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Resilient decentralized filtering of interconnected discrete-time systems

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Abstract

The objective of this paper is to propose new tools for robust and resilient filter design of a class of interconnected discrete-time systems with uncertain function of nonlinear perturbations by exploiting the decentralized information structure constraint. We seek to establish complete LMI-based procedures for linear filtering by basing all the computations at the subsystem level. The robustness property of filter design is assessed in terms of ℓ_∞ performance while the resilience property is evaluated in face of additive gain variations that reflect the imprecision in filter implementation. By a suitable convex analysis, it is shown that both design problems can be formulated as convex minimization problem over linear matrix inequalities (LMIs). Numerical examples are provided to illustrate the effectiveness of the developed design methods.

1. Introduction

For dynamical systems, the topic of robust filtering arose in view of the desire to determine estimates of non-measurable state variables when the system undergoes parametric uncertainties. From this perspective, robust filtering can be viewed as an extension of the celebrated Kalman filter to uncertain dynamical systems. The past decade

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has witnessed major developments in robust filtering problem [3,4,7,9,10,15]. There has been two basic categories of approaches: the first is based on the Riccati equation (RE) through the search of an appropriate scaling parameters and the other relies on feasibility testing of linear matrix inequalities (LMIs) formulation. The later approach has gained widespread popularity in view of the development of the interior point algorithm for convex optimization. When dealing with large-scale or interconnected systems, the topic becomes more compounded as one has to be careful with the issues of dimensionality, nonlinearities and/or robustness. In [1], an approach to robust $\mathcal{H}_\infty$ filtering for a class of nonlinear with time-varying uncertainties was presented in the LMI framework using a general dynamical observer structure. The central finite-dimensional $\mathcal{H}_\infty$ filter for nonlinear polynomial systems with multiplicative noise was fully characterized in [2]. The filter is suboptimal for a given threshold level with respect to a modified Bolza–Meyer quadratic criterion. Recently, a discrete-time decentralized neural identification and control for large-scale uncertain nonlinear systems was developed in [14] using recurrent high order neural networks. The problem of robust $\mathcal{H}_\infty$ filtering for uncertain systems with time-varying distributed delays was discussed in [17], whereas the problem of $\mathcal{H}_\infty$ filtering for neutral systems with mixed time-varying delays and nonlinear perturbations was investigated in [18]. It seems from the previous results that the topic of decentralized filtering has received little attention.

In another research front and during the course of filter implementation based on different design algorithms, it turns out that the filters can be sensitive with respect to errors in the filter coefficients [5,8,11–13,16]. The sources for this include, but not limited to, imprecision in analogue–digital conversion, fixed word length, finite resolution instrumentation and numerical roundoff errors.

The objective of this paper is to address two problems for a class of interconnected discrete-time nonlinear systems. The first problem deals with robust decentralized filtering and the second problem studies the resilient decentralized filtering.[1] Specifically, the robust ℓ_∞ filtering design problem is treated for a class of interconnected discrete-time systems with uncertain function of nonlinear perturbations by exploiting the decentralized information structure constraint. We develop linear matrix inequalities (LMIs)-based conditions for designing the robust decentralized filters. Then by considering additive filter gain perturbations, we solve the resilient decentralized filtering and express the results as convex minimization over LMIs. Simulation examples are provided to illustrate the theoretical developments.

Notations and facts: We use W^t, W^{-1} and $\mathrm{Tr}(W)$ to denote, respectively, the transpose, the inverse and the trace of any square matrix W. We use $W>0$ $(\geq, <, \leq 0)$ to denote a symmetric positive definite (positive semidefinite, negative, negative semidefinite matrix W with $\lambda_m(W)$ and $\lambda_M(W)$ being the minimum and maximum eigenvalues of W and I denote the $n\times n$ identity matrix. Matrices, if their dimensions are not explicitly stated, are assumed to be compatible for algebraic operations. In symmetric block matrices or complex matrix expressions, we use the symbol $\bullet$ to represent a term that is induced by symmetry.

Sometimes, the arguments of a function will be omitted when no confusion can arise.

[1]Throughout the paper we use the phrase 'resilient' to imply robustness with respect to plant parametric uncertainties and against gain perturbations in filter matrices.