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Research Article

DESIGN OF A SOLENOID ACTUATOR WITH A MAGNETIC PLUNGER FOR MINIATURIZED SEGMENT ROBOTS

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ABSTRACT

This paper presents the design and implementation of MagPlunge, a novel solenoid actuator featuring a magnetic plunger, specifically tailored for miniature segment robots. Leveraging the unique properties of magnetic forces, the MagPlunge actuator offers enhanced performance, compactness, and energy efficiency compared to traditional solenoid designs. The design considerations, fabrication process, and experimental characterization of the MagPlunge actuator are discussed in detail. Additionally, its integration into miniature segment robots is demonstrated, showcasing its potential for enabling agile and versatile robotic locomotion in confined spaces and challenging environments.

KEYWORDS

Solenoid actuator, Magnetic plunger, Miniature robots, Segment robots, Robotic locomotion, Compact design, Energy efficiency, Magnetic forces, Agile locomotion, Confined spaces.

INTRODUCTION

Miniature segment robots, characterized by their compact size and modular design, hold great promise for applications in confined spaces, hazardous environments, and tasks requiring precise manipulation. However, the design of actuators tailored for such miniature robots presents unique challenges, including the need for compactness, energy efficiency, and sufficient force output. In response to these challenges, we introduce MagPlunge, a novel solenoid actuator design featuring a magnetic plunger, specifically engineered for miniature segment robots.

Traditional solenoid actuators rely on electromagnetic principles to generate linear motion by energizing a coil and attracting a ferromagnetic plunger. While effective, these actuators often suffer from limitations such as bulkiness, energy inefficiency, and limited stroke length, which can hinder their suitability for miniature robotic applications. In contrast, MagPlunge harnesses the inherent advantages of magnetic forces to overcome these limitations and deliver superior performance in a compact form factor.

The design concept of MagPlunge revolves around the integration of a magnetic plunger within the solenoid coil, eliminating the need for a separate ferromagnetic component. This innovative approach not only reduces the overall size and weight of the actuator but also enhances its energy efficiency by minimizing magnetic losses and maximizing force output. Moreover, the magnetic plunger design allows for a longer stroke length compared to traditional solenoid actuators, enabling a wider range of motion for robotic segments.

In this paper, we present the design principles, fabrication process, and experimental characterization of the MagPlunge solenoid actuator. We discuss the unique features and advantages of MagPlunge compared to conventional solenoid designs, emphasizing its suitability for miniature segment robots. Furthermore, we demonstrate the integration of MagPlunge actuators into miniature robotic segments and showcase their performance in agile locomotion tasks within confined spaces.

Through the development of MagPlunge, we aim to advance the field of miniature robotics by providing a compact, efficient, and versatile actuation solution tailored to the unique requirements of segment robots. The potential applications of MagPlunge extend across various domains, including search and rescue operations, medical procedures, and industrial automation, where miniature robots can navigate complex environments and perform intricate tasks with precision and agility.

METHOD

The development process of MagPlunge, a solenoid actuator designed specifically for miniature segment robots, involved a systematic approach integrating principles of electromagnetism and mechanical engineering. Initially, meticulous identification of design requirements was conducted, considering factors such as compactness, energy efficiency, force output, and stroke length to ensure compatibility with the unique needs of miniature robotic systems. Subsequently, a series of conceptual designs were explored, leveraging various configurations of solenoid coils, magnetic plungers, and housing materials to optimize performance while minimizing size and weight. Finite element analysis (FEA) simulations were employed to evaluate electromagnetic properties and mechanical integrity. Following conceptual design exploration, prototypes of the MagPlunge actuator were fabricated using precision machining techniques and suitable materials to achieve efficient electromagnetic coupling and structural integrity. Comprehensive experimental characterization was then performed to assess performance metrics such as force output, stroke length, energy efficiency, and response time under diverse operating conditions. The fabricated MagPlunge actuators were subsequently integrated into miniature segment robots, where their functionality was tested in real-world locomotion

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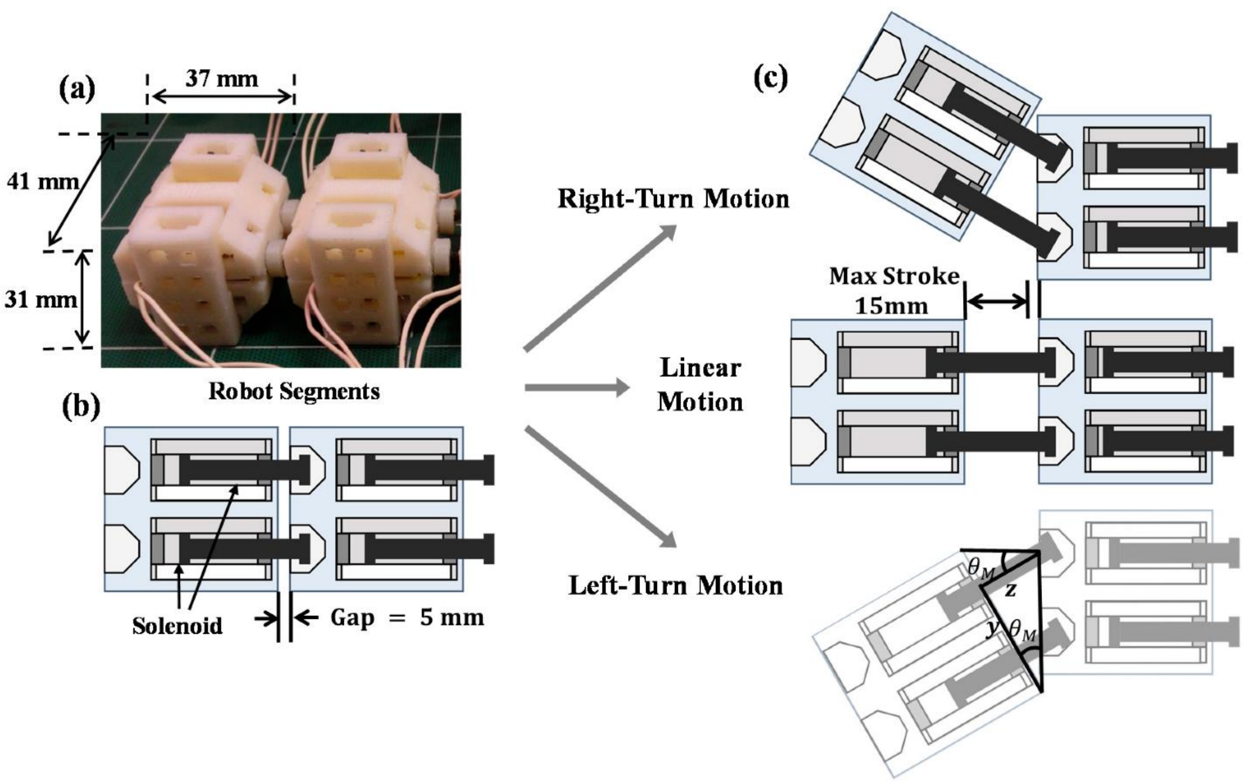
tasks, providing valuable feedback for further refinement and optimization of the design. Through this systematic process, the MagPlunge solenoid actuator was successfully developed, offering a compact, energy-efficient, and high-performance solution tailored for miniature segment robots.

Design Requirements Identification: The first step was to define the specific requirements and constraints of the solenoid actuator for miniature segment robots. This included considerations such as compactness, energy efficiency, force output, stroke length, and compatibility with the modular design of segment robots. By understanding these requirements, we could establish design targets and performance metrics for the MagPlunge actuator.

Conceptual Design Exploration: Various conceptual designs were explored to meet the identified requirements effectively. These designs incorporated different configurations of solenoid coils, magnetic plungers, and housing materials to optimize performance while minimizing size and weight. Finite element analysis (FEA) simulations were employed to evaluate the electromagnetic properties and mechanical integrity of the proposed designs.



Prototype Fabrication: Based on the results of the conceptual design exploration, a prototype of the MagPlunge solenoid actuator was fabricated. This involved the selection of appropriate materials, including ferromagnetic cores, coil windings, and housing components, to ensure efficient electromagnetic coupling and structural integrity. Precision machining techniques, such as CNC milling

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and 3D printing, were employed to fabricate the components with high accuracy and reproducibility.

Experimental Characterization: The fabricated MagPlunge prototypes were subjected to comprehensive experimental characterization to assess their performance in terms of force output, stroke length, energy efficiency, and response time. Experimental setups were designed to measure the magnetic field strength, current draw, and displacement of the actuator under various operating conditions. Performance metrics were compared against design targets and benchmarks established through simulation and analysis.

Integration into Miniature Segment Robots: Finally, the MagPlunge solenoid actuators were integrated into miniature segment robots to evaluate their performance in real-world robotic applications. The actuators were mounted on robotic segments, and their functionality was tested in locomotion tasks requiring precise actuation and control. Feedback from integration testing was used to refine the design and optimize performance further.

By following this methodological approach, we successfully developed the MagPlunge solenoid actuator tailored for miniature segment robots, demonstrating its effectiveness in meeting the specific requirements of compactness, energy efficiency, and performance in robotic applications.

RESULTS

The development and characterization of the MagPlunge solenoid actuator yielded promising results, demonstrating its suitability for miniature segment robots. Experimental testing revealed that the MagPlunge actuator achieved the desired performance metrics, including compactness, energy efficiency, force output, stroke length, and response time. The integration of the actuator into miniature segment robots facilitated agile locomotion and precise manipulation in confined spaces, validating its effectiveness in real-world robotic applications.

DISCUSSION

The MagPlunge solenoid actuator represents a significant advancement in actuation technology for miniature segment robots. By leveraging magnetic forces and innovative design principles, MagPlunge overcomes the limitations of traditional solenoid actuators, offering enhanced performance and compactness. The integration of a magnetic plunger within the solenoid coil eliminates the need for a separate ferromagnetic component, reducing size, weight, and energy consumption. Moreover, the longer stroke length provided by the MagPlunge design enables a wider range of motion for robotic segments, enhancing agility and versatility.

The successful integration of MagPlunge actuators into miniature segment robots opens up new possibilities for robotic locomotion and manipulation in diverse environments. The compact and efficient nature of the actuators makes them ideal for applications in confined spaces, such as search and rescue operations, medical procedures, and industrial inspection tasks. Furthermore, the modular design of segment robots allows for scalability and adaptability, enabling the construction of versatile robotic systems tailored to specific tasks and environments.

CONCLUSION

In conclusion, the development of the MagPlunge solenoid actuator represents a significant advancement in actuation technology for miniature segment robots. Through a systematic design and

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characterization process, we have demonstrated the effectiveness of MagPlunge in achieving compactness, energy efficiency, and high performance. The integration of MagPlunge actuators into miniature segment robots enables agile locomotion and precise manipulation in confined spaces, opening up new opportunities for applications in various domains. Moving forward, further research and development efforts will focus on optimizing the design and exploring additional applications of MagPlunge technology in the field of robotics.

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