19th International Conference on Innovative Computing, Information and Control (ICICIC2025)
August 26-29, 2025, Kitakyushu, Japan

PS-22: ICICIC2025-110

Design and Optimization of a Dual-Piezoelectric-Actuated Microgripper with Two-Stage Flexure Amplification

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Introduction

With the advancement of micro/nano technology, micro/nano grippers have been widely applied in various fields. However, existing designs are predominantly single-functional, struggling to balance high stiffness and precise force control while lacking real-time force feedback. To address these limitations, this study proposes a novel piezoelectric-driven micro/nano gripper based on a dual-actuation mechanism. By incorporating an innovative amplification structure and modular design, the gripper achieves a high displacement amplification ratio and rapid adjustability of gripping force. Furthermore, the integration of force sensing enables closed-loop control, significantly enhancing versatility and operational intelligence. This research provides a new technical approach for developing multifunctional micro-manipulation tools with promising theoretical and practical implications.

Research Questions

This study focuses on addressing three critical challenges in micro-gripper technology: 1) functional singularity, where existing designs are limited to either high-stiffness/high-force or low-stiffness/precision operation modes; 2) insufficient adaptability, requiring device redesign for different operational scenarios; and 3) intelligent control deficiencies, particularly the lack of real-time force feedback capability. Through systematic investigation of these limitations, we aim to develop a novel micro-gripper system that overcomes these fundamental constraints in micro-nano manipulation applications.

Methodologies

This study proposes an intelligent micro-gripper based on dual piezoelectric actuation and a two-stage amplification mechanism, achieving a displacement amplification ratio of 10.8 and force resolution of 1 mN through theoretical modeling, parametric simulation, and multiphysics coupling analysis, while integrating modular design for both high-stiffness/large-force and low-stiffness/precision-force control capabilities.

Mathematical Formulas

$$A_{m1} = \frac{\Delta x_1}{\Delta y} = \frac{\sin\theta_2 - \sin\theta_1}{2(\cos\theta_1 - \cos\theta_2)} \quad (1)$$

$$A_{m2} = \frac{\Delta x}{\Delta x_1} = \frac{l_{hf}}{l_{gh}} \quad (2)$$

$$\boldsymbol{A_m} = \boldsymbol{A_{m1}} \times \boldsymbol{A_{m2}} \quad (3)$$

Figures

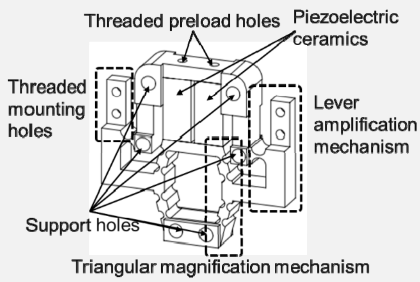

Figure 1. Structural diagram of the microgripper base

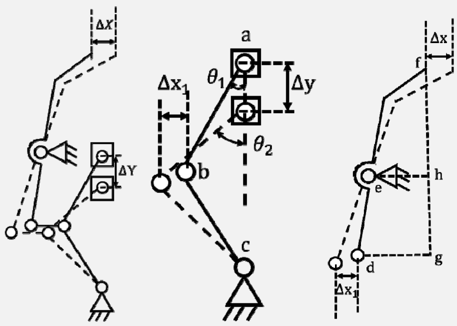

Figure 2. Structural schematics

Figures

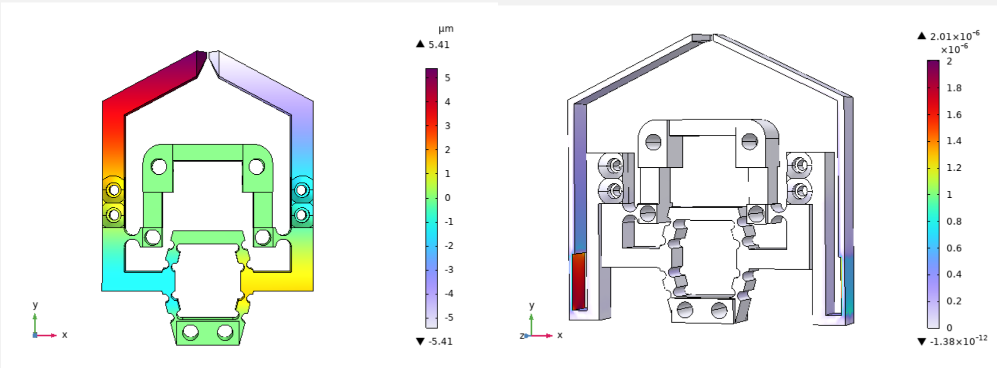

Figure 3. Simulation results

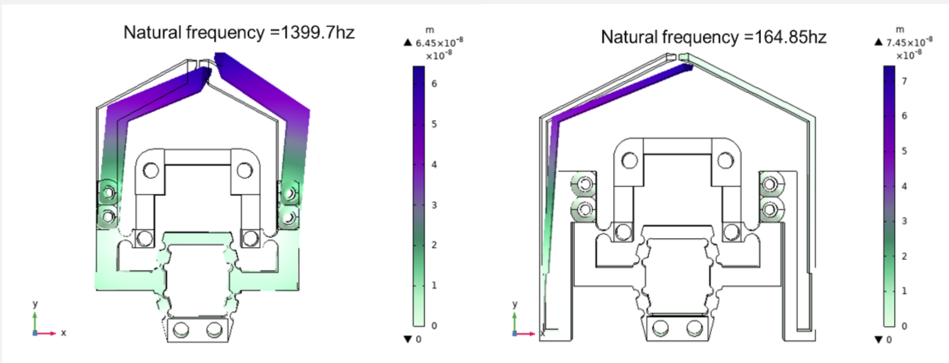

Figure 4. Natural frequency

Table

Table 1. Table of key parameters

Main parameters	R /mm	θ_1 /°	l_{hf} /mm	l_{gh} /mm
Value	0.75	15	29	9

Conclusion

In this work, we have presented the design and optimization of an intelligent micro-gripper capable of adapting to diverse operating conditions. The key innovations include dual piezoelectric actuation, a two-stage displacement-amplification mechanism, and modular, interchangeable gripping units. Through parametric simulation, the mechanism achieved an average displacement-amplification ratio of 10.8 (versus a theoretical 12.02) and demonstrated force-sensing sensitivity sufficient to resolve external loads as low as 1 mN.