Identification and Control of Overactuated Mechatronic Systems

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Background

Stringent performance demands in next-generation mechatronic systems necessitate active control of structural dynamics. Important examples include adaptive optics in satellite communication and astronomy and motion stages in lithography. To achieve faster movements in motion systems, lightweight and flexible motion stages are being envisioned. Similarly, deformable mirrors are expected to become increasingly large to support both i) larger ground-based telescopes and ii) deformable mirrors early in the optical path [1]. As a result, these systems are envisioned to exhibit structural dynamics within the frequency range that is relevant for control [2]. Therefore, next-generation mechatronic systems are envisioned to widely adopt active control of the structural dynamics as an integral part of the control strategy.

Challenges

The next-generation mechatronic system design and the resulting presence of flexible dynamics within the control bandwidth leads to three main consequences that are addressed in this abstract.

1. Mechatronic systems often require high-performance operation at locations that cannot be accessed by measurement, for example, the exposure location on a wafer. Due to the internal spatio-temporal deformations as a result of the flexible dynamic behavior, the control performance strongly depends on the quality of spatio-temporal models.
2. Moreover, many mechatronic systems are composed of subsystems that must be validated before full integration. For instance, deformable mirrors in adaptive optics need to be experimentally validated before integration into the telescope. Specifically, validation efforts should experimentally confirm whether the dynamics align with the expected system characteristics [3].
3. Next-generation mechatronic systems contain a large number of spatially distributed actuators and sensors which leads to a significant amount of measurement time to obtain accurate models using traditional methods.

Aim and Contribution

The aim of this poster is to present a unified approach for spatio-temporal models of overactuated mechatronic systems. The approach consists of all the steps from identifying non-parametric models [4] to the construction of spatio-temporal models based on updated finite-element method simulations [5]. To facilitate accurate models with limited measurement time, the local rational method is employed [4], see Figure 2. To facilitate accurate modeling and physical interpretability of the spatial nature of flexible dynamics, a dedicated modal modeling approach is pursued [6],[7] , see, e.g., Figure 3. To deal with the limited amount of spatially distributed sensors, prior mechanical systems knowledge is employed by exploiting reciprocity, i.e. the Betti-Maxwell theorem [5], and/or finite element models, which extends to the previous result in [3]. The proposed approach is illustrated in several case studies, including two deformable mirrors, see Figures 1 and 3. The proposed approach enables detailed spatio-temporal analysis with limited measurement time and subsequently acts as an enabler for next-generation motion control of next-generation motion stages and deformable mirrors in astronomy and lithography.

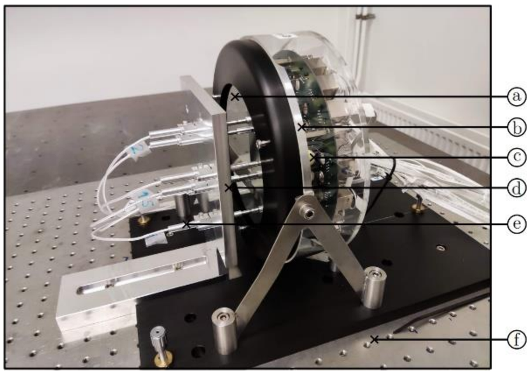

*Figure 1. Experimental DM1 deformable mirror which is designed by TNO (Hamelinck et al., 2008) with the six capacitive sensors mounted to a repositionable **aluminum** bracket. (a) Reflective surface, (b) actuator backplate, (c) one of the hybrid reluctance actuators, (d) **aluminum** sensor bracket, (e) one of the six capacitive sensors, and (f) heavy testbench.*

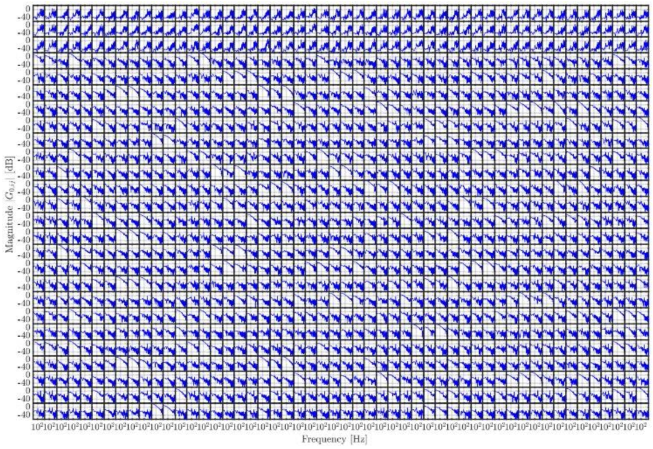

Figure 2. 26 × 52 elementwise Bode magnitude plot of the frequency response function of the experimental DM1 deformable mirror at TNO Delft. The estimate is based on 3 random noise experiments with a total measurement time of only several minutes. This is enabled using local parametric modeling techniques. The top three rows represent the results of the acceleration sensors mounted to the actuator backplate. The remaining rows represent the response measured by 6 capacitive sensors that measure the deflection of the reflective surface.

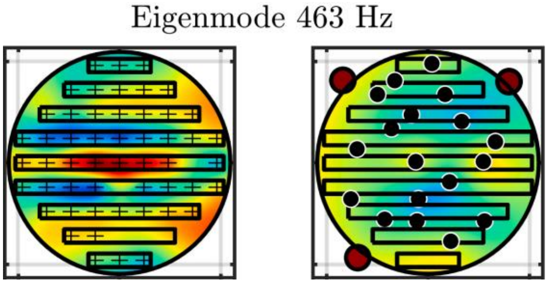

Figure 3. Visualization of a mechanical mode of the experimental deformable mirror system DM1. The mode is caused by the limited stiffness of the actuator support frame. The left figure visualizes the relative mode shape vectors on the locations of the 52 actuators (+). The right figure visualizes the absolute mechanical mode measured at the sensor locations.

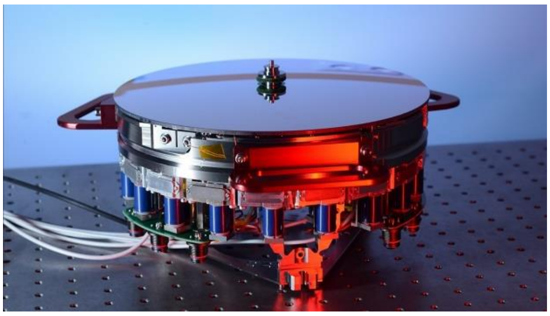

Figure 4. Image courtesy of TNO. Adaptive secondary mirror from TNO for the NASA-IRTF telescope in Hawaii.

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