Exploiting directionality in Optimal Experiment Design for Multivariable Systems

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1 Background

Non-parametric Frequency Response Function (FRF) identification plays an essential role in identifying dynamic systems and is considered fast, inexpensive, and accurate [1]. The resulting FRF constitutes a key intermediate step towards parametric modeling and (model-based) control design [2].

2 Problem

The accuracy of the identified FRF directly depends on the excitation signals. Hence, suitable excitation design, or experiment design, is essential [3], especially for complex Multiple Input Multiple Output (MIMO) systems. For MIMO systems, excitation design does not only require appropriate design of the magnitudes of the excitations, but also their directionality.

In traditional experiment design methods, the excitation directions are a priori restricted to be orthogonal to each other [1, 4]. As a result, the full potential to address the directionality of the MIMO system as function of frequency is not exploited.

The aim of this research is to develop an Optimal Experiment Design (OED) approach that explicitly addresses this directionality to improve the identification accuracy FRF models for MIMO systems in closed-loop.

3 Approach

The problem of OED for non-parametric system identification is posed as the minimization of a cost function $\mathscr{J}(\Phi_w)$ related to the FRF acccuracy, over the input spectrum Φ_w, while satisfying the system constraints:

$$\begin{aligned} &\text{minimize} && \mathscr{J}(\Phi_w) \\ &\text{subject to} && g(\Phi_w) \leq 0. \end{aligned} \tag{1}$$

Here, $g()$ is the set of constraint functions, typically constituting limitations in the allowable (excitation) signal power or amplitude. The OED problem in (1) is highly challenging because of non-convexity and large dimensionality.

4 Results

The OED method is experimentally validated on a cnext-generation wafer stage with 8 inputs and 7 outputs operating in closed-loop control, see the photo in Fig. 1. Constraints apply to the input power of the system.

Three different excitation designs are compared:

D1) Non-optimized excitation magnitude (uniform). Non-optimized directions.

D2) Optimized excitation magnitude, but non-optimized directions.

D3) Optimal design resulting from (1) wherein both the excitation magnitude and directions are optimized.

Fig. 1 shows the 95% confidence regions of a single entry of the identified FRFs (solid), including the corresponding estimated standard deviations (dashed). Through optimized excitation directions, D3 (red) achieves a factor 3 lower standard deviation compared to D2 (blue), and a factor 10 compared to the non-optimized design in D1 (black).

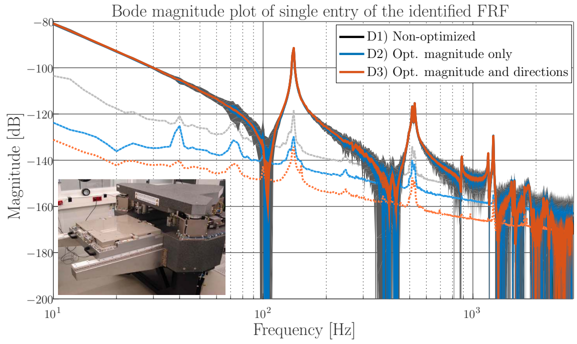

Figure 1: Identified FRFs using design D1 (black), D2 (blue), and D3 (red). Lower left: wafer stage setup.

5 Ongoing work

Ongoing research includes:

- methods to relax or solve the non-convex problem (1) for both input and output signal power and amplitude constraints,
- control-relevant OED.

References

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