Digital Twins in Control: From Fault Detection to Predictive Maintenance in Precision Mechatronics*

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Abstract

The economic value of high-tech production equipment is to a large extent determined by its productivity. In order to maximize productivity, it is essential to minimize unscheduled downtime. Equipment downtime can be minimized by means of predictive maintenance, which can be pursued via the process of predicting and detecting faults and simultaneously pinpointing its origin, which is called Fault Detection and Isolation (FDI).

Traditional FDI systems are either data-driven or based on physical models. As next generation FDI system, a physics-based model is envisaged that is learned from data to improve the predictive capability of the digital counterpart. Models of the system are often available prior to commissioning a machine, for instance, through Finite Element Modeling or identified models during system integration. After system integration and control design, the model is generally left unused. Evidently, this model is valuable and can be exploited in the form of a digital twin that is informed with real-time data through a large number of sensors and actuators. Comparison of this digital counterpart to the physical plant allows to monitor the ageing of critical components and allows to detect anomalies at an early stage. The underlying physics enable to isolate the origin of anomalous behaviour, which in turn allows for effective self-healing or specific hardware maintenance.

The envisioned approach involving data-enriched physics-based digital twins is general in nature and therefore likely to be applicable to a large range of systems, including production machines and scientific instruments. The proof-of concept will demonstrate that the envisioned approach can be applied to a broad industrial range of mechatronic systems far beyond wafer scanners. In this way, the present research project (2020-2024) focuses on bridging the gap between data-based and model-based FDI approaches, which are currently largely separated.

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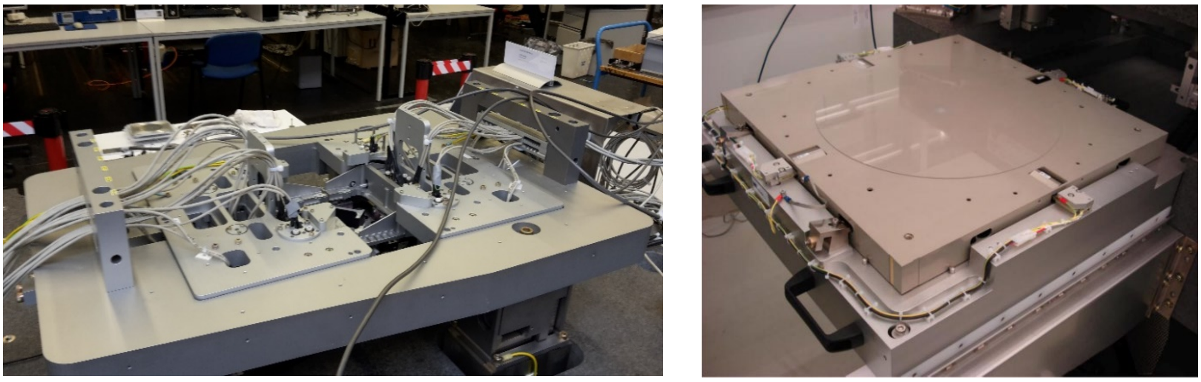

(a) Free floating reticle stage. (b) Overactuated test rig.

Figure 1: Two experimental setups to illustrate predictive maintenance via digital twinning.

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