Modeling and feedforward control for high performance galvanometer scanners

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Abstract

Galvanometer scanners are widely used in the industrial and scientific applications serving as the key components of laser manufacturing systems. The scanner deflects the laser beam via two orthogonally distributed galvanometers with reflecting mirrors, thereby achieving high-speed scanning in two directions. Recently, with the development of ultrafast laser micromachining, there are increasing demands for the galvanometer scanners to achieve high precision motion quality. Hence, it is necessary to optimize every aspects of the scanning for optimal performances, including the precise modeling of galvanometers, power amplifiers, and appropriate servo control strategies. In this work, we mainly focus on the modeling and control for high performance galvanometer scanners.

Note that the existing modeling methods of the galvanometer consider the dynamics of the motor and the mirror. It is mainly because that the traditional galvanometer utilizes the optical position detector, of which the weight is light enough to be neglected in the dynamic model. Recently, the digital galvanometer scanners are developed to meet the requirements of high-speed and high-precision scanning purpose, wherein the rotary optical encoders are adopted with ultra-high sensing resolution. However, the ring glass ruler of the optical encoder has a relatively larger inertia, and its inertia cannot be neglected at high frequency. In addition, when the galvanometer operates at high frequency, the displacement measured by the rotary sensor and the actual deflecting angle of the mirror are inconsistent due to the high frequency vibration and limited rigidity of the motor shaft, and this will introduce additional errors which affect the precision of the galvanometer scanning system.

In this paper, we propose the modeling of the galvanometer scanner with the consideration of the above conditions, and further design the feedforward control for high performance scanning. Specifically, a multi-degree-of-freedom lumped mass model is established considering the rotational inertia of the motor shaft, the mirror and the encoder. Then, the dynamic analysis of the established

multi-degree-of-freedom model is carried out, and the transfer function between these components is obtained. Finite element analysis is also conducted to verify the theoretical analysis. Finally, we design a feedforward controller with the command shaping, which considers the high-frequency dynamics and compensates the inconsistence between the encoder and the mirror. Simulation and experimental results verify that the proposed method can effectively improve the dynamic performance and motion precision of the galvanometer scanning system.

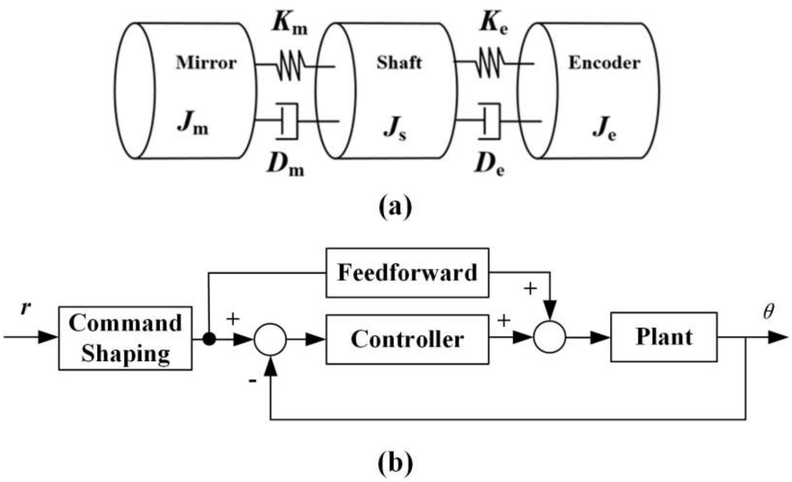

Figure 1: The proposed galvanometer scanner system: (a) multi-degree-of-freedom lumped mass model of the galvanometer; (b) schematic of the proposed feedforward control system.