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# Robust weighted fusion Kalman estimators for systems with multiplicative noises, missing measurements and uncertain-variance linearly correlated white Noises

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**Abstract** For linear discrete time-varying and time-invariant multisensor uncertain systems with multiplicative noises, missing measurements and uncertain-variance linearly correlated white noises, by introducing the fictitious noises to compensate the stochastic uncertainties, the system under consideration can be converted into one with only uncertain noise variances. According to the minimax robust estimation principle, based on the worst-case system with conservative upper bounds of uncertain noise variances, the four robust weighted state fusion time-varying and steady-state Kalman estimators(predictor, filter, smoother) are presented respectively. They include the three fusers weighted respectively by matrices, scalar and diagonal matrices and a new modified covariance intersection (CI) fuser. They are designed in a unified framework, such that the filters and smoothers are designed based on the predictors. By the Lyapunov equation approach, their robustness is proved in the sense that for all admissible uncertainties, their actual estimation error variances are guaranteed to have the corresponding minimal upper bounds. The convergence in a realization between the robust fused time-varying and steady-state Kalman estimators for the time-varying and time-invariant systems are proved by the dynamic error system analysis (DESA) method. Their accuracy relations are also proved. A simulation example applied to uninterruptible power system(UPS) shows the effectiveness of the proposed results.

*Keywords:* Weighted fusion; Minimax robust Kalman filtering; Multiplicative noise; Missing measurement; Uncertain noise variance; Convergence in a realization

## 1. Introduction

With the development of high technology fields, the multi-sensor data fusion has received much attention. Its aim is how to combine or to weight local estimators or local measurement data of the system state to obtain a fused state estimator, whose accuracy is higher than that of the each local state estimator. The optimal information fusion Kalman filtering theory and methods have been widely used in many fields including military, defense, robotics, unmanned aerial vehicles(UAV), target tracking, GPS positioning and remote sensing[1].

The classical Kalman filtering is only suitable for systems with exactly known model[2]. In practical applications, there inevitably exist uncertainties of model parameters and/or noise variances, due to unmodeled dynamics, stochastic disturbances, and so forth. The classical Kalman filter performance for uncertain systems will deteriorate or the filter may be divergent. Thus, the study of robust Kalman filtering for uncertain systems received extensive attention. The so-called robust Kalman filtering problem is to find a Kalman filter such that its actual filtering error variances yielded by all admissible uncertainties are guaranteed to have a minimal upper bound [3]. Such property is called robustness, and such Kalman is called robust Kalman filter. There are the the linear matrix inequality (LMI) approach and the Riccati equation approach[3] for systems with norm bounded uncertain parameters but known noise variances.

Based on the minimax robust estimation principle[4], for systems with uncertain noise variances but known model parameters, the four robust weighted state fusion time-varying and steady-state Kalman estimators were presented by the Lyapunov equation approach[5-8]. For the multisensor uncertain systems with unknown cross- covariances, the original covariance intersection (CI) fusion method was presented by Julier and Uhlmann [9,10]which gives a special state fuser with matrix-weights. Its advantages is that it gives a conservative upper bound of actual fused error variances, and the computation of cross-covariances is avoided. However, its disadvantages is that the local state estimators and the conservative upper bounds of their actual error variances are assumed to be known, and the cross-covariances information is not used, so that it gives a larger conservative upper bound of actual fused error variances. For systems with uncertain noise variances but known model parameters, using the Lyapunov equation approach, a modified CI fuser was presented in[6-8] which used the information of conservative local estimation error cross-covariances. The modified CI fuser has the advantages that the local estimators and the minimal upper bounds of their actual error variances can be obtained by the local robust Kalman filters, and it gives the minimal upper bound of actual fused error variances. So it improved the robust accuracy [6-8]of the original CI fuser.

Multiplicative noises or state-dependent noises are applied to describe the stochastic parametric uncertainties, and have already received much attention in recent years. They can widely be applied to many fields including communication, aerospace, image processing and stochastic signal processing, and so on. The variations of stochastic parameters can be described as random perturbations to their nominal values (mathematical expectations or mean values). i.e., each stochastic parameters can be decomposed as its mean plus random perturbation with zero mean. By taking the expectation operations, the system with random parameter matrices can be converted to a system with deterministic parameter matrices and state-dependent noises (multiplicative noises) [11-12].

For the sensor network systems, the missing measurements frequently appear, for example, due to limited bandwidth of network, the missing measurements appear with a random missing rate. The missing rate is described as Bernoulli white

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