MODELING AND CONTROL OF A CLASS OF NONLINEAR OPTO-MECHATRONIC SYSTEMS WITH THE LINEAR PARAMETER VARYING REPRESENTATION

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ABSTRACT

Opto-Mechatronics is an evolving technology that integrates optical components into mechanical, electronic/electrical and computer technologies to improve and expand the characteristics of the traditional technologies and provide high precision and reliability for modern engineered devices. As the Opto-Mechatronic technology advances, the need for better performance brings the challenges to the control design of the systems.

In this thesis, a systematic modeling and control approach is established for a family of Opto-Mechatronic motion systems that exhibit nonlinear behaviors. The overall approach consists of the following: 1. definition of relevant image-based metric, 2. model identification, 3. controller design and optimization based on the full model, and 4. experimental validation. The imaging application means that the performance metric is driven by the image quality rather than the direct sensor output measurement from the optical component. There, a novel output variance metric is proposed to effectively capture the image quality and can be used in simulation for controller tuning.

Linear system description alone is often inadequate to meet the design and performance assessment requirements. Linear Parameter Varying (LPV) formulation is a promising approach to address system nonlinearity by using a family of linear time invariant (LTI) systems parameterized at the operating points. In the work presented in this thesis, it is proposed to obtain a high fidelity model in an LPV description to approximate the nonlinear dynamics of the system. The identification of the LPV model parameters is formulated as a nonlinear least square problem based on interpolation among operating points. An efficient relaxation algorithm is proposed to convert the nonlinear optimization into an iterative linear least square problem.

With a high fidelity LPV model built for control, model based control design methodology is proposed with a goal to preserve good closed-loop performance for small range motions in each linear neighborhood while large motion performance

dominated by nonlinear behaviors can be addressed. The same LPV interpolation technique is applied for gain-scheduling based control design. For most Opto-Mechatronic systems with slow varying nonlinear dynamics, the closed-loop stability is guaranteed.

The Fast steering mirror system for imaging applications serves as an exemplary Opto-Mechatronic system to demonstrate the effectiveness of the methodology. First, the imaging test results from two FSM systems shows a good correlation between the variance based metric and the image quality for imaging applications. Therefore it can be used to guide and optimize the feedback controller design. Secondly, the experimental results in modeling and control steps obtained from the FSM prototypes also shows that the proposed local based interpolation procedure is capable of carrying out the LPV system with both the exogenous and endogenous dependency. Experimental tests show good agreement between the estimated frequency and time responses based on the LPV simulation models and the nonlinear physical responses.