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Relaxed nonquadratic stabilization conditions for Markovian jump fuzzy systems with incomplete transition descriptions

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Abstract

This paper focuses on deriving relaxed mean-square stability and $\mathcal{H}_\infty$ performance conditions for discrete-time MJFSs under a general description of transition probabilities. In the derivation, some available constraints are exploited on the basis of the property of transition probabilities, and then a two-stage relaxation scheme is proposed to reduce the conservatism that can arise from incomplete knowledge of probabilities as well as from fuzzy basis functions. Finally, nonquadratic stabilization conditions are derived in terms of LMIs, whose effectiveness is shown by two illustrative examples.

1. Introduction

Markovian jump fuzzy system (MJFS) has emerged as a popular choice among control researchers because the system model is suitable to represent a class of nonlinear systems subject to random abrupt variations in their structure (see [1–3] and the references therein). In this light, the issue of stability analysis and control synthesis for MJFSs has been extensively investigated in various directions, and the involved results have been successfully applied to a variety of practical applications such as fault-tolerant nonlinear systems [4,5], networks [6,7], networked nonlinear control systems [8–10], and power systems [11–13]. In particular, under the assumption that the mode transition probabilities or

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rates can be completely established, the past few years have witnessed significant progress in the study of MJFSs [14–20].

However, as argued in [21–24], it is hard to exactly obtain the transition probabilities of MJFSs in real situations. Moreover, since an incomplete description of probabilities plays a limited role in the design of an MJFS model-based control, there is a need to thoroughly explore the adverse impacts arising from the presence of unknown transition probabilities or rates. However, despite the need mentioned above, little effort has been made to investigate the issues that arise from both the incomplete transition description and the parameterized stabilization conditions of MJFSs. By contrast, recently, several studies have been performed regarding the stability analysis and control synthesis of discrete-time Markovian jump linear systems (MJLSs) with incomplete knowledge of probabilities. Among the representative works, [25] investigated the stability and stabilization problems of MJLSs with partly unknown transition probabilities (PUTPs) via a separation inequality technique, which had a beneficial effect on [23,35]. Following that, as a way to reduce the conservatism of [25], [26] developed an innovative approach to derive necessary and sufficient conditions for the analysis and synthesis of MJLSs with PUTPs. However, despite the fact that all PUTPs are bounded between zero and one (and their sum also becomes one), these results have shown a little progress toward combining the available boundary constraints with the derived conditions. Alternatively, in practice, [27,28] proposed two different approaches to solve control problems of continuous-time MJLSs with bounded uncertain transition rates (BUTRs), which may be able to be partly used, through an extension, as a possible way to deal with a class of discrete-time MJFSs with BUTPs. However, extra effort is still needed to reduce the conservatism that remains in the over-bounding approaches, as well as in the relaxation process of fuzzy basis functions. For this reason, this paper establishes a method capable of deriving a relaxed nonquadratic stabilization conditions for discrete-time MJFSs, which allows the available constraints on BUTPs (as well as PUTPs) to be fully exploited therein.

Motivated by the above concerns, the attention of this paper is wholly focused on deriving relaxed mean-square stability and $\mathcal{H}_\infty$ performance conditions for discrete-time MJFSs under a general description of TPs. That is, specific efforts are made to address realistic situations regarding the TPs. Furthermore, compared to other results, the following contributions are worth to be highlighted. First, some available constraints involving slack variables are introduced on the basis of the property of TPs, which plays an important role in enhancing the interactions among mode-dependent local stability conditions. Second, a two-stage relaxation scheme is proposed to reduce the conservatism that can arise from incomplete knowledge of probabilities as well as from fuzzy basis functions. Third, to create more freedom in the process of searching feasible solutions leading to mode-dependent fuzzy control gains, the nonquadratic Lyapunov function approach is applied in parallel with non-parallel-distributed compensation (non-PDC) scheme [29–31]. This is because the use of the common quadratic Lyapunov function can entail a set of conservative design solutions in the presence of a large number of local linear approximations for T–S fuzzy systems, as reported in [31–33]. Finally, two illustrative examples are given to demonstrate the effectiveness of the derived conditions in terms of LMIs.

Notations: Throughout this paper, $X \geq Y$ and $X > Y$ indicate that $X - Y$ is positive semidefinite and positive definite, respectively. $(\Omega, \mathcal{F}, \mathcal{P})$ denotes a probability space, where Ω, $\mathcal{F}$, and $\mathcal{P}$ represent the sample space, the algebra of events, and the probability measure defined on $\mathcal{F}$, respectively. The notation $\mathcal{L}_{2+} = \mathcal{L}_2[0, \infty)$ refers to the space of square summable infinite vector sequences; $\mathbf{E}\{\cdot\}$ denotes the mathematical expectation; $\mathbf{diag}(\cdot)$ stands for a block-diagonal matrix; $\otimes$ denotes the Kronecker product; $\mathbb{A} \setminus \mathbb{B}$ indicates the set of elements in the set $\mathbb{B}$, but not in the set $\mathbb{A}$; $|\mathbb{A}|$ means the cardinality of the set $\mathbb{A}$; $\lambda_{\min}(\cdot)$ denotes the minimum eigenvalue of its argument matrix; and the symbol $\ast$ is used to denote a matrix that can be inferred by symmetry.