Multi-loop Hysteresis and Recursive Remnant Control

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Summary

Hysteresis is a non-linear phenomenon that describes a quasi-static dependence between variables of a system. Although hysteresis was originally found to affect the relationship between the magnetization and magnetic field of iron, hysteresis phenomena have been observed in different classes of systems in the past decades. For this reason, hysteresis has attracted the attention of scientists in different fields and the efforts to describe it have focused on so-called phenomenological models, which attempt to capture its behavior independently of the physical processes behind it.

A well-known characteristic of the systems that exhibit hysteresis is the loops that occur in the input-output phase plot when the input is periodic. In literature, we can find the characterization of the class of hysteresis behavior based on the orientation of these loops as clockwise or counter-clockwise hysteresis. However, complex hysteresis loops that exhibit a combination of sub-loops with both orientations have also been observed. This class of complex hysteresis behavior has been denominated butterfly hysteresis and has been observed in, for instance, smart-materials, optical systems, and mechanical systems. Despite the extensive literature on the analysis of hysteresis, the particular characteristics that would allow the current hysteresis models to describe butterfly hysteresis loops have not been well-established. In this thesis, we investigate two hysteresis models: the Preisach hysteresis operator and the Duhem hysteresis operator. We characterize conditions over these models parameters such that butterfly hysteresis loops can appear in their corresponding input-output phase plot under the application of periodic inputs.

We study examples of systems that include hysteretic elements based on our characterization. For instance, we analyze the classical problem of a Lur'e system whose feedback non-linearity is a Preisach butterfly operator, i.e., a class of Preisach operator that can exhibit butterfly loops in its input-output phase plot. Furthermore, inspired by a new class of systems whose working principle is based on using the memory effect of hysteresis to hold a particular output configuration, we introduce the so-called remnant control problem. We call remnant to the remanence in the output value of a hysteretic system whose input value has been set permanently to zero after varying within a compact time interval. Therefore, the remnant control problem surges from the idea to drive the remnant to a reference value. When dealing with physical systems, such as piezoelectric actuators, setting the input to zero after the remnant has attained its reference value can reduce power consumption and energy dissipation. We investigate a recursive algorithm capable of driving the output remnant of a Preisach butterfly hysteresis operator and a class of Duhem hysteresis operators. Being able to hold a particular configuration without the necessity of a constant input enables the time multiplexing of the control input in systems with multiple actuators that exhibit hysteresis. Based on this attribute, we also investigate and propose a control algorithm for a novel complex hysteresis-based system denominated the Hysteretic Deformable Mirror (HDM).