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Fault detection filter design with varying gains for multi-delay uncertain systems

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Abstract

The paper is concerned with the fault detection (FD) filter design problem in finite frequency domains for multi-delay systems subject to affine uncertainties. An adaptive mechanism is introduced to construct a new FD filter with varying gains, and the H_∞ tracking method is used to generate the residual signal. By defining appropriate Lyapunov functional, the performance analysis is firstly conducted in finite frequency domains via Parseval's theorem. Subsequently, the FD filter design conditions are derived based on the result of performance analysis. Moreover, it is shown that, for the considered multi-delay uncertain systems, the FD filter with varying gains can achieve better FD performances than the existing ones with fixed gains. Finally, a numerical example is given to illustrate the advantages of the proposed theoretical result.

1. Introduction

With the increasing demand for reliability and safety in application processes, fault detection played an important role in dynamic systems, which has attracted more attention over the past decades. The delay systems appear in many practical systems, which often causes the closed-loop systems unstable and deteriorates performances of the systems. Hence, many FD methods

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on time-delay systems have been studied. For example, the delay-dependent FD filter design conditions are studied in [1] for linear and nonlinear time-delay systems. The fault isolation and FD problem are studied in [2] for neutral and retarded time-delay system. In [3,4], the fault estimation approaches based on adaptive observer are investigated for neutral and retarded time-delay systems. The problem of fault detection is studied in [5,6] for a class of fuzzy positive and switched positive systems with time-varying delays. However, the FD problems in [1–6] are all considered in full frequency domain. In fact, the information of incipient faults is always contained within low frequency bands as the fault development is slow [7], in this case the full frequency FD design methods will be much conservative due to overdesign.

By introducing a weighting matrix to limit frequency ranges, the disturbance attenuation and fault sensitivity requirements have translated into an H_∞ tracking problem in finite frequency domains in [8–13]. Although the weighting method has been proven to be useful in practice, the additional weights tend to increase the system complexity, and the process of selecting appropriate weights can be time-consuming.

To resolve these problems, the generalized Kalman–Yakubovic–Popov (KYP) lemma [14] is introduced to address the FD problems in finite frequency domains [15,16], where any weighting matrix is not exploited. In [17], the problem of H_-/H_∞ fault detection for two-dimensional (2-D) systems with disturbances in Roesser model is investigated. Moreover, the generalized KYP lemma is also used to design filters and controllers for the linear time-delay systems and the delta operator systems, respectively [18–20]. Especially, the actuator FD problem in finite frequency domain for linear multi-delay systems with time-varying uncertain parameters is studied in [21]. In [22], the FD filter design for uncertain linear continuous-time systems is investigated. The model reduction problem of two-dimensional (2-D) digital filters is studied in [23].

Although the above methods have been proven to be successful in detecting various faults, the FD filter with fixed gains [15,16,21,22] may be conservatism when large parameter uncertainties are encountered. To reduce the conservatism, the H_∞ controller with varying gains is designed in [24] in finite frequency domains for uncertain linear systems by using adaptive techniques. It should be pointed out that the states in [24] are required to be available to design adaptive laws. However, in many practical situations, the system states are not always known. In this case, how to design the FD filter with varying gains in finite frequency domain for multi-delay uncertain systems has not been investigated. The motivation of this paper is to further investigate the FD filter with varying gains in finite frequency domain for multi-delay uncertain systems, and reduce the conservatism of the existing FD results. The proposed FD method has a promising feature that the system states will be not known to construct a new FD filter.

The paper is concerned with designing the FD filter in finite frequency domains for multi-delay systems with affine uncertainties. The considered affine uncertainties are assumed to be time-invariant, unknown, but bounded. By decomposing the state variables, a new adaptive mechanism is introduced to construct an FD filter with varying gains, and the H_∞ tracking method is used to generate the residual signal. By defining appropriate Lyapunov functional, the performance analysis is firstly conducted in finite frequency domains via Parseval's theorem. Subsequently, the FD filter design conditions are derived based on the result of performance analysis. It is shown that the FD filter with varying gains can achieve a better FD performance than the existing FD filter with fixed gains. Finally, a numerical example is given to illustrate the effectiveness and advantages of the proposed FD method.

The rest of the paper is organized as follows: the problem statement and preliminary results are presented in Section 2. The problem of finite frequency performance analysis is given in Section 3.