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On Robust Fault Detection for Precision Mechatronics

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1 Background

Rising market demands for computer chips necessitate the continuous operation of high-tech production equipment. Downtime due to unexpected faults has impact on uptime having negative financial consequences. To minimize downtime, industry is shifting towards predictive maintenance tools by exploiting fault diagnosis systems [1]. This work focuses on solving the *fault detection* (FD) system design problem for uncertain closed-loop systems, which builds the core for diagnostic systems.

2 Problem formulation

Consider the uncertain closed-loop controlled system with augmented FD system in Fig. 1. The FD system design consists of two steps; 1) the design of $(M_u(s), N_u(s)) \in \mathscr{RH}_\infty$ and subsequently 2) the design of $R(s) \in \mathscr{RH}_\infty$. While M_u and N_u focus on minimizing the impact of r for the case without uncertainty, i.e., $\Delta = 0$, the post-filter R aims at maximizing the sensitivity to faults f and minimize the effect of uncertainty Δ and disturbances d into the residual ε. Provided that the residual dynamics is described by

$$\varepsilon = R(s)T_{\tilde{\varepsilon},rd}(s,\Delta)\begin{bmatrix} r \\ d \end{bmatrix} + R(s)T_{\tilde{\varepsilon}f}(s,\Delta)f, \qquad (1)$$

the optimization problem is to find post-filter $R(s)$ in (1) such that $\left\|R(s)T_{\tilde{\varepsilon},rd}(s,\Delta)\right\|_\infty \leq \gamma$ for all $\Delta \in \boldsymbol{\Delta}$, and performance index $J_{-/\infty}(R)$ is maximized, that is,

$$\sup_{R(s)\in\mathscr{RH}_\infty} J_{-/\infty}(R) = \sup_{R(s)\in\mathscr{RH}_\infty} \frac{\|R(s)T_{\tilde{\varepsilon}f}(s,\Delta)\|_-}{\|R(s)T_{\tilde{\varepsilon},rd}(s,\Delta)\|_\infty}. \qquad (2)$$

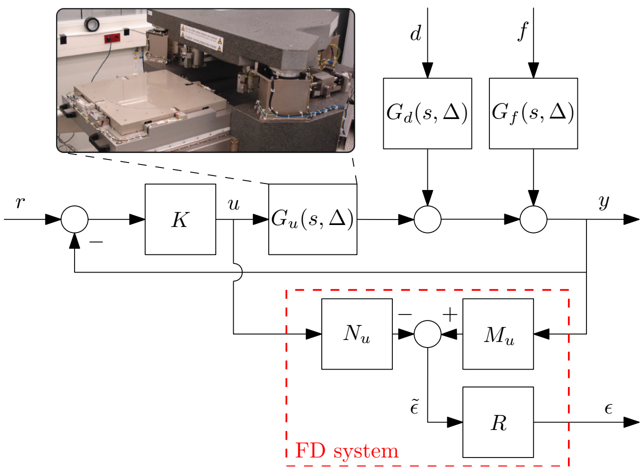

Figure 1: General uncertain closed-loop FD configuration, with $G_u(s,\Delta)$ the uncertain plant model of the prototype wafer stage that was used for synthesis.

3 Approach

The multiobjective optimization problem in (2) is solved in two steps. First, filters $M_u(s)$ and $N_u(s)$ are obtained by applying a left coprime factorization to the nominal plant, i.e., $G_u(s,0) = M_u^{-1}(s)N_u(s)$. Second, a worst-case overbound of uncertain disturbance transfer function matrix $T_{\tilde{\varepsilon},rd}(s,\Delta)$ is found. This allows to solve problem (2) with a single Riccati equation, giving the optimal post-filter $R(s)$ in view of (2) [2].

4 Results and Outlook

The approach is experimentally validated on a prototype wafer stage as shown in Fig. 1. It is shown that the residual signal only exceeds the detection threshold γ if a fault is present in the system, while being robust to the effects of model uncertainty and disturbances, as is shown in Fig. 2. A next step is to extend this solution to optimally solve the *fault detection and isolation* problem.

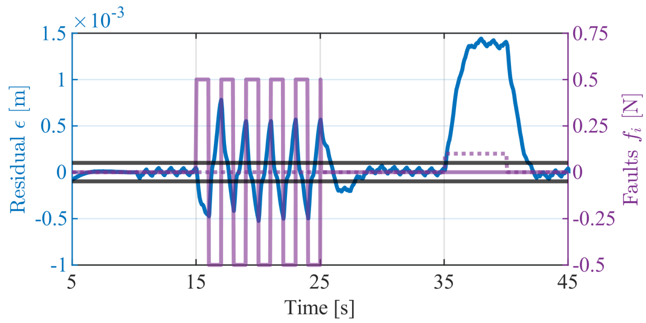

Figure 2: Time response of a residual in (—) together with the detection threshold γ shown in (—). The faults are shown in (—) and (⋯). Indeed, the residual remains within the bound if no fault is acting on the system.

References

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