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Robust state estimation for jump Markov linear systems with missing measurements

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Abstract

This paper is concerned with the robust state estimation problem for a class of jump Markov linear systems (JMLSs) with missing measurements. Two independent Markov chains are used to describe the behavior of the system dynamics and the characteristic of missing measurements, respectively. A robust filtering algorithm is developed by applying the basic interacting multiple model (IMM) approach and the H_∞ technique, which is different from the traditional Kalman filtering with minimum estimation error variance criterion. A maneuvering target tracking example is provided to demonstrate the effectiveness of the proposed algorithm.

1. Introduction

Jump Markov linear systems (JMLSs) have received significant attention in recent years which may result from their successful modeling for the phenomena of random abrupt changes. For instance, in the target tracking community, they have been used for modeling the motion of a maneuvering target that can switch between a finite number of dynamics [1]. Another motivation on these systems is the recent interest in the networked control systems, in which the behavior of packet dropout or missing can be

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modeled as a Markov chain [2]. Several authors have analyzed many different aspects of JMLSs such as controllability and observability [3,4], stability [5–7], and filter design [8–10].

Recently, the problem of H_∞ filtering for JMLSs has been studied in the literature [11–15]. In contrast to the conventional Kalman filter (KF) which requires an exact and accurate system model as well as perfect knowledge of the noise statistics, the H_∞ filter tries to minimize the effect of the worst disturbances on the estimation errors and therefore it is more robust against model errors and noise uncertainties [16]. Thus, the H_∞ filter seems to be more applicable in real world applications. However, these results are derived based on a critical assumption that the jumping mode should be accessible at any time, which is also known as mode-dependent filters. Although mode-independent filters have been developed in [17,18], the design procedure might be conservative since a set of linear matrix inequalities (LMIs) has to be solved. An alternative approach to overcome this problem is the well-known suboptimal interacting multiple model (IMM) estimation technique, which is initially proposed to address the state estimation problem for JMLSs with white Gaussian noise based on KF [19]. Different from the mode-dependent filters and mode-independent filters, the IMM-KF does not make a hard decision as to which mode is effective, but it assigns a probability to each mode in the mode set. It then finds an overall estimate as a probabilistic combination of the individual filter estimates. Another important feature of the IMM-KF is that the mode probabilities given to the individual filter estimates are calculated dynamically according to the likelihood function from the individual filter. Nevertheless, as stated in [20], the performance of the IMM-KF might not be satisfactory in the presence of unmodeled dynamics or disturbances due to the fact that the KF lacks robustness against model errors and noise uncertainties.

The phenomenon of missing measurements usually occurs owing to a variety of causes such as sensor failures or network-induced packet dropout. Hence, it is not surprising that robust filtering for systems with missing measurements has attracted much attention, see [21–23] and the references therein. Basically, there are mainly two approaches to model the characteristics of missing measurements including binary switching sequence and jump linear systems. However, to the best of the authors' knowledge, the problem of robust state estimation for JMLSs with missing measurements has not been addressed despite its practical applications. For example, the target may not be detected when the presence of sensor fails.

In this paper, we aim to investigate the problem of robust state estimation for a class of JMLSs with missing measurements. The behavior of missing measurements is described by a two-state (i.e., missing and normal) Markov chain with known transition probability matrix, so that the resulting system can be modeled as a jump Markov linear system with two jumping parameters. By defining a product set of two mode sets, we cast the model into the framework of the IMM and hence the filtering procedure can be carried out in a layered manner. In addition, a group of H_∞ filters are combined with the IMM instead of Kalman filters. Thus, the proposed algorithm is more feasible for JMLSs with model errors and noise uncertainties. Simulation results show the excellent performance over the KF counterpart.

The remainder of this paper is organized as follows. In Section 2, the problem is formulated and some preliminary results are reviewed to derive the main results of this paper in Section 3. A numerical example is provided to show the effectiveness of the proposed algorithm in Section 4. Conclusion is drawn in Section 5.

2. Problem formulation and preliminaries

Consider the following jump Markov linear system defined on a complete probability space $(\Omega, \mathfrak{F}, \{\mathfrak{F}_k\}_{k\geq 0}, \mathcal{P})$

$$x_{k+1} = F(\gamma_k^1)x_k + G(\gamma_k^1)w_k(\gamma_k^1) \tag{1}$$