Chapter 12

Experimental Study of Laser Interferometry Based Motion Tracking of a Flexure-Based Mechanism

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ABSTRACT

This paper presents an experimental study of laser interferometry-based closed-loop motion tracking for flexure-based four-bar micro/nano manipulator. To enhance the accuracy of micro/nano manipulation, laser interferometry-based motion tracking control is established with experimental facility. The authors present and discuss open-loop control, model-based closed-loop control, and robust motion tracking closed-loop control for flexure-based mechanism. A comparative error analysis for closed-loop control with capacitive position sensor and laser interferometry feedback is discussed and presented. Model-based closed-loop control shows improvement in position and motion tracking over open-loop control. Robust control demonstrates high precise and accurate motion tracking of flexure-based mechanism compared to the model-based control. With this experimental study, this paper offers evidence that the laser interferometry-based closed-loop control can minimize positioning and tracking errors during dynamic motion, hence realizing high precision motion tracking and accurate position control.

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INTRODUCTION

Ultra-precision manipulation is one of the very important techniques for the micro/nano engineering and for many applications in manufacturing and medical sciences. Precise control and accurate motion tracking at micro/nano level is a requirement for present and future automation systems. Such precise actuation and control can be achieved with piezoelectric actuator driven flexure-based mechanisms. These mechanisms are highly appropriate platforms for micro/nano manipulation (Chung, Choi, & Kyung, 2006; Li & Xu, 2010; Spanner & Vorndran, 2003; Speich & Goldfarb, 1998; Tian, Shirinzadeh, & Zhang, 2009). Flexure-based mechanisms have no backlash, zero friction and negligible hysteresis, and can offer unlimited motion resolution (Paros & Weisbord, 1965; Mohd Zubir & Shirinzadeh, 2009; Smith, 1997; Tian, Shirinzadeh, & Zhang, 2010). However, piezoelectric actuators possess non-linearities including the hysteresis and creep/drift effects. The presence of such non-linearities cannot guarantee positioning accuracy and precise motion tracking of the flexure-based mechanism. However, in the past decade, increased demand for high-precision micro/nano motion tasks has generated high level of research interests in precise positioning and accurate motion tracking of micro/nano manipulators. Many appropriate closed-loop control strategies have been proposed to achieve the desired motion tracking of piezoelectric actuator-driven flexure-based mechanisms (Bashash & Jalili, 2008; Liaw & Shirinzadeh, 2008, 2009; Motamedi et al., 2010; Rakotondrabe, Haddab, & Lutz, 2009; Saeidpourazar & Jalili, 2006; Shiou et al., 2010; Xu & Li, 2009, 2010). An important component associated with closed-loop control of micro/nano multi-axis manipulator is the sensing and measurement of motion characteristics. Use of interferometry-based sensing to measure changes in position, length, distance and optical length is well demonstrated in recent past (Som-margren, 1987; Speckle 2010; Optical Metrology, 2010). Laser interferometry-based sensing and measurement system is capable of delivering sub nanometer accuracy when used for displacement measurement (Lee, Yoon, & Yoon, 2011; Minoshima, 2010; Schott, 2010; Schuldt et al., 2010; Shelley, 2007; Zeng & He, 2009; Zhou, Zhang, & Cheng, 2009). There has also been a number of research studies carried out on laser interferometry-based motion control for flexure-based mechanisms (Qi, Zhao, & Lin, 2007; Yeh, Ni, & Pan, 2005; Zhang & Menq, 2007) and it shows immense potential for further research.

Research proposed in this work is motivated by our previous efforts in the control of the flexure-based mechanism driven by piezoelectric actuators (Liaw, Shirinzadeh, & Smith, 2007, 2008b), as well as model-based control, and a robust motion tracking control (Liaw, Shirinzadeh, & Smith, 2008a). In model-based closed-loop control, we use supposed knowledge of system parameters to design the motion controller. The robust motion tracking control is employed in such a way that, it adapts the unknown system parameters, piezoelectric actuators nonlinearities, and external disturbances in the micro/nano manipulation system. In this study, the primary research objective is to track a specified motion trajectory using laser interferometry-based motion control. The secondary research objective is to validate experimental results for positioning accuracy and tracking performance with error analysis for capacitive position sensor and laser interferometry-based sensing and measurement technique.

The model of a piezo driven flexure-based micro/nano manipulator is described before presenting model-based and the robust motion tracking controller designs. Further, measurement error analysis and experimental study is detailed and results are presented and discussed ahead of conclusion.