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Distributed sampled-data asynchronous H_∞ filtering of Markovian jump linear systems over sensor networks

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A B S T R A C T

This paper is concerned with distributed sampled-data asynchronous H_∞ filtering for a continuous-time Markovian jump linear system over a sensor network, where jumping instants of system modes and filter modes are asynchronous. A group of sensor nodes are deployed to measure the system's output and to collaboratively share the measurement with neighboring nodes in accordance with Markovian switching topologies. First, the measurement on each sensor node is sampled at separate discrete instants and transmitted to a remote filter through a communication network. Network-induced signal transmission delays are incorporated in data transmission channels. Second, distributed sampled-data asynchronous H_∞ filters, governed by a finite piecewise homogeneous Markov process, are delicately constructed. The resultant filtering error system is transformed into a piecewise homogeneous Markovian jump linear system with delays. Third, sufficient conditions on the existence of desired distributed sampled-data asynchronous H_∞ filters are derived such that the filtering error system is stochastically stable with the prescribed weighting average H_∞ performance. Finally, three illustrative examples are given to show the effectiveness and advantage of the proposed theoretical results.

1. Introduction

Sensor networks have attracted ever-increasing attention from signal processing and computer networking communities due to their wide applications in areas such as infrastructure security, environment and habitat monitoring, industrial and manufacturing automation, and military applications. A fundamental issue over sensor networks is to develop a distributed filtering algorithm which estimates an unavailable state signal through noisy measurement and a disturbed plant. In the published literature, considerable research efforts have been made on distributed H_∞ filtering in sensor networks [1–8].

In a traditional H_∞ filtering architecture, sensor and filter are assumed to be point-to-point connected via a hardwired connection. As a result, the measurement output $y(t)$ of a continuous-time system can be perfectly transmitted to a filter acting as an input $\hat{y}(t)$ of the filter, giving rise to $\hat{y}(t)=y(t)$, see, e.g., [9–12]. However, in practical networked systems, the system and the filter may be physically remotely located. Thus, the measured output signal $y(t)$ is required to be sampled at discrete instants of time by a sensor before it is transmitted through a digital communication channel to a remote filter for processing. In this case, due to discrete/sampled measurement and the introduction of communication channels, the filter input signal $\hat{y}(t)$ may not be equal to $y(t)$, which makes the filtering problem complicated. Even though periodic/constant sampling techniques are proposed in the literature to address the filtering problem, they may not capture the inter-sample behavior of a system in the case of variable/

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time-varying sampling [3]. In practice, it is natural to lower the sampling rate when a system's state approaches to its equilibrium and no external disturbance acts on the system. Furthermore, the traditional periodic/constant sampling techniques may increase the frequency with which a sensor samples, thereby leading to increased energy consumption while a sensor usually has limited battery. Hence, it is both in theory and in practice an important research topic to address distributed sampled-data H_∞ filtering when sampling period varies with time.

Notice that the sampled-data H_∞ filtering problem with variable sampling has not been paid adequate attention with a few exceptions [3,6,13–17]. Among these results, a prevailing approach, i.e., an output delay approach [18], has been used to deal with variable sampling. By assuming that the distance between consecutive sampling instants does not exceed a given bound, sampled-data systems under discrete measurement were modeled as continuous systems with delayed measurement outputs. With this output delay approach, the sampled-data H_∞ filtering problems were studied in [14] for linear-invariant systems and in [15] for a class of Itô stochastic systems subject to signal quantization; the fuzzy sampled-data H_∞ filtering problem was investigated in [16] for continuous-time Takagi–Sugeno fuzzy systems with interval time-varying state delays. In [17], the stochastic sampled-data approach, which was proposed in [19] to address the robust sampled-data H_∞ control with variable sampling, was adopted to address the problem of H_∞ filtering for continuous-time systems under probabilistic sampling. The basic idea of this stochastic sampled-data approach was to partition the whole sampling period into small intervals. The occurrence probability of each interval was known and the probability satisfied Bernoulli distribution. Then, combining the output delay approach, sampling intervals were converted into bounded time-varying delays and the filtering error system was formulated as a continuous system with delays and stochastic parameters. Consequently, the stochastic delay system theory was used to design desired sampled-data H_∞ filters. However, it should be pointed out that only single sensor node is deployed for measuring the system output in [14–17], which means that the measurement is required to be sampled by a dedicated sensor and sent together in a single packet to a remote filter. Such an assumption may not hold in practical distributed and networked systems since information exchanged among neighboring system components plays an important role in collaborative information processing. In [3], the stochastic sampled-data approach was employed to tackle the problem of distributed H_∞ filtering for nonlinear systems in sensor networks. Recently, a switched system approach was developed in [6] to solve the distributed H_∞ filtering problem for continuous-time linear systems in sensor networks with nonuniform sampling periods. Based on a synchronous sampling scheme, the system under consideration was discretized and transformed into a switched system with a finite number of subsystems. It is noteworthy that there are still several issues which are not fully addressed and may limit the application scope of the results presented in [3,6]. The first important issue is that the effects of network-induced signal transmission delays on the global filtering performance are ignored in [3,6]. It is well acknowledged that these delays may degrade the system performance and even destabilize the system. The second important issue is the negligence of the effect of random sensing topologies on the global filtering performance because the sensing topology studied in [3,6] needs to be fixed in advance. In this sense, neighboring nodes from which each individual sensor collects information are known during whole running periods of a sensor network. In practice, however, each sensor's neighboring nodes may vary with time because of node mobility, link failure, and limited sensing range. Consequently, random sensing topologies, which may deteriorate system performance and even lead to divergence of filtering algorithms, inevitably occur [20]. Another important issue is that all sensors in [6] are required to have the same sampling periods. However, it is not an easy task to keep all sensors synchronously in reality as sensor nodes may be spatially distributed and each node has its own notion of time. A more practical and general consideration is that different sensors possess distinct sampling periods. Therefore, it is desirable to develop a novel distributed sampled-data H_∞ filtering algorithm over sensor networks by simultaneously investigating the effects of distinct variable sampling periods, network-induced delays and random sensing topologies, which is the first motivation of this study.

Markovian jump linear systems (MJLSs) are commonly seen as suitable mathematical models to represent a class of dynamic systems subject to random abrupt variations in system structure and system parameters [21]. A number of practical applications can be modeled as MJLSs such as economic systems, manufacturing systems, power systems, aerospace systems, and communication networks. Depending on whether or not system jumping modes are available to a filter, the existing H_∞ filtering algorithms in the continuous-time MJLSs framework can be generally classified into two types: global mode-dependent filtering algorithms and global mode-independent filtering algorithms. For global mode-dependent filtering algorithms, an underlying assumption made by researchers is that the global knowledge of system modes should be completely accessible to a remote filter at every instant of time [9,11,12,22]. In other words, jumping instants of filter modes and system modes are rigorously synchronous. In practice, however, it is usually difficult and costly to obtain complete information of system modes for filter design when there are variations in system structure and parameters which are difficult to be measured; or when there are changes in system structure and parameters which are associated to failures of components. For global mode-independent filtering algorithms, system modes are completely not available for filter design [20,23,24]. In this case, a filter possesses same filter gains at different operation modes irrespective of a system's parameter and structure changes. In practical jumping systems, a more complex asynchronous phenomenon unavoidably occurs when the system model signal is transmitted to a remote filter node through communication networks. On this account, filter modes may differ from system modes due to time delays and/or data losses in the transmission of the