

Experimental Validation of a Motor–SMA Hybrid Actuation for Lightweight Wearable Robot

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Abstract— Conventional motor-driven wearable robots often suffer from increased weight and limited torque output. To address this issue, this study proposes a motor–SMA hybrid actuation approach that combines the advantages of electric motors and shape memory alloy (SMA) actuators.

A dedicated testbed was developed to evaluate the proposed method under varying load conditions. Experimental results show that the SMA actuator provides additional assistive torque of approximately 3 N·m compared to motor-only operation, without significant increase in system weight.

These results demonstrate the feasibility of hybrid actuation for achieving lightweight and high-performance wearable robotic systems.

I. INTRODUCTION

Wearable robots have been widely studied to assist human motion in daily activities, particularly for elderly users and individuals with mobility impairments. Most existing wearable robotic systems rely on electric motors as primary actuators[1]. While motor-driven systems can provide stable and controllable actuation, they often require high power and large capacity to generate sufficient assistive torque. This leads to increased weight and bulkiness, which significantly reduces wearability and limits long-term use in daily environments.

On the other hand, lightweight actuation approaches, including artificial muscle-based systems, have been explored to improve portability and user comfort. However, these approaches typically suffer from limited force output, slow response characteristics, or restricted operational bandwidth, making them insufficient for tasks that require high torque such as stair ascent, sit-to-stand motion, or load-bearing assistance.

To address these limitations, a hybrid actuation approach that combines the advantages of electric motors and shape memory alloy (SMA)-based actuators has been proposed. In such systems, the motor provides fast and precise actuation for low-load and repetitive motions, while the SMA actuator supplements additional force when high output is required. This complementary operation enables efficient utilization of



Fig. 1. Concept design of a wearable robot for elderly users and individuals with lower-limb paralysis.

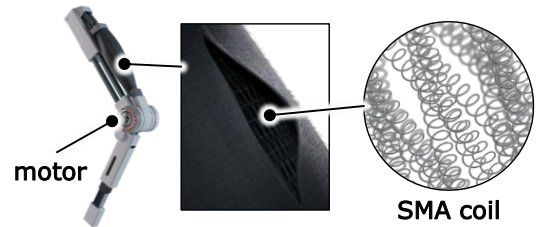


Fig. 2. Concept of the motor–SMA hybrid actuation mechanism.

actuator capacity and improves the overall torque-to-weight performance of the system.

In this work, we investigate the feasibility and effectiveness of a motor–SMA hybrid actuation module for wearable robotic applications. A dedicated experimental testbed was developed to evaluate the performance of the proposed hybrid actuation strategy, focusing on force generation and assistive capability. The results demonstrate the potential of hybrid actuation to overcome the fundamental limitations of conventional motor-driven wearable systems.

II. MOTOR-SMA HYBRID ACTUATION MODULE

To evaluate the proposed hybrid actuation approach, a dedicated testbed was developed by integrating a motor-driven rotary actuator and an SMA-based linear actuator in a parallel configuration. The SMA actuator was connected to the rotational axis through a wire-roller mechanism, enabling its contraction force to be effectively converted into assistive torque. This configuration allows both

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independent and simultaneous operation of the motor and SMA actuator, facilitating direct performance comparison. In

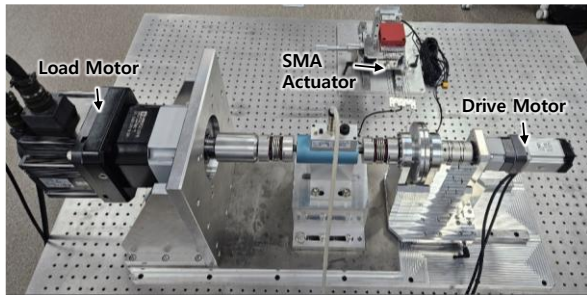
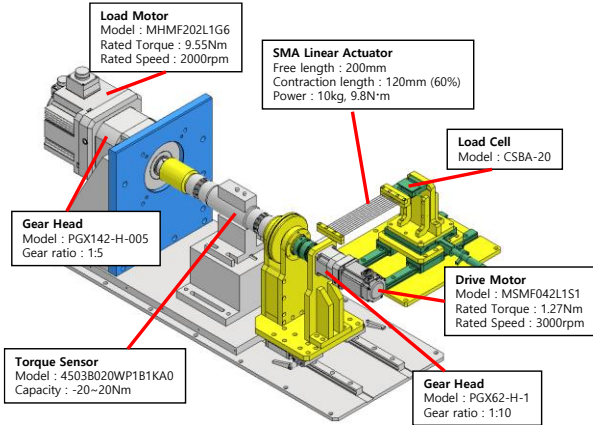


Fig. 3. Design and experimental setup of the hybrid actuation testbed, including motor, SMA actuator, and load system.

addition, a load motor was incorporated to enable testing under various loading conditions, providing a flexible experimental environment for performance evaluation.

Experiments were conducted by fixing the rotational motion to 120° and measuring the motor shaft torque under varying load conditions ranging from 0 to 7 N·m. For each load condition, two actuation modes were evaluated: motor-only actuation and hybrid actuation with simultaneous SMA activation. This experimental setup enables a clear comparison of the contribution of the SMA actuator under identical loading conditions.

The results show that the hybrid configuration provides an additional assistive torque of approximately 3 N·m compared to motor-only operation across multiple load conditions. This value is consistent with the theoretical torque estimated from the SMA actuator based on its contraction force, indicating that the SMA module effectively contributes to torque generation in the hybrid system.

These results demonstrate that the proposed hybrid actuation approach can enhance torque output without increasing motor capacity, while enabling efficient load sharing between actuators. This validates the feasibility of the hybrid actuation strategy as a lightweight and high-performance solution for wearable robotic systems.

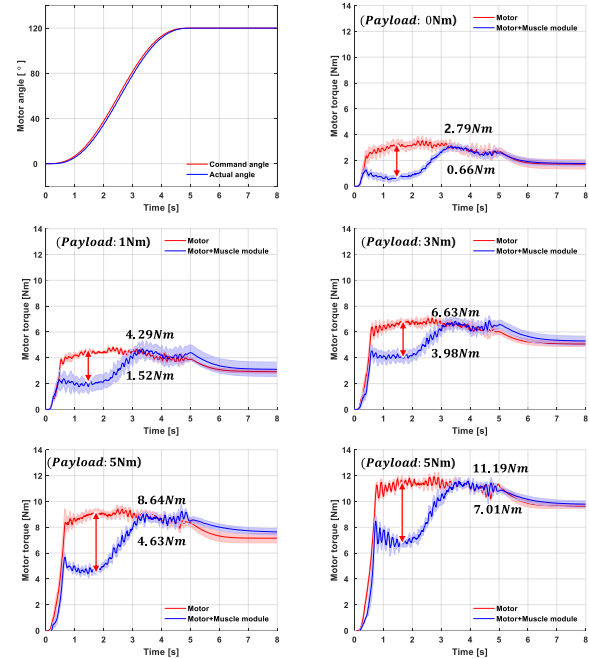


Fig. 4. Comparison of motor-only and hybrid actuation under varying load conditions.

III. CONCLUSION

In this work, a hybrid actuation approach combining a motor and an SMA actuator was investigated for wearable robotic applications, aiming to achieve both lightweight design and high output performance. To validate the feasibility of the proposed concept, a hybrid actuation testbed was designed and developed, enabling independent operation of each actuator as well as simultaneous hybrid actuation under controllable load conditions.

Through experiments under varying load conditions, it was confirmed that the SMA actuator provides an assistive torque to the motor. This result demonstrates that the hybrid actuation module can effectively enhance torque output without requiring a larger motor or significant additional system complexity.

These findings indicate that the proposed hybrid actuation approach has strong potential as an effective actuation solution for wearable robots, where both high performance and lightweight design are critical. Future work will focus on developing optimal control strategies to efficiently coordinate the motor and SMA actuator for improved performance and energy efficiency.

REFERENCES

[1] Huo, W., Mohammed, S., Moreno, J. C., & Amirat, Y. (2014). Lower limb wearable robots for assistance and rehabilitation: A state of the art. *IEEE systems Journal*, 10(3), 1068-1081.