Highly Dynamic Micrometer Positioning using an Ultrasonic Piezoelectric Actuator

Degree programme: BSc in Mechatronics and Systems Engineering (Medical technology | Robotics)
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Miniswys has developed an ultrasonic piezoelectric actuator offering micrometer precision, high velocity, and high power density. The actuator is ideally suited for highly dynamic applications such as in cameras, medical devices, and haptic feedback in VR. However, the nonlinear behavior and high dynamic requirements complicate the feedback control design. This project investigates a model-based pole placement controller to ensure precise and fast positioning of the actuator.

Introduction

For this project, the ultrasonic piezoelectric actuator is integrated into a linear stage module shown in Fig. 1. It includes a slider, a preload system and a Tunnel Magneto Resistance (TMR) sensor to measure the slider position. The actuator uses a piezo-actuated resonator, vibrating at specific resonance frequencies for either forward or backward motion.

Classical control methods such as PID controllers limit the performance. The design of advanced, model-based controllers for highly dynamic positioning is complicated due to the nonlinear properties of the material, manufacturing variations, and actuator saturation.

Goals

- Calibration and accurate position measurement using the TMR sensor
- Deriving and validating a physical model of the system's dynamics
- Model-based design and software implementation of a discrete-time feedback control algorithm for fast and robust positioning

Methods

Position measurement - Depending on the magnetic field strength, a TMR element changes its electrical resistance measurably. Moving a magnetic strip above two slightly shifted TMR elements (TMR sensor, see Fig. 1) results in two phase-shifted sinusoidal signals, allowing relative position calculation.

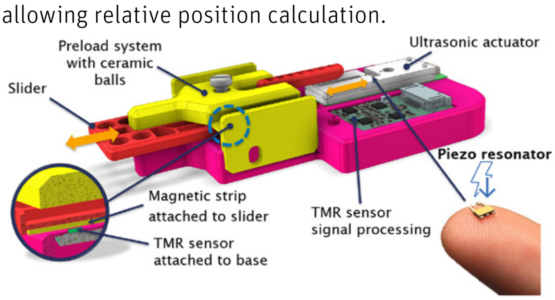

Fig 1. Demonstration module from Miniswys

System identification - A transfer function is derived from a simplified electro-mechanical model of the system. The unknown system parameters are determined using experimental data and a PEM algorithm, minimizing the weighted norm of the prediction error.

Feedback control for the slider position - Based on the derived transfer function, two model-based feedback controllers are designed and tested: a PID controller as reference and a pole placement controller using second order dominant poles.

Results

Accuracy of position measurement - The calculated slider position manifested an accuracy of ±15 µm before calibration and ±1 µm after calibration.

Feedback control - The discrete-time PID- and pole placement controllers are implemented on the STM32 microcontroller driving the actuator. Fig. 2 shows the measured and simulated step responses of both controllers. The settling time is 120ms and 60ms for the PID- and pole placement controllers, respectively.

Discussion

Using a pole placement controller halved the settling time. The proposed workflow for system identification and controller design can be automated, allowing quick adaptation to manufacturing variations of different modules.

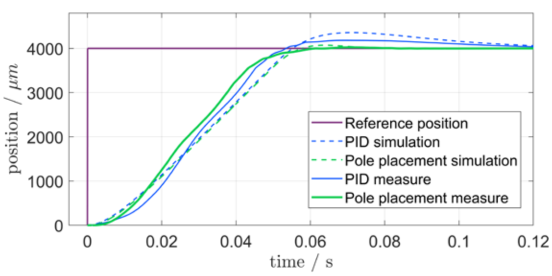

Fig 2. Simulation and measurement of a step response for the PID- and pole placement controllers

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