Pneumatic Soft Haptic Glove for Immersive Mixed-Reality Rehabilitation

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***Abstract*— Haptic feedback gloves have numerous potential uses in rehabilitation, assistance, teleoperation, and entertainment. For rehabilitation in particular, these glove provide patients with neurological or musculoskeletal injury the ability to interact with a range of virtual objects in a more naturalistic manner. To address the varying needs of patients with different degrees of hand strength, it is important to prioritize the weight and safety features of a glove. With this in mind, we have developed a haptic rehabilitation glove that is lightweight and soft and coupled it with a virtual environment guidance system for personalized training and real-time feedback.**

I. Introduction

Most soft haptic feedback gloves rely on motors, cables, and mechanical linkages to provide reaction forces to the user [1], which can add extra weight and increase the potential risk of injury to users. Additionally, these designs can be fragile and difficult to repair if components malfunction. To address these issues, we propose a pneumatically actuated soft haptic feedback glove for interacting with 3D objects in a mixed-reality environments. The glove is lightweight and easily reproducible with a soft pneumatic mechanism and modular design. Mixed reality techniques generate adjustable force feedback for a realistic sensation of touching virtual objects.

II. Hardware and Software

A. Hardware and Mechatronics

The soft rehabilitation glove proposed here uses pneumatic bellows made of silicon rubber to provide gentle haptic feedback for therapeutic purposes. The bellows are powered by a pneumatic pump, solenoid, and electromagnetic trigger, which enable separate control of airflow and electrical circuits. The system is controlled by an Arduino UNO microcontroller and relays to ensure safe and stable operation. A pressure sensor is also incorporated to monitor the air pressure within each bellow (see Fig. 1).

The bellows are designed to remain inflated until the user's hand is removed from the virtual object or until the pressure reaches a pre-set threshold. This allows for a more nuanced and responsive experience, as the air pressure can be adjusted in real-time to reflect changes in the virtual environment. When the user's finger is completely removed from the object, the air in the bellow is discharged through a release valve, ensuring that the haptic feedback is precise and safe.

B. Handtracking and Virtual Environment

Our proposed hand-tracking approach is based on the Google MediaPipe Hand Tracking tool, which effectively detects 21 key landmarks on a hand from a single frame. To improve the system's robustness, we integrated depth information from a RealSense D405 camera. Once the landmarks are detected, their 3D coordinates are sent to the virtual environment via a UDP socket (see Fig. 2). The resulting system provides a high degree of accuracy and reliability for a range of therapeutic applications.

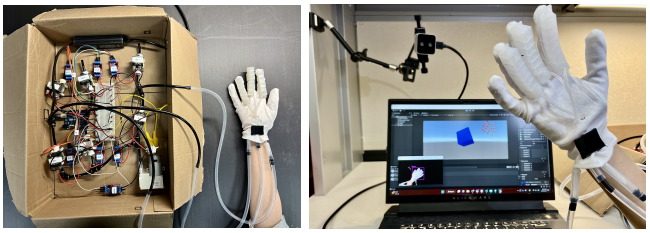

Fig. 1: Left: Integrated mechatronics and haptic gloves. Right: Demo of the glove in a virtual environment.

III. Conclusion and Future Work

In conclusion, we have developed a lightweight, flexible glove with gentle touch capabilities. While the prototype shows promise, we will continue to enhance its features by adding bending and force sensors to accurately predict user actions, allowing the glove to perform more precisely. Furthermore, we will improve robot design. These improvements will increase the glove's versatility and effectiveness in therapeutic and assistive applications, ultimately supporting personalized rehabilitation training for patients.

References

[1] Diego Fernández-Vázquez, Roberto Cano-de-la-Cuerda, and Víctor Navarro-López. "Haptic Glove Systems in Combination with Semi-Immersive Virtual Reality for Upper Extremity Motor Rehabilitation after Stroke: A Systematic Review and Meta-Analysis". In: *International Journal of Environmental Research and Public Health* 19.16 (2022).

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