur and shift parameters. The response is computed by subtracting the weighted inhibitory input from the excitatory input. The quantitative experiments demonstrate the effectiveness of the proposed inhibition-augmented COSFIRE filters in three applications: the exclusive detection of vascular bifurcations in retinal images (DRIVE data set), the recognition and localization of architectural and electrical symbols (GREC2011 data set) and the recognition of handwritten digits (MNIST data set). In the first two applications, inhibition-augmented COSFIRE filters showed better discrimination ability. This is because in such applications it is common to find that a symbol is contained within another symbol of a different class, for instance, a bifurcation is contained within a crossover. In the third application, the descriptor based on the proposed inhibition-augmented COSFIRE filters results in a sparser representation and it contributes to a better recognition rate with less number of filters.

Chapter 3 focuses on the proposed computer-aided system for the analysis of retinal fundus images. In that chapter, I describe two algorithms that I and my collaborators propose for optic disc localization and diameter estimation, which are preliminary and necessary steps in most automatic screening systems for ophthalmic pathologies. The first approach uses circular Hough transform (CHT) to detect circular candidates for the optic disc and then selects the one that encloses the highest proportion of vessel pixels. The experiments on two public data sets, CHASEDB1 and ONHSD, result in the localization accuracies of 96.43% and 93.55%, respectively. For the diameter estimation, the CHT-based approach achieves relative errors of 10.69% and 8.78%, respectively. It turns out that this approach suffers from insufficient robustness with respect to retinal images with pathologies, in particular the ones that have signs of hard exudates. In the second approach, we use trainable COSFIRE filters that are selective for the divergence of vessel trees and bright disc patterns to localize the optic discs and then fit ellipses to their boundaries. The localization accuracies are 96.43% and 91.92% on the CHASEDB1 and ONHSD data set, respectively, while the relative errors on the diameter estimation are 10.74% and 8.53%, respectively. Further evaluation of the approach on more retinal images from eight data sets (including CHASEDB1 and ONHSD data set) shows an overall localization accuracy of 99.43%. For the diameter estimation, the average relative error is 9.05%.

Further progress on this application is made in Chapter 4, which describes the implementation of a systematic approach to assist ophthalmologists in glaucoma screening. The system consists of four steps: the localization and boundary delineation of the optic disc, the segmentation of the cup, the computation of the vertical cup-to-disc ratio (VCDR), along with a measurement that reflects the confidence of the system with regards to its performance. For the localization and boundary delineation, the second (COSFIRE-based) approach proposed in Chapter 3 is performed. For the cup segmentation step, we employ unsupervised clustering to segment the disc region into the neuroretinal rim and the cup. Finally, we compute the VCDR value that represents the ratio between the heights of the segmented cup and disc and provide a reliability score to indicate the confidence of the obtained value. We experiment on eight data sets and evaluate the performance of the proposed approach. For 1558 out of 1712 images on which the system provides confident results, the achieved mean VCDR error is 0.17 with respect to the manual annotations. The system provides very reliable delineation of the optic disc (MCC=0.90), from which we obtain its height. The segmentation of the cup, and thus the measurement of its height, turns out to be the most challenging part of the system (MCC=0.47). Bland-Altman analysis shows that the system achieves better agreement with respect to the manual annotations for large VCDRs, which indicate pathology. For the classification performance, the algorithm achieves an AUC of 0.74 when the ophthalmologist marks the images as healthy with VCDRs less than 0.7 and as glaucomatous otherwise.

The work presented in this thesis draws research interests from the design of computational models to practical medical applications in ophthalmology. It contributes to a novel idea for the development of computational models to visual pattern recognition and a promising solution to assist ophthalmologists in part of the population-based glaucoma screening program.

5.2 Outlook

The proposed work can be extended in the following directions for future research.

In the first part of the thesis, I and my collaborators focus on a brain-inspired computational model, namely inhibition-augmented COSFIRE filter, with applications to object recognition. In the configuration of such filters, we preassign the values of some parameters, for instance, the blurring and weighting parameters. A learning model that automatically determines the optimal parameter values from some training data can be investigated in the future. The output of the inhibition-augmented COSFIRE filter is currently modeled as the difference between the excitatory and the weighted inhibitory inputs from the afferent layer. Also here, learning algorithms can be investigated to determine the output function automatically.

The proposed approach has been demonstrated to be effective in three applications. In future, more applications that require localization and recognition of patterns of interest could also be investigated. In particular, medical applications require the detection and recognition of features that may indicate a certain pathology.

In the proposed inhibition-augmented COSFIRE filters, we consider only a feedforward approach. There is neurophysiological evidence, however, that the communication between neurons is not only feedforward but it also consists of feedback loops (Lamme and Roelfsema, 2000). Studies have shown that feedback connections carry predictions of expected neural activity from the higher to the lower cortical area and store temporal dynamics recurrently (Rao et al., 2002). This could be another direction in which the proposed inhibition-augmented COSFIRE filter approach could be extended. We speculate that this additional functionality could further improve the selectivity of the filters and thus broaden the applications where the filters can be applied.

In the second part of the thesis, the focus is on an important medical application in ophthalmology. The goal of this application is to detect all retinal fundus images that contain signs of glaucoma and forward them to medical experts for further analysis. In future work, I and my collaborators aim to investigate more sophisticated segmentation algorithms for the delineation of the cup within the optic disc. In particular, we will explore the fully convolutional network (FCN) (Shelhamer et al., 2017) that uses deep neural network for semantic segmentation. Another direction is to explore other glaucoma-related features besides the VCDR. These include hemorrhages inside the optic disc and the cup excavation. Subsequently, a fusion of classifiers can be investigated that combine all the relevant features and come up with a final decision of whether a given image has signs of glaucoma or not.