

Chapter 15

Identification and Response Prediction of Switching Dynamic Systems Using Interval Analysis

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ABSTRACT

A novel method based on interval analysis is proposed in this work for modeling and response prediction of SISO uncertain switching dynamic systems. To describe the system's dynamic in any operating mode, a local linear model is used. The validity domain of any local model is determined in system's input-output space. To take into account the modeling error, adjustable parameters of local models are considered time-varying and characterized by intervals of real numbers. A model whose parameters are characterized by intervals is called an interval model. A procedure is also developed to perform n -step prediction of system's response using the multi-mode interval model. Since the model parameters are intervals, the predicted response at any instant is not a real number anymore but an interval of real numbers. The set of predicted intervals at different instances generates a tube through time called wrapping envelope. However, the identification/characterization procedure proposed in the early stage of this work guarantees that the wrapping envelope includes the system's response taking into account possible modeling error and perturbations. This envelope can be used in diagnosis to supervise healthy operation of the system as well as in process safety analysis to guarantee that the physical variables of the system never enter in forbidden operating zones and the system remains in safe operating conditions.

INTRODUCTION

Modeling, parameter identification/characterization and response prediction of uncertain switching dynamic systems is of the most challenging problems

in control engineering especially in diagnosis and process safety analysis in which one wishes to calculate accurately system's response to determine whether the system is in healthy operational state/condition or to guarantee that it never enters in forbidden operating zones. This is classically performed with the aide of a mathematical model

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of the system whilst the latter usually describes the system's behavior in a simplified manner. This leads to a difference between the system's response and the predicted value called *modeling error*. There exist three major approaches to deal with this problem that are the deterministic, probabilistic, and set-membership approaches. In the deterministic approach, the model parameters are constant scalars and are adjusted in such way that a certain optimization criterion e.g. the power of the error is minimized. However, this approach does not provide any information on modeling error in prediction phase. An alternative is to use the probabilistic approach in which the modeling error is characterized by a probability density function (PDF). In this case, the PDF is used to calculate a probabilistic interval for the system's response at any instant. Though, it suffers from three major shortcomings:

- It is not always an easy task to characterize modeling error by a certain PDF,
- The properties of the PDF may be modified during iterative algorithms, and
- The existence of the system's response in the probabilistic interval at any instant is not guaranteed.

In the third approach, the model parameters are considered time-varying but bounded variables which are characterized by an interval of real numbers. Since the model parameters are intervals, the predicted system's response at any instant is not anymore a real number but an interval of real numbers. The set of predicted intervals at different instances generates a tube through time called *wrapping envelope*. If the model parameters are characterized properly, it is guaranteed by the inclusion property of interval analysis that the wrapping envelope includes the system's response (Neumaier, 2001). This fundamental property is the main motivation of exploring this approach in modeling, identification and response prediction of uncertain dynamic systems.

On the other hand, switching dynamic systems can always be described by single-mode interval models. However, wrapping envelope generated by single-mode interval model for the system's response is not generally precise enough to perform an adequate diagnosis or process safety analysis. One eventually can use multiple-mode strategy to improve the precision of the envelope; a multi-mode model consists of a set of local models in such way that any of them describes the system's behavior in an operating mode. Many research projects have already been carried out on multiple modeling among which (Takagi, 1985) is one of the early ones in control engineering. In this work, the input space has been partitioned in fuzzy sets and every partition has been described by a local model. The output of the multi-mode model has then be the fuzzy interpolation of the outputs of local models. Following the original work and in adaptive control, Tagaki-Sugeno-Kang and Quasi-Linear-Fuzzy models have been proposed in (Sugeno, 1988) and (Yager, 1993) respectively. T.A. Johansen and B.A. Foss also suggested a heuristic algorithm in which splitting the system's operating regime, structural and parametric identification are carried out in parallel and the validity of every local model is determined in input space (Johansen, 1995). The output of the multi-mode model is the weighted-sum of the outputs of local models. Another method has been proposed in (Venkat, 2003) in which system's input space is split into local zones to describe the non-linear dynamic of a chemical system. System's output is the fuzzy interpolation of the local models' outputs. A hybrid observer has been proposed in (Balluchi, 2001). The remarkable point in this work is that the observer consists of two blocks. The first block determines the active local model with respect to the system's inputs and outputs and the second block uses the information of the first block to estimate the system's state variables. This work has been followed by (Balluchi, 2002), (Ragot, 2003), (Babaali, 2005) and (Domlan, 2006). Other works which can be cited in multiple model approach

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