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Estimation fusion for networked systems with multiple asynchronous sensors and stochastic packet dropouts

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Abstract

This paper studies the asynchronous state fusion estimation problem for multi-sensor networked systems subject to stochastic data packet dropouts. A set of Bernoulli sequences are adopted to describe the random packet losses with different arriving probabilities for different sensor communication channels. The asynchronous sensors considered in this paper can have arbitrary sampling rates and arbitrary initial sampling instants, and may even sample the system non-uniformly. Asynchronous measurements collected within the fusion interval are transformed to the fusion time instant as a combined equivalent measurement. An optimal asynchronous estimation fusion algorithm is then derived based on the transformed equivalent measurement using the recursive form of linear minimum mean squared error (LMMSE) estimator. Cross-correlations between involved random variables are carefully calculated with the stochastic data packet dropouts taken into account. A numerical target tracking example is provided to illustrate the feasibility and effectiveness of the proposed algorithm.

1. Introduction

With the wide application of networks in practical systems, the filtering and estimation problems for networked systems have attracted considerable attentions in recent years [1,2]. The essential challenge of these problems is the uncertainties induced by the unreliable network, such as random delay, packet dropout, and fading channels [3–5]. Data packet dropout is quite a

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common phenomena in a networked environment, which may happen due to node failures or network congestion. Since packet dropout can degrade the estimation performance severely, it is important to take into account the packet dropout phenomena in the design of filter and estimator for networked systems.

Many research works have already been reported to address the filtering and estimation problem for networked systems with data packet dropout. In [6], it is known whether the measurement at each sampling time instant is lost or not, and the one-step prediction of Kalman filtering is performed once the measurement is lost. It is proved that there exists a critical arrival probability, below which the mean of the state error covariance diverges for some initial condition, and also the upper and lower bounds of this critical probability are provided. A similar problem is studied in [7], where the packet arrival is modeled by a Markov process. The trace of the Kalman estimation error covariance is shown to follow a power decay law and the critical value of arrival probability is computed for a class of non-degenerate systems. To better deal with the uncertainty caused by multiple packet dropouts, a moving horizon state estimation algorithm is proposed in [8]. By transforming random packet dropout rates into stochastic parameters in the system representation, both an optimal H_2 filter and an optimal H_∞ filter are designed based on the linear matrix inequality (LMI) approach in [9,10] for systems with multiple packet dropouts, respectively. The considered stochastic packet dropouts are independent and Bernoulli distributed. Reference [11] adopts a similar model as in [9] and investigates the finite-horizon optimal filtering, prediction and smoothing problems in LMMSE sense by applying the innovation analysis approach. The optimal full-order and reduced-order LMMSE estimators are proposed in [12] for systems with packet dropouts in both sensor-to-controller and controller-to-actuator channels. The LMMSE estimators proposed in [12] are derived based on an augmented stochastic parameter system. To reduce the computational cost caused by state augmentation, an alternative form is given in [13]. Moreover, for a class of nonlinear networked systems with multiple packet dropouts, a recursive networked strong tracking filter is designed in [14] with parameter perturbations and unknown inputs also considered. Reference [15] analyzes the stability of the discrete-time modified unscented Kalman filter over unreliable communication networks with Markovian packet dropouts. In addition, the packet dropout is considered simultaneously with random sensor delay and uncertain observation in [16–18], and the robust fault detection problem for networked system is studied in [19,20].

On the other hand, estimation fusion, or data fusion for estimation, is one of the fundamental research topics in the area of information fusion [21]. The purpose of estimation fusion is to estimate an unknown parameter or process state by effectively utilizing information from multiple data sources, such as multiple sensors. Since estimation fusion can improve the performance of estimation, it has widespread applications in many practical problems, such as target tracking [22] and fault diagnosis [23].

Recently, there have also been some research works considering the estimation fusion problem for networked systems with multiple sensors subject to multiple packet dropouts. In [24], the optimal centralized fusion estimation algorithm is first proposed in the linear minimum variance sense, and then an suboptimal scalar-weighted distributed fusion estimation algorithm is presented to reduce the computational cost of the centralized algorithm. The work in [24] is extended to multi-sensor stochastic systems with mixed uncertainties of random sensor delays, packet dropouts and missing observations together in [25]. Above two works consider only the single-rate and synchronous multi-sensors. In other words, sensors in above works are required to have the same sampling rate and the measurements from these sensors are exactly time-coincident. For multi-rate multi-sensors, the networked fusion filtering problem with missing