



A Preliminary Study on a Unified Haptic Glove for Multi-Domain Applications

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Abstract: Virtual Reality (VR) systems require effective interaction techniques to improve realism and user immersion. Conventional VR interaction methods mainly rely on visual and audio responses, offering limited physical interaction within virtual environments. This paper presents a unified haptic glove designed for multi-domain virtual applications. The proposed system integrates flex sensors, MPU6050 motion sensors, vibration motors, and an ESP32 microcontroller to detect hand movement and provide real-time tactile feedback. The glove architecture supports wireless communication and can be adapted for applications such as pilot training, rehabilitation, gaming, and emergency response simulation without modifying the hardware framework. The proposed approach focuses on lightweight design, portability, reduced hardware complexity, and cost-effective implementation for immersive human-computer interaction.

Keywords: Haptic Glove, Virtual Reality, ESP32, Flex Sensor, Tactile Feedback, Motion Tracking, Human-Computer Interaction.

I. INTRODUCTION

Virtual Reality (VR) and Human-Computer Interaction (HCI) technologies are widely used in modern training, simulation, healthcare, and entertainment systems. Most conventional VR interaction methods mainly depend on visual and audio communication, which limits physical interaction inside virtual environments. The absence of touch-based feedback reduces realism and user immersion during simulation activities. Haptic technology improves interaction by introducing tactile sensation through wearable devices capable of detecting human movement and generating physical feedback. A haptic glove enables users to interact naturally with virtual environments by combining gesture sensing and real-time tactile response mechanisms.

The proposed project, "A Unified Haptic Glove for Multi-Domain Applications," presents a wearable glove system designed for immersive virtual interaction across multiple application domains. The system integrates flex sensors, MPU6050 motion sensors, vibration motors, and an ESP32 microcontroller to detect finger movement, track hand orientation, and generate vibration-based tactile feedback. Unlike many existing systems that involve bulky hardware and domain-specific implementation, the proposed glove focuses on portability, low-cost integration, and adaptable system architecture. The glove can support applications such as pilot training, rehabilitation, gaming, and emergency response simulation using a common hardware platform while maintaining real-time interaction and improved user experience.

II. LITERATURE SURVEY

1) Jiawen Qi, Xiaonan Li, Yuhan Wu "HaptGlove — Untethered Pneumatic Glove for Multimode Haptic Feedback", June 2023.

This study describes a wireless pneumatic haptic glove developed for immersive interaction inside Virtual Reality environments. Pneumatic actuators, pressure regulation modules, and fiber-based sensing units are utilized to create touch sensation, resistance response, and object interaction effects during virtual activities. The wearable structure improves freedom of movement and interaction experience during VR usage. Despite these advantages, the design depends on bulky air-pressure components, increased energy usage, and complicated pneumatic control mechanisms, reducing portability and increasing hardware complexity. The proposed project adopts a simplified architecture using flex sensors, MPU6050 sensing, vibration motors, and ESP32 processing to achieve lightweight and energy-efficient tactile interaction for multi-domain applications.



2) J. Boutin, M. Nadeau, and A. Parent, “Smart Haptic Gloves for Virtual Reality Surgery Simulation”, January 2024. This work introduces a smart wearable glove intended for hand movement analysis and gesture-based interaction in virtual simulation environments. The system combines flex sensors, force sensing elements, and IMU modules to monitor finger activity and hand orientation. Sensor information is analyzed through machine learning techniques for gesture identification and virtual interaction control. The study improves movement tracking and interactive response during simulation activities. However, factors such as sensor instability, computational dependency, and moderate recognition consistency affect continuous operation and overall efficiency. The proposed project minimizes these challenges through ESP32-based signal processing and vibration-driven tactile feedback with reduced hardware dependency and simplified system integration.

3) Filipowska, P. S. Nowak, and Research Collaborators, “Machine Learning-Based Gesture Recognition Smart Glove”, September 2024. This research discusses a wearable glove developed for gesture monitoring and real-time hand tracking using learning-based recognition methods. Multiple sensing units including flex sensors, force sensors, and motion tracking modules are integrated to capture finger and hand activity during interaction. Sensor outputs are analyzed through deep learning algorithms for gesture classification and virtual control applications. Improved interaction response and movement monitoring are achieved through multi-sensor integration. Nevertheless, issues related to computational load, sensor variation, and processing complexity influence reliability during continuous operation. The proposed project addresses these concerns using a compact ESP32-controlled framework with vibration-based tactile response and simplified sensor processing for portable multi-domain interaction.

4) Guoqiang Xu, Haoyu Wang, Guangyao Zhao, Jingjing Fu, Kuanming Yao, and Shengxin Jia, “Self-Powered Electro-Tactile Textile Haptic Glove for Enhanced Human-Machine Interface”, January 2025. This study introduces a textile-oriented wearable glove capable of generating self-powered electro-tactile feedback for digital interaction environments. Triboelectric nanogenerator technology converts physical hand motion into electrical energy for touch sensation generation without external power dependency. Textile electrodes and energy management circuits are incorporated into the wearable structure to support tactile interaction during virtual activities. Although the system improves flexibility and wearable comfort, limitations related to high-voltage operation, unstable feedback generation, and restricted force sensation remain present. The proposed project replaces electro-tactile mechanisms with low-voltage vibration feedback and ESP32-controlled processing to improve operational safety, portability, and practical usability across multiple application domains.

5) Huazhi Dong, Chunpeng Wang, Mingyuan Jiang, Francesco Giorgio-Serchi, and Yunjie Yang, “Modular Soft Wearable Glove for Real-Time Gesture Recognition & Dynamic 3D Shape Reconstruction”, July 2025. This research presents a modular wearable glove developed for gesture monitoring and dynamic hand-shape reconstruction during interactive applications. Capacitive sensing elements and liquid metal electrode structures are utilized to capture finger movement and hand activity with improved precision. Learning-based processing models are employed for gesture interpretation and 3D hand reconstruction within virtual and robotic systems. Flexible structural design improves movement adaptability and tracking capability. However, the system involves costly hardware integration, advanced computational processing, and increased implementation complexity due to AI-driven operation. The proposed project simplifies the architecture through flex sensing, MPU6050 tracking, and ESP32-based control for efficient tactile interaction with lower computational demand and improved portability.

III. PROPOSED SYSTEM

The proposed system is a wearable haptic glove designed to provide gesture tracking and vibration-based tactile feedback during virtual interaction. The glove integrates flex sensors, MPU6050 motion sensors, vibration motors, and an ESP32 microcontroller within a compact architecture. Finger bending and hand orientation are continuously monitored through embedded sensors, while the ESP32 processes the collected data and supports wireless communication with the virtual environment. The system is designed as a unified platform capable of supporting multiple domains such as pilot training, rehabilitation, gaming, and emergency response simulation using the same hardware structure. The proposed architecture focuses on portability, low hardware complexity, and real-time interaction within virtual environments.

The glove is designed as a unified platform capable of supporting multiple application domains such as pilot training, rehabilitation, VR gaming, and emergency response simulation without changing the hardware structure. Whenever the user interacts with objects inside the virtual environment, vibration motors generate touch-based feedback to improve realism and user immersion. Unlike many existing haptic systems that depend on bulky hardware and complex feedback mechanisms, the proposed system focuses on portability, lightweight design, low power consumption, and cost-effective implementation while maintaining efficient real-time interaction. time interaction within virtual environments.



IV. SYSTEM COMPONENTS

1) **Flex Sensors**

Flex sensors are integrated on the fingers of the glove to detect bending movement and hand gestures. The sensor resistance changes according to finger motion, allowing the system to identify user interaction patterns within the virtual environment.

2) **MPU6050 Motion Sensor**

The MPU6050 sensor combines an accelerometer and gyroscope to measure hand orientation and movement. This sensor enables real-time tracking of hand position and rotational motion during virtual interaction.

3) **ESP32 Microcontroller**

The ESP32 microcontroller acts as the central processing unit of the glove. It receives sensor data, processes gesture information, and manages wireless Bluetooth communication with the VR environment.

4) **Vibration Motors**

Vibration motors are used to generate tactile feedback whenever interaction occurs inside the virtual environment. The motors simulate touch sensation and improve immersion during virtual activities.

V. METHODOLOGY

- 1) **Hardware Design** – A wearable glove platform is developed where sensors and actuators are integrated to detect hand and finger movements.
- 2) **Sensor Integration** – Flex sensors are attached to the fingers to detect bending while motion sensors (IMU) track the orientation and movement of the hand.
- 3) **Microcontroller Data Processing** – The collected sensor signals are processed using a microcontroller such as ESP32, converting analog signals into digital data.
- 4) **Haptic Feedback Generation** – Vibration motors are activated to provide tactile feedback when the user interacts with virtual objects.
- 5) **Application Integration** – Simulation software is used to create virtual environments such as pilot training, gaming, emergency response, and rehabilitation modules, where hand movements are mapped to actions.

VI. CONCLUSION

Development of wearable haptic technology creates new possibilities for natural interaction inside Virtual Reality environments. The proposed glove architecture combines hand gesture sensing, motion tracking, and vibration-based tactile response using compact embedded components. Use of flex sensors, MPU6050 sensing modules, ESP32 processing, and wireless communication supports interactive virtual applications through a lightweight and adaptable platform. Multi-domain compatibility allows utilization of the same wearable framework in rehabilitation systems, training simulations, gaming environments, and emergency response applications. Reduced hardware dependency, portable structure, and simplified integration improve the practicality of the system for future immersive Human-Computer Interaction technologies.

REFERENCES

- [1]. Christos Papakonstantinou, Konstantinos Giannakos, George Kokkonis, and Maria S. Papadopoulou, "The Effect of Tactile Feedback on the Manipulation of a Remote Robotic Arm via a Haptic Glove," *Electronics*, vol. 14, no. 24, Dec. 2025.
- [2]. Jiawen Qi, Xiaonan Li, and Yuhan Wu, "HaptGlove: Untethered Pneumatic Glove for Multimode Haptic Feedback in VR," 2023 International Conference on Haptic and Virtual Interaction Technologies, Nov. 2023.
- [3]. A. Filipowska and P. S. Nowak, "Machine Learning-Based Gesture Recognition Smart Glove," 2024 International Conference on Intelligent Wearable Technologies, Aug. 2024.
- [4]. J. Boutin, M. Nadeau, and A. Parent, "Smart Haptic Gloves for Virtual Reality Surgery Simulations," 2024 International Conference on Virtual Reality and Medical Simulation Systems, Oct. 2024.
- [5]. Guoqiang Xu, Haoyu Wang, Guangyao Zhao, Jingjing Fu, Kuanming Yao, and Shengxin Jia, "Self-Powered Electrotactile Textile Haptic Glove for Enhanced Human-Machine Interface," *Science Advances*, vol. 11, no. 12, Mar. 2025.
- [6]. Huazhi Dong, Chunpeng Wang, Mingyuan Jiang, Francesco Giorgio-Serchi, and Yunjie Yang, "Modular Soft Wearable Glove for Real-Time Gesture Recognition and Dynamic 3D Shape Reconstruction," 2025 International Conference on Wearable Computing and Intelligent Systems, Jul. 2025.