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Classification and statistical learning for detecting of switching time for switched linear systems

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HIGHLIGHTS

- Method for the detection of switching time.
- Clustering and classification approach.
- Statistical learning approach.
- Technique of detection given an explicitly estimation of switching time.
- To demonstrate the efficiency and feasibility of our approaches and validate the results obtained, we conducted a numerical example.

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ABSTRACT

In this paper, a new method for the detection of switching time is proposed for discrete-time linear switched systems, whose switching mechanism is unknown. The switching instant estimation problem consists to predict the mode switching for discrete behavior from a finite set of input–output data. First, the proposed method use a clustering and classification approach define the number of submodels and the data repartition. Then, by the use of statistical learning approach, we define the linear boundary separator of each validity region. Finally, a technique of detection given an explicitly estimation of switching time. A numerical example was reported to evaluate the proposed method.

1. Introduction

Hybrid systems are defined as dynamic systems that explicitly and simultaneously interact phenomena of continuous and event nature. The continuous behavior is the result of the natural evolution of the physical process, while the discrete or events behavior may be due to the presence of switches, operating phases, transitions, computer program codes, etc. . . .

The hybrid dynamic systems (HDS) switch between several operating modes where each mode is governed by its own dynamic. Therefore, the modeling of HDS involves estimating the discrete dynamics on the one hand and to identify the sub-models of the continuous behavior, on the other

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hand. Several approaches have been proposed to solve this problem. The method presented in [1], for linear switched system a class of HDS, is based on an application of the Multivariable Output-Error State Space (MOESP) identification technique [2] for the estimation of sub-models, in a noisy environment. In this approach, the authors assume that the discrete state, which models the discrete dynamics, and the number of sub-models are known a priori. Further, the switching instants are separated by a minimum dwell time. In [3], the considered model does not suffer from state databases matching problem such as a switched linear systems model. Indeed, the different linear submodels do not interact but they evolve independently of each other so that one can represent each of them in an arbitrary base. But the application of the presented method for the identification of this model (according to the authors formulation) may require a very important dwell time. Thus, there are many work in different search domain such as works of identification [1,3], control [4,5], stability analysis [6–9] and state estimation [10,11], make the knowledge of the switching mechanism as a basic assumption.

Other researchers have opted recently to other approaches based on artificial intelligence, learning and classification. These new methods showed quite encouraging results for several automatic issues. Boukharouba [12], Tarhouni [13] have proposed a modelling approach of hybrid systems and nonlinear system based on the classification. In [12], the switching mechanism is modelled by a piecewise linear functions defining the validation boundaries of each sub-models. The parameters adaptation of these functions are provided by a new incremental and decremental classification algorithm multi-class support vector. The proposed approach, in [13], is based on Least Squares Support Vector Machines (LS-SVM) with combined kernel for NARMA system identification. It's consisted in considering the two terms of auto- correlation and the terms of cross-correlation and for every block a kernel function is used. Ackerson and Fu [14] are the first which have considered the determination problem of the active mode through state estimation in noisy environment. A recent result for Markov Jump Linear System (MJLS) a class of hybrid system, developed in [15], is presented to the state estimation in the presence of polyhedral bounded disturbances. The approaches [16–18] are proposed to identify the switching instants for a class of switched linear systems described in the state form. In these works, an identification recursive algorithm and dynamic classification algorithm are used to estimate the discrete state.

In this paper, a new approach is presented for detecting of switching time of switched linear systems defined in discrete-time. Our aim is to develop a method for the switching time estimate from a finite set of input–output system. The proposed method is based on classification techniques. The clustering algorithm affects all available data on an observation horizon N to their respective sub-models. Then, we proceed to classify online a new observation and we calculate its distances from the hyperplanes boundaries of its region. These distances present the decision criterion for the detection of the switching time. In fact, if their minimum value is less than a threshold, defined in practice, then the next instant $(k+1)$ presents a switching time.

This paper has the following structure. Section 2 deals with the problem statement. Section 3 presents the new approach for switching time detection. In Section 4, we present the simulations in order to illustrate the effectiveness of the proposed method.

2. Problem statement

The considered switched linear systems are described in the discrete time by the following state space model:

$$\begin{cases} x(k+1) = A_i x(k) + B_i u(k) \\ y(k) = C_i x(k) \end{cases} \tag{1}$$

where $x(k) \in R^n$, $y(k) \in R$ and $u(k) \in R$ are respectively the continuous state, the output and the input of the system A_i, B_i and C_i are the parameter matrices associated with the submodel indexed by $i \in S = \{1, \ldots, s\}$. The discrete state i indexes the submodel under evolution at instant k, s is the number of submodels. In general, the switching law of this state may be due to external variables controllable or uncontrollable, as it can be in terms of change of a invariant condition.

A switched linear system, defined in (1), presents a collect of linear (affine) submodels connected by a discrete state. Therefore, each submodel evolves according to a fixed linear dynamic on a time intervals. The switching mechanism between the various submodels is usually undetermined. In this case, it is advantageous to be able to predict the switching time for proper tracking of the overall system behavior.

Given data $\{y(k), u(k)\}_{k=1}^{N}$ generated by a switched linear model of the form as in (1), we are interested in determining switching time of discrete state. Before solving this problem, we make the following assumptions:

(i) The considered switching mechanism is undetermined and without dwell time, it corresponds to a time interval in which no switching is franchise. In fact, the switches can be exogenous, deterministic, state-driven, event-driven, time-driven or totally random.
(ii) The number of submodels s are a priori unknown.
(iii) The order n is the same for all submodels and is available.

3. Switching time estimation

In this paper, we deal the problem of switching time detection for switched linear systems. The proposed approach is based on a data clustering method combined with an online detection technique of mode change. this technique consists in defining the hyperplanes limited of the each submodels region by a combination of a binary linear classifiers series, and in calculating the distance between the current data and the hyperplane of an appropriate region for an estimate of the instant switching.

Given the input–output measures $\{y(k), u(k)\}_{k=1}^{N}$ on an observation horizon N, generated by the system (1), the procedure, presented in Fig. 1, consists in

(i) solve a data classification problem whose purpose is to separate the available data according to their respective affine submodels.
(ii) Online estimate the switching instants of the discrete state of the system.