System analysis and improved digital feedback control of a piezo-actuated laser scanning system

Degree programme: Master of Science in Engineering
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Piezoelectric actuators are commonly utilized in applications that demand fast and precise positioning, such as laser-based eye surgery. Paired with a moving mirror, they provide the high level of precision required for directing the laser beam. Achieving optimal performance relies on a control system that ensures both speed and accuracy, which in turn necessitates a system model that accurately represents the dynamics and includes all relevant perturbations.

Background

The system comprises a piezoelectric actuator controlling a two-axis mirror for precise laser beam positioning. Mechanical coupling causes crosstalk (CT) between the axes, meaning that movements from one axis can actuate the second axis, particularly at resonance frequencies. These disturbances impact performance in high-precision tasks like laser surgery, making accurate crosstalk modeling essential for advanced control strategies to mitigate disturbances and improve performance.

System modeling and Methods

The system's frequency response was measured to identify multiple resonance frequencies. The Butterworth-Van Dyke (BVD) model was chosen to represent a mechanical spring-damper system as an equivalent electrical circuit. To capture the system's multiple resonances, a second branch was added to account for two resonances in a single axis. While the mechanical tilt of one axis is proportional to the charge in the mechanical branch of the BVD model, the CT is modeled to be proportional to the current in the mechanical branch.

The model parameters were identified using an optimization algorithm minimizing the error between measured and modeled amplitude responses with a least-squares approach. Model validation was performed by comparing step response data from the physical system and the model (see figure 1). A similar strategy was used to validate the crosstalk model through step response comparisons.

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Feedback Control

Using the validated model, various controllers were implemented and their performances were compared. Initially, a simple PID controller was applied (see figure 2). Advanced model-based controllers were then tested to capitalize on the new system model and address the challenges posed by crosstalk more effectively.

Discussion

The crosstalk model improved system representation, as shown in Figure 2, but incorporating hysteresis could further enhance the response by reducing controller corrections. Advanced controllers, like the pole placement controller, reduced settling time by four times compared to the PID. However, for faster responses, the crosstalk model provided no additional benefit.

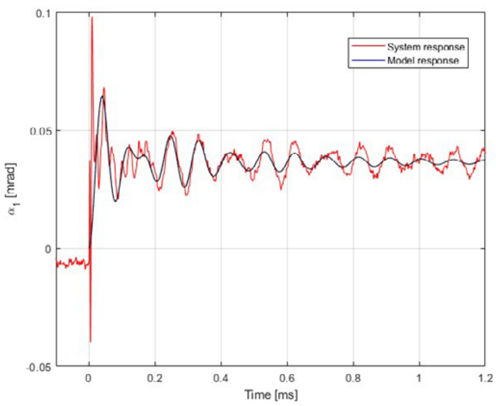

Figure 1, Step response comparison

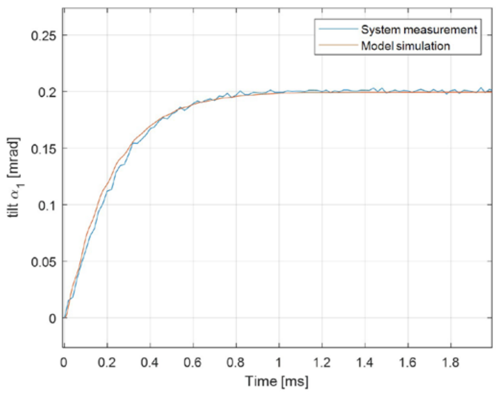

Figure2 , Step response comparison with PID