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Estimation from a multisensor environment for systems with multiple packet dropouts and correlated measurement noises

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ABSTRACT

This paper addresses the problem of distributed fusion estimation from measurements with packet dropouts and cross-correlated noises acquired from different sensors. Assuming that the packet dropouts are modelled by independent Bernoulli random variables with different characteristics for each sensor and that measurement noises are cross-correlated at the same and at consecutive sampling times, filtering and smoothing algorithms are derived using the distributed fusion method. The distributed fusion filter and smoother are obtained as a matrix-weighted linear combination of corresponding local least-squares linear estimators, verifying that the mean squared error is minimum. The local linear filtering and fixed-point smoothing algorithms are derived using the first and second-order moments of the signal and the noises present in the observation model. Simulation results are provided to illustrate the feasibility of the proposed algorithms, using the error estimation covariance matrices as measure of the quality of the estimators.

1. Introduction

Modern systems are becoming complex and observation mechanisms based on a single sensor are often unable to provide sufficient information for their study. In response to this problem, complex systems such as navigation systems, target tracking, among many others, are often studied using multiple sensors. In this situation, the signal estimation problem is addressed considering the information provided by the different sensors and combining this information by means of two different techniques: centralized and distributed fusion. Both methods have been widely utilized, although nowadays the distributed method tends to be preferred due to its computational advantages. In this technique, the distributed estimator is derived by combining the estimators obtained from each sensor by the application of optimization criteria. In early studies in this field, assuming that the noises involved in the system are white and uncorrelated between different sensors, the distributed filtering problem was addressed applying the traditional Kalman filter in order to determine the local filters, (see e.g. [1–4]). However, the hypothesis of uncorrelated noises may not be realistic; indeed, in many practical situations, all sensors are observed in the same noisy environment, and then the measurement noises of different sensors are usually correlated. Under this hypothesis, distributed filtering algorithms have been developed; see, for example [5–7]. Moreover,

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in engineering systems, there may well exist cross-correlation between noise processes involved in the system. Taking into account these two assumptions, i.e., correlated noise processes and correlated measurement noises of the different sensors, Feng et al. [8] derived distributed Kalman filtering fusion algorithms without feedback for linear dynamic systems. In the above-mentioned papers, correlated noises at the same sampling time are considered; at present, the estimation problem for dynamic systems with finite-step cross-correlated noise processes is attracting great interest among researchers; see, for example [9–11].

In the transmission of measurement data, errors frequently occur, due to intermittent failures in the observation mechanism or limited battery energy, among various possible causes. These errors can lead to different kinds of uncertainties in the measurement, which are inherently random; a very common consequence of such uncertainty is the loss of data, or packet dropouts. The estimation problem in multiple packet dropout systems has been studied using different models to describe the packet dropout phenomenon; for example, considering switched systems (see [12]), modelling packet dropouts by Markov chains (see e.g. [13]) or assuming that the packet dropouts are realizations of independent Bernoulli random variables. Under the latter assumption, the signal estimation problem has been addressed assuming both uncorrelated (see e.g. [14] and [15]) and autocorrelated and finite-step cross-correlated noises (see [16–18]).

As commented above, the estimation problem in complex systems is now normally addressed using multiple sensors. In this context, the signal estimation problem from observations affected by packet dropouts has been considered assuming different hypotheses about the noises involved in the system. For example, Song et al. [19] developed a distributed H_∞ filtering algorithm for a class of sensor networks with uncertain rates of packet losses assuming that the observations of the signal are not affected by additive noises. Zhang et al. [20] obtained a distributed fusion algorithm to estimate the state of a dynamic process with random packet losses when the measurement noises of the different sensors are correlated at the same time. However the estimation problem for systems with packet dropouts and cross-correlated measurement noises at the same and at consecutive sampling times, to the best of our knowledge, has not been studied previously. Therefore, in this paper, our interest is focused on investigating this problem under this assumption of correlation which, as commented, is more realistic hypothesis than the usual one of uncorrelation.

In this paper, we consider observations with packet dropouts from multiple sensors and, motivated by the advantages of the distributed fusion method, propose algorithms to obtain distributed fusion linear estimators of a signal when the measurement noises are cross-correlated. Specifically, we assume that the packet dropouts are modelled by independent sequences of independent Bernoulli variables, which have not necessarily identical distribution for all sensors; that is, for each sensor, different probabilities of successful packet transmission are considered. Furthermore, for each sensor the measurement noise is one-step cross-correlated and cross-correlated between different sensors. Under these assumptions and assuming that the state-space model of the signal is not fully available, local least-squares (LS) linear estimators, including the filter and the smoother, are derived from the information provided by the first and second-order moments of the processes involved in the observation model. Once the local estimators are derived, the distributed fusion filter and the fixed-point smoother are obtained as a matrix-weighted linear combination of the corresponding local estimators using the mean squared error as the criterion for optimality.

We emphasize that, unlike previous published work in this field, in this paper the distributed fusion estimation problem from observations with both packet dropouts and cross-correlated noises is addressed without requiring knowledge of the evolution model of the signal process. Only the expression of the signal covariance in semi-degenerate kernel form and the mean and covariance functions of the processes involved in the observation equation are needed to obtain the proposed algorithms, which are also applicable for conventional formulation using the state-space model. Note also that, although a state-space model can be generated from covariances, when only this kind of information is available, it is preferable to address the estimation problem directly using covariances, thus obviating the need for prior identification of the state-space model.

The covariance information and the innovation approach were also applied in a previous paper by the authors [21] to address the distributed fusion estimation problem in networked systems with uncertain observations and one-step random delays in the measurements. Nevertheless, it should be noted that, considering different types of uncertainty in the data transmission, namely, random delays in [21] and random packet losses in this paper, the observation models in these papers, and hence the practical applications, are totally different. Furthermore, cross-correlation in the measurement noises, which was not taken into account in [21], is now considered. The simultaneous consideration of packet dropouts and correlated noises is a novelty in itself and involves some additional complications, in comparison with our previous paper, for example, those associated with obtaining the one-stage noise predictor which is necessary to derive the innovation process.

The rest of this paper is organised as follows. In the next section, the observation model is described. In Section 3, distributed fusion filtering and the fixed-point smoothing problems are addressed. Using an innovation approach, local LS linear filtering and smoothing algorithms are given for each sensor and the cross-covariance matrices between any two local estimators are then calculated in order to obtain the distributed fusion estimators. In Section 4, the effectiveness of the proposed estimators is illustrated by means of a simulation example in which a scalar signal is estimated from observations obtained from two sensors affected by cross-correlated measurement noises and packet dropouts with different characteristics for each sensor. Finally, some concluding remarks are made in Section 5.