On Nullspace-based Fault Diagnosis of Complex Mechatronic Systems

Koen Classens[1], W.P.M.H. (Maurice) Heemels[1] and Tom Oomen[1,2]

[1]Dept. of Mechanical Engineering, Eindhoven University of Technology, The Netherlands
[2]Delft Center for Systems and Control, Delft University of Technology, The Netherlands
{K.H.J.Classens,W.P.M.H.Heemels,T.A.E.Oomen}@tue.nl

1 Background

The economic value of high-tech production equipment is proportional to productivity. Key enablers are fast and accurate positioning systems which rely on a refined mechanical design and effective control algorithms. Despite incredible progress over the past decades, high-tech production equipment still breaks down. To minimize downtime, fault diagnosis systems are crucial to facilitate optimal and targeted maintenance such that productivity is maximized [1].

2 Problem

Fault detection and isolation (FDI) for large scale closed-loop controlled multi-input multi-output (MIMO) systems is challenging and successful application to complex mechatronic production equipment remains to be proven. For this purpose, accurate fault diagnosis system of low computational complexity are required, enabling to isolate a large number of possible actuator and sensor faults.

3 Approach

The proposed approach integrates prior information, i.e., accurate models available from controller design, with posterior information in the form of experimental input/output data during normal operating conditions. The fault diagnosis system, see Fig. 1, is based on an accurate low-order MIMO model and is synthesized by means of a numerically reliable nullspace-based FDI approach [2]. The residual signals, denoted by ε, are invariant to exogenous disturbances r, d, and w, and allow to isolate the root-cause fault f, highlighted in real-time in a digital counterpart (×), see Fig. 2.

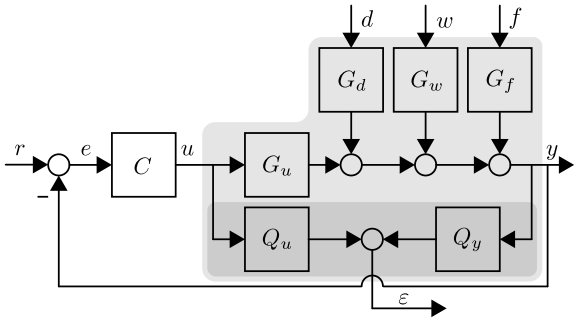

Figure 1: Closed-loop controlled system with augmented residual generator, highlighted in (■).

4 Results

It is shown that effective fault diagnosis filters can be synthesized which solve the FDI problem. By means of a numerical case study and experimental validation on a next-generation prototype wafer stage, see Fig. 2, its effectiveness is illustrated. The fault diagnosis system guarantees fault detection and isolation of a large number of imposed actuator and sensor faults.

5 Outlook

The main focus of this abstract is on successful application to a large scale MIMO industrial setup. Next, more emphasis will be put on incorporating modeling uncertainty into the synthesis tools to provide robustness guarantees.

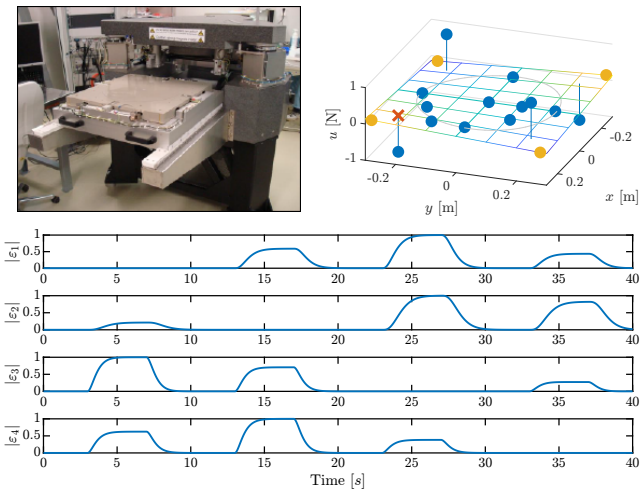

Figure 2: FDI on a prototype wafer stage with 4 sensors (●) and 13 actuators (●). To this end, a bank of 13 residuals signals ε are used, of which 4 are depicted. These signals allow to isolate the root-cause of the faulty system, highlighted in real-time by (×).

References

[1] K. Classens, W. P. M. H. Heemels, and T. Oomen, "Digital Twins in Mechatronics: From Model-based Control to Predictive Maintenance," in *2021 IEEE International Conference on Digital Twins and Parallel Intelligence*, Beijing, China, 2021.

[2] A. Varga, *Solving Fault Diagnosis Problems*. Springer International Publishing, 2017.

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