

**ROBUST FILTER DESIGN OF
TAKAGI-SUGENO FUZZY
SYSTEMS AND ITS APPLICATIONS**

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**Robust Filter Design of Takagi-Sugeno
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Takagi—Sugeno模糊系統魯棒
濾波器設計及應用

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Abstract

Industrial processes or systems always exhibit nonlinear or even complex dynamic behavior, which can be in general described or approximated by nonlinear differential or difference equations. In this case, the conventional powerful linear time-invariant control and filtering theory is of little use. Nonlinear system theory is thus developed for analysis and synthesis of a complex nonlinear system if a mathematical model of the system can be established. However, obtaining the solution to a general nonlinear system problem is very difficult if not impossible at all, or the obtained results are too restrictive to be used. Moreover, a global nonlinear model is extremely difficult to build for many complex industrial processes or systems. Quite often no exact mathematical models can be constructed in practice. Thus control and filtering of complex nonlinear systems is still a challenge in the area of systems and control.

On the other hand, delays occur in many physical, industrial and engineering systems and are one of the main causes of instability and poor performance of systems. When both complex nonlinearity and time delay are present, the control and filtering of complex nonlinear time-delay systems is even a greater challenge.

During the last two decades or so, T-S fuzzy models have been developed to approximate complex nonlinear systems. Unlike conventional modeling which uses a single model to describe the global behavior of a system, T-S fuzzy models are essentially a multi-model approach with simple linear models combined to describe the global behavior of the system, and thus provide alternative approaches to modeling of general complex nonlinear systems.

One of the objectives of this thesis is to exploit T-S fuzzy models to construct some systematic H_∞ filter schemes for nonlinear systems with time-varying delays. A distinctive feature reported in this thesis is that all the proposed methods are relative to time-varying delays and all filter gains can be obtained by solving a set of linear matrix inequalities.

Based on piecewise Lyapunov functions, robust piecewise H_∞ filters are proposed

and one of their advantages is less conservative compared with common Lyapunov function based filters. Then the results are extended to systems with time-varying delays. By presenting two novel delay-dependent piecewise Lyapunov- Krasovskii functionals and employing different model transformations and techniques, delay-dependent H_∞ filters are obtained, which includes memory and memoryless ones. In addition, a unified framework to design both full-order and reduced-order filters is provided.

Furthermore, a more general case of non-synchronized filtering problem for T-S fuzzy systems with time-varying delays is investigated. The key issue needs to be addressed for this problem is that the states of plant and the filter might stay in the different regions from time to time due to the unknown premise variables of fuzzy rules. Based on the obtained results on delay-dependent stability conditions, novel approaches are presented to design of non-synchronized H_∞ filter of T-S fuzzy delay systems.

Finally, the application of the robust filtering design approaches to the fault detection is investigated. It is known that contingent failures are possible for all sensors, actuators or system components in a system, which may result in severe performance degradation. Therefore the complexity of today's control systems requires some schemes to provide early warning of faulty system components, and this issue is not only theoretically interesting and challenging, but also very important in practical applications. This thesis presents systematic fault detection filter design schemes for T-S fuzzy systems with time-varying delays. The basic idea is to make a tradeoff between robustness and sensitivity of residual signals and to take the fault detection filtering as a multi-objective H_∞ optimization problem.

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