

Leveraging Non-Minimum-Phase Property for Active Damping Control of Nanopositioning Systems

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Leveraging Non-Minimum-Phase Property for Active Damping Control of Nanopositioning Systems

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1 Introduction

Nanopositioning systems frequently encounter limitations in control bandwidth due to their lightly damped resonance behavior. With conventional control, the bandwidths are often limited to a small fraction of the resonance frequency. Active damping control enhances the bandwidth by suppressing the resonant peak in a dual closed-loop control architecture (see Fig. 1). Although state-of-the-art damping controllers can effectively dampen resonance with moderate tolerance to frequency variations, their performance is limited because of the interdependence between gain and phase.

2 Research Contributions

This work introduces a novel Non-Minimum-Phase Resonant Controller (NRC) designed for active damping control in dual closed-loop architectures, applied to piezo-actuated nanopositioning systems [1]. The NRC is described by the transfer function:

$$C_d(s) = k \cdot \left(\frac{s - \omega_a}{s + \omega_a} \right), \quad (1)$$

where ω_a signifies the tuned corner frequency of the controller, and k represents the controller's gain. The NRC leverages non-minimum-phase characteristic to achieve complete damping and the bifurcation of the double resonant poles of the primary resonance peak through a constant-gain design with a tunable phase (see Fig. 2), ensuring robustness even under varying load conditions. In addition, the NRC is capable of damping higher-order flexural modes. The proposed NRC can provide high gains at low frequencies within the inner loop, which, complemented by a standard proportional-integral tracking controller, facilitates the

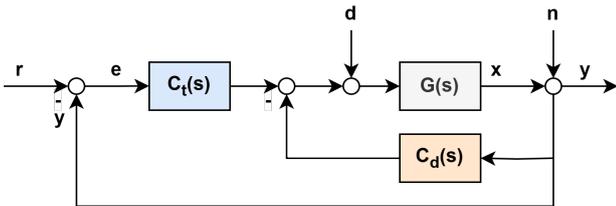


Figure 1: Dual closed-loop control architecture incorporating active damping control.

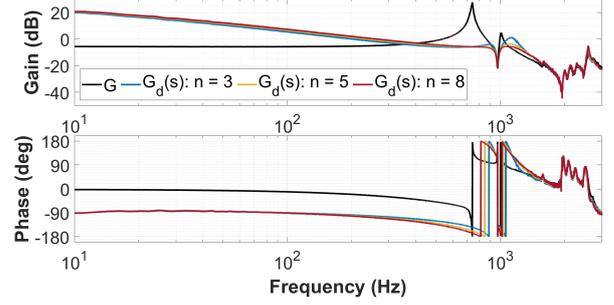


Figure 2: Experimentally identified inner closed-loop frequency response $G_d(s)$ tuned for different $\omega_a = n \cdot \omega_n$ in NRC.

system in achieving high dual closed-loop bandwidths that potentially surpass the primary resonance frequency.

3 Experimental Results

To validate NRC's performance, the experimental setup utilizes a commercial P-621.1CD PIHera linear precision piezo-actuated nanopositioner. The experimental results demonstrate dual closed-loop bandwidths of 895 Hz and 845 Hz (within ± 3 dB and ± 1 dB bounds, respectively) that exceed the first resonance frequency (ω_n) at 739 Hz (see Fig. 3), even amidst significant system delay.

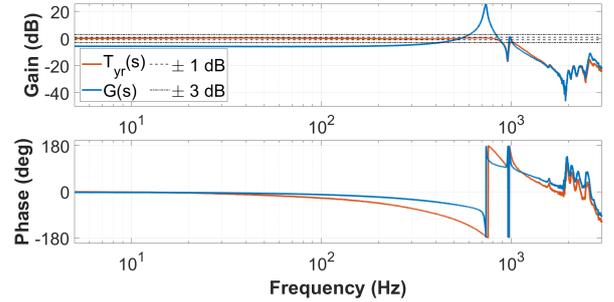


Figure 3: Experimentally identified dual closed-loop frequency response $T_{yr}(s)$.

References

- [1] Natu, Aditya M., and S. Hassan HosseinNia. "Non-Minimum-Phase Resonant Controller for Active Damping Control: Application to Piezo-Actuated Nanopositioning System." *arXiv preprint arXiv:2412.18374* (2024).