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Stochastic finite-time boundedness on switching dynamics Markovian jump linear systems with saturated and stochastic nonlinearities

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ABSTRACT

In this paper, problems of finite-time boundedness are investigated for a class of discrete-time switching dynamics Markovian jump linear systems with saturated and stochastic nonlinearities. The time-varying transition probabilities are described by a piecewise-constant matrix subject to a high-level average dwell time (ADT) switching. Sensor and actuator saturations are characterized by a vector-valued decomposition method and the stochastic nonlinearities are approximated by a statistical method. In general, not all trajectories originating from the admissible initial states could be stabilized in the mean square sense or sufficient conditions are too restrictive to yield feasible solutions. Therefore, the purpose of studying the problems addressed here is to design an output feedback controller via the ADT approach such that the resulting closed-loop systems are stochastically finite-time bounded and have a guaranteed disturbance attenuation capability. Simulation results demonstrate the potential and effectiveness of the theoretical results.

1. Introduction

The past decades have witnessed an ever-increasing research interest on Markovian jump linear systems (MJLSs) due to its great practical potential in many fields. To name a few, **s**olar boiler stations [12], economics [13], DC motor device [28] and networked control systems [25], etc. Some fundamental issues of both discrete-time and continuous-time MJLSs, such as mean square stability and stabilizability, H_∞/H_2 controller design, finite-horizon and infinite-horizon optimal control problems, robust filtering problems, etc., have been intensively studied [12,13]. A discrete-time MJLS in general is represented by stochastic difference equations including a family of operation modes and a Markov chain that orchestrates the jumping process between them.

Since the transition probability (TP) plays an important role in the system behavior, rich references appear with burgeoning research topics. Recently, a new research tendency is to investigate MJLS with time-varying transition probability (TVTP). One of the interesting research topics is to investigate piecewise homogeneous MJLS, which means the TVTP matrix is governed by a high-level switching dynamics. The high-level arbitrary switching and stochastic switching have been studied in [35], and in the latter case, the TVTP matrix is governed by a high-level time invariant TP matrix. The high-level deterministic switching

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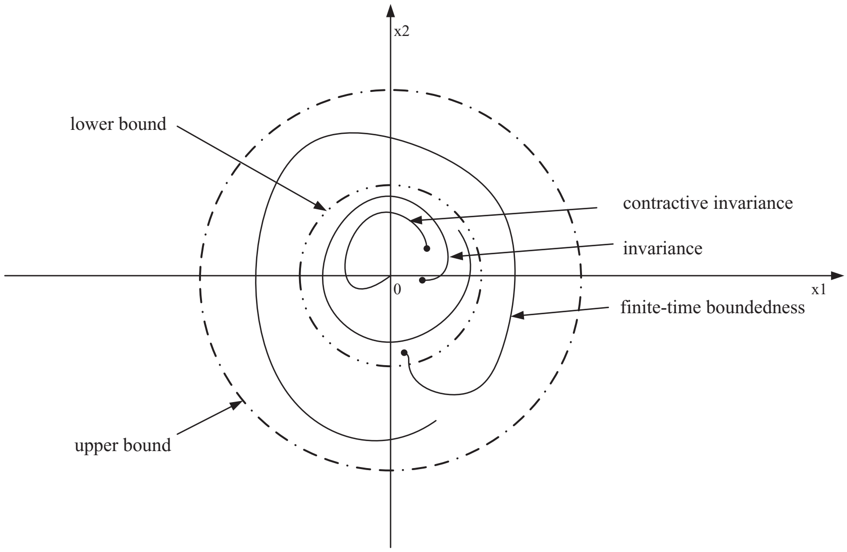

Fig. 1. Scheme of finite-time boundedness, invariance and contractive invariance.

subject to average dwell time (ADT) constraint, however, only has impact on the TVTP, has been studied in [9,41] . A new dynamic model named as switching dynamics Markovian jump linear system (SD-MJLS), in which the high-level ADT switching not only affects the TVTP but also the state dynamics, is introduced in [4]. Sufficient conditions for the mean square stability with dwell-time require each individual MJLS is mean square stable and the monotone decreasing of Lyapunov-like function holds at each switching instants subject to ADT constraint.

To motivate the research interest for such a class of systems, A DC motor device could be taken as a typical example. The evolution between three operating modes of the DC motor (normal, low and medium power modes, for example) is determined by the TVTP, which could be regulated by the potentiometer. The choice of the control voltage may affect the TP of random jumps (for instance, an aggressive control may increase the risk of fault occurrence). The almost sure stability, l_2-l_∞ analysis and synthesis of SD-MJLSs have been well discussed [5,6,18,19]. However, the related control theories for SD-MJLSs have not been fully developed and the references mentioned before are all considered on the infinite horizon.

It is worth mentioning that a SD-MJLS, which could be mean square stable, may possess undesirable transient performance, due to (1) inherent structure complexity, (2) state time-delay and stochastic nonlinearities, and (3) actuator and sensor saturations. For all these reasons, it is not trivial to explore the dynamic behaviors of SD-MJLS over a fixed finite-time interval. The original concept of finite-time control and the finite-time control problems for common MJLSs could be reviewed in [1,2,10,11,16,17,32,38,39,40,42,43,44]. For a SD-MJLS, the controller design approaches available rely on the ideal assumption that the control move and the measurement signal can be obtained with unlimited amplitudes. However, in practical engineering, especially in a networked environment, the actuator and sensor saturations could hardly be avoided, which has not been studied in the above mentioned references.

Most notably, in the finite-time case, the analysis and design method to deal with saturation problems could be quite different from the infinite-time one. First, we would like to show the main differences between finite-time boundedness [2], invariance [3] and contractive invariance [20,21], which is outlined in Fig. 1. Note that the concept of finite-time boundedness is more flexible than contractive invariance and invariance, that is to say, the state is allowed to exceed the invariant set but not exceed a larger given performance level. The system state being contractive invariant and invariant can be recovered as particular cases depicted by the condition of finite-time boundedness. Therefore, the standard approach of stability analysis, controller design and estimate of the domain of attraction for saturated systems could not be directly applied to tackle with the case of finite-time boundedness. Second, it could be concluded that the existence of the two ellipsoidal boundaries (not the controlled invariant set compared with [20,21]) is a fundamental step in the solution of several control synthesis problems especially in presence of deriving a control law by means of the two ellipsoids. As the basis of this study, some pioneering work can be briefly reviewed. The problems of controller design for system with actuator saturation [24,34,36] and sensor saturation [30,22,23] have been well addressed. Moreover, the controller design problems for systems with both actuator and sensor saturations have been developed in [14,27,15,31,45]. To avoid the nested saturations, most of the references adopt dynamic output-feedback control strategy [8,26].

Moreover, the considered finite-time control in this note is quite different from the finite-horizon control in [31], which also based on the scheme of contractive invariance but the control action performed on a finite horizon. The concept of stochastic finite-time boundedness (SFTB) developed for SD-MJLSs is more general than the concept of finite-time stability [1] and finite-time boundedness [2] proposed for linear systems because of the complex switching and jump dynamics.

Up to now, the problem of SFTB for SD-MJLSs has not been fully investigated, especially in the case that containing time-delay, saturated and stochastic nonlinearities, which motivates us to carry out the present study. It is worth noting that SFTB