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Learning-Based High-Precision Tracking Control: Development, Synthesis, and Verification on Spiral Scanning With a Flexure-Based Nanopositioner

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Abstract: The traditional methodology utilized in dynamic tracking control synthesis is usually model-based and therefore the performance is highly dependent on a precise mathematical model. However, with the growth in system complexity, extremely precise dynamic models for modern robotic and automation systems are very hard to obtain. This challenge has sparked the interest of researchers in moving towards data-driven learning-based concepts, specifically aiming to fully exploit the abundant data available to learn better controls. Along this research direction, continued efforts have been spent on learning a single feedback controller.

However, just attempting learning procedures on the feedback controller alone could suffer from severe performance limitations due to its reactive nature, i.e., an error must occur first before any corrective action is taken. In line with this consideration, we propose an integrated two-degree-of-freedom (2-DOF) learning-based tracking control synthesis for high-precision systems, consisting of both feedforward and feedback controllers. Unlike the traditional control design where full knowledge of the dynamics is assumed, we explore the use of actual motion data to iteratively determine the optimal controller parameters using gradient-based optimization. The key step here is to estimate the gradient and Hessian of the cost function without a priori knowledge about the dynamics. Experiments are further conducted based on a prototype flexure-based nanopositioner for spiral scanning applications, demonstrating high-precision nanometer-scale tracking performance that is close to the sensor resolution.

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