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Distributed Kalman consensus filter with intermittent observations ☆

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Abstract

We consider the problem of distributed state estimation for linear time-varying systems with intermittent observations. An optimal Kalman consensus filter has been developed by minimizing the mean-squared estimation error for each node. To derive a scalable algorithm for the covariance matrices update, a suboptimal filter is proposed by omitting the edge covariance matrices among nodes. By using the Lyapunov-based approach, a sufficient condition is presented for ensuring the stochastic stability of the suboptimal filter. Two numerical examples are provided to verify the effectiveness of the proposed filter.
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1. Introduction

We consider the problem of distributed state estimation for linear time-varying systems with intermittent observations over a not fully connected sensor network. The objective of distributed state estimation is for every node to derive an estimate of the unobserved state based on local observations and neighboring interactions. Such problem abounds in the context of target tracking and localization, security and surveillance, and cooperative control of multi-robot systems [1].

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In the past few years, distributed Kalman filters have been proposed by adopting the consensus technique [2–7] and diffusion strategy [8–11]. See a recent bibliographic review for further discussions on distributed Kalman filters [12]. One important class of distributed Kalman filter is the Kalman consensus filter (KCF) developed in [5]. The KCF is derived by adding a consensus term on the local state estimate of a standard Kalman filter for each node, where the consensus term is constructed by a difference between local state estimate and its neighboring state estimates with a consensus gain. As stated in [5], the KCF achieves a superior performance in comparison to the previous distributed Kalman filters. In [13], the KCF has been used to develop distributed estimation algorithms with event triggered communication protocols and homogeneous detection criteria are designed on each sensor node to determine the broadcasting instants. In [14], the KCF has been extended to the scenario with stochastic sensor activation to reduce the sensor energy consumption in communications. It should be pointed out that the algorithm in [14] is not scalable since the edge covariance matrices are required to be computed among nodes. In [15], a distributed estimation strategy has been proposed for network design based on the KCF.

The recent trend of utilizing networks introduces new problems due to the unreliable characteristics of networks such as random data packet dropout and quantized measurement. In [16], the problem of delay-dependent robust H_∞ filtering for uncertain discrete-time state-delayed Takagi–Sugeno (T–S) fuzzy systems has been studied, in which a unified framework has been developed for designing full-order and reduced-order filters. In [17], the static-output-feedback controller was designed for networked nonlinear systems with data-packet dropouts where the Bernoulli random-binary distribution is used to characterize the behavior of data-missing. In [18], the robust H_∞ output feedback controller has been developed for continuous-time T–S fuzzy affine dynamic systems with quantized measurements. In [19], the coordination problem of multiple robots with limited communication ranges and communication failures has been investigated, where a rendezvous algorithm is developed. The result is extended to address the distributed rendezvous problem of multi-agent systems by using event-triggered controllers [20]. As stated in [21], the effect of communication delays and loss of information in the control loop cannot be neglected when data travel along unreliable communication channels in a large, wireless, multihop sensor network. In [21], Kalman filter with intermittent observations has been studied where observations are available intermittently with independent probability. It has been shown that there exists a critical value of the arrival probability such that the expected value of the covariance matrix is unbounded. The authors in [22] consider the case where the availability of observations is regulated by a Markov chain. In [23], a suboptimal Kalman filter with intermittent observations is derived by minimizing the mean squared estimation error and the mean square stability has been analyzed. In [24], by modeling the behavior of intermittent observations as a two-state Markov chain, a distributed KCF has been developed by applying the interacting multiple model (IMM) approach. The distributed algorithms for nonlinear systems have been developed by using the extended Kalman filter [25,26] and the unscented Kalman filter [27]. In [28], the distributed estimator with missing measurements, random transmission delays and packet dropouts has been proposed, where a fusion center is adopted for fusing local estimates. To the best of the knowledge of the authors, the problem of distributed state estimation with intermittent observations over a not fully connected sensor network has not been addressed.

In this paper, we attempt to develop a KCF for linear time-varying systems with intermittent observations. We present an optimal KCF by minimizing the mean squared estimation error for each node. Since the optimal KCF is not scalable with respect to the nodes, a suboptimal filter is developed, where the consensus gain is designed related to the packet arrival probability. A key contribution of this work is not only to propose a KCF with intermittent observations but also to present the stability analysis in some details. The latter task is challenging due to the interactions between neighboring nodes.

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