On Robust Fault Diagnosis of Complex Mechatronic Systems

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1 Background

The economic value of high-tech production equipment is proportional to its productivity. A key enabler for high productivity in manufacturing machines are positioning systems. The accuracy and speed of these positioning systems rely on an excellent and refined mechanical design in conjunction with effective control algorithms. Despite excellent mechanical system design and advanced control strategies, high-tech production equipment still undergoes a significant amount of downtime. To minimize this downtime, fault diagnosis systems are essential which facilitate effectively scheduled and targeted maintenance such that productivity is maximized [1].

2 Problem

Many fault diagnosis systems are based on parametric first principle models of the system. However, a complete and perfectly accurate mathematical model is never available, and the characteristics of the disturbances and noise are typically unknown. Hence, there is always a mismatch between the actual process and its mathematical model, even in the absence of faults. These discrepancies cause fundamental difficulties in fault detection and isolation (FDI) applications. The effect of modeling uncertainties is therefore a crucial point in the model-based FDI concept, and the solution of this problem is the key for its practical applicability. The aim is to explicitly take model uncertainty into account, such that a robust FDI system can be designed that provides performance guarantees when implemented on the true system.

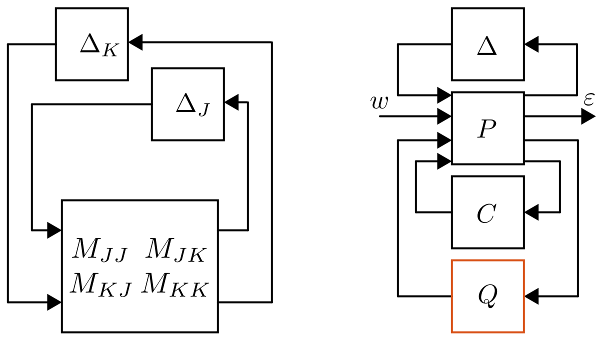

Figure 1: Generalized structured singular value, μ_g, analysis test (left) and closed-loop configuration for fault detection by means of the residual signal ε (right).

3 Approach

The proposed approach integrates prior information, i.e., models that are available from controller design, with posterior information in the form of experimental input/output data during normal operating conditions. The fault diagnosis system is designed by explicitly taking uncertainty and disturbances into account, while guaranteeing a specified fault sensitivity. To this end, the problem is posed as an $\mathscr{H}_\infty/\mathscr{H}_-$ optimization problem, which builds upon well-established theory adopted from the field of advanced motion control, i.e., the generalized structured singular value μ_g [2] and μ synthesis [3], see Figure 1. The approach is evaluated through a numerical analysis.

4 Results

It is shown that effective robust fault diagnosis systems can be synthesized by means of LMI optimization, solving the $\mathscr{H}_\infty/\mathscr{H}_-$ problem. By means of a numerical case study, resembling a next-generation positioning system, its effectiveness is illustrated. The fault diagnosis system guarantees specified performance criteria, which are analyzed using the generalized structured singular value μ_g [2].

5 Outlook

The main focus of this abstract lies in the generation of useful residual signals. In the future, more emphasis will be put on fault isolation. In addition, the proposed robust fault diagnosis filters will be implemented on a next-generation wafer stage.

References

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