Identifying Thermal Dynamics for Precision Motion Control

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1 Background

Thermal-induced deformations are becoming increasingly important for the control performance in precision mechatronics. These deformations limit overlay performance in lithography applications and cause drift induced image blur in transmission electron microscopes.

2 Problem

Experimental modeling is needed to accurately describe the thermal dynamics of these mechatronic systems. Identification of thermal systems is challenging due to large transients, large time constants, excitation signal limitations and environmental disturbances. In this work, Frequency Response Function (FRF) identification is used as a first step towards high fidelity modeling.
The response of a discrete linear time invariant system can be represented in the frequency domain as

$$Y(k) = G(\Omega_k)U(k) + \mathscr{T}(\Omega_k) + \mathscr{V}(k). \tag{1}$$

where $G(\Omega_k)$ is the relevant FRF of the LTI system and $\mathscr{T}(\Omega_k)$ an additional term due to transients and $\mathscr{V}(k)$ the effect of noise and disturbances. Where the latter is large due to disturbances in the ambient temperature, making the term $\mathscr{V}(k)$ increasingly significant.

3 Approach

The framework presented in [3], 1) exploits a newly developed local parametric modeling technique parametrized with prescribed poles (LRMP) tailored for thermo-mechanical systems by specifying poles to improve the estimation accuracy by explicitly estimating the transient. It was first introduced in [2] and is an extension of the initial concept of local parametric modeling described in [1]. And 2) includes the ambient temperature measurement as an additional input a achieve a reduced estimation error and improved variance for low frequencies.

4 Results

To achieve improved FRF estimation, the transient is explicitly taken into account. The results shown in Fig.1 illustrate that the proposed method estimates the same FRF in both the transient and validation data set. Here, the ETFE obtains a significantly biased estimate due to the transient component $\mathscr{T}(\Omega_k)$. In Fig.2 the reduction in variance at low frequencies by incorporating the ambient temperature measurements is shown. The presented methods facilitate the implementation of advanced model based control techniques and error compensation strategies, enabling increased accuracy and throughput in high precision motion control.

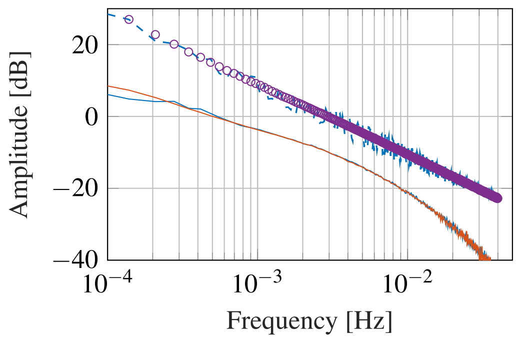

Figure 1: The LRMP (——), unlike the ETFE (- - -), is invariant to the transient contribution (—o—) and provides a good estimate compared to the validation data (——).

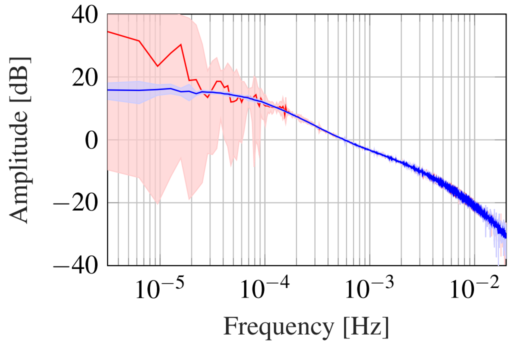

Figure 2: FRF estimation of $u_1 \to T_1$ using (a) LRMP with only input u_1 (——) and (b) using the additional input (——). The variance, shown as (,), is significantly reduced at low frequencies.

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References

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