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A Compact Lockable Module for A Modular Wearable Robot System

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***Abstract*— We introduce a "lockable module" for controlling rotary degrees of freedom (DoFs) in a modular wearable robot system. We begin by outlining the biomechanics requirements, then present the brake design within the module. Subsequently, we demonstrate the integration of the module in a wearable system. Finally, we conclude our contributions and propose future research directions.**

I. Introduction

Based on prior biomechanics research on the effects of providing external support to the human trunk, we hypothesize that such force/torque could potentially improve obstacle avoidance performance for the elderly. Our previous work on an origami-inspired, serial-link, trunk support device [1] featured a *global* belt-driven locking strategy. However, due to system-level complexity and limited force amplitude, we now improve the robot by 1) implementing a *modular* design principle for rapid system reconfiguration, and 2) introducing a *local* brake to reduce system-level design complexity.

II. Material and Method

A. Lockable module

The lockable module, shown in Fig.1(b), consists of three main components: the base, rotary plate, and brake system. To achieve high force density, we employ a self-locking inspired brake design that controls linear DoFs in one direction on each side. A spring-loaded clamper compresses the belt against a brake pad coated with sandpaper, generating a large locking force (∼250N) in the reserve direction of pulling, as illustrated in Fig. 1(a) and (b). In a full module, two single brakes in a rotational symmetry pattern fully constrain the DoF.

A spring-loaded linear tensioner is installed under the plate to maintain belt tension and reduce slack. The total belt length routed in the module varies as a function of system configuration, improving the locking force performance (10Nm for the module according to tensile testing). To unlock the module, a micro-gearmotor with extension arms is mounted in the middle of the base, spinning two clampers to release the belt from its locked state. We balance the springs and the motor so that the clamper can stay unlocked using the motor back-driving torque, which also reduce the energy consumption.

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B. Modular Wearable Robot

Building on the lockable module, we introduce our concept of a "modular wearable robot". The module is equipped with a modular connector based on a slot structure, which allows sliding with a male connector at the bottom and a female connector on top.

The modular wearable robot also includes three mounting interfaces with connectors for the hip, chest bone, and shoulder. The lockable module connects to these interfaces according to the desired biomechanics model, allowing for adaptation to users of different heights. To fill the gap between the lockable module and the wearing interface, we install extension spacers on demand for additional customization, as demonstrated in Fig.1(c).

III. Conclusion and Future Work

We have introduced a modular wearable robot system featuring a compact brake module as a derivative of our previous prototype. We have demonstrated the effectiveness of rapid customization and alignment with biomechanics models, as well as the ability to change the number and location of external support force based on experimental needs. Future work will involve human experiments and data collection to investigate our biomechanics hypothesis further.

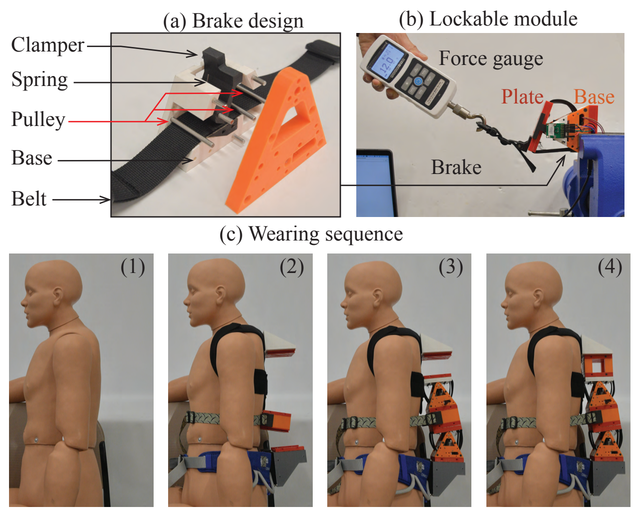

Fig. 1: Lockable module, brake design and the wearing sequence

References

[1] D. Li, E. Q. Yumbla, A. Olivas, T. Sugar, H. B. Amor, H. Lee, W. Zhang, and D. M. Aukes, "Origami-inspired wearable robot for trunk support," *IEEE/ASME Transactions on Mechatronics*, 2022.