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# COST-EFFECTIVE DATA GLOVE AND MECHANICAL HAND FOR THE ANALYSIS AND SIMULATION OF FINGER MOVEMENTS

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**Abstract:** The present work introduces a modern cost-effective data glove prototype designed for versatility, particularly in the fields of virtual reality, remote control or medical rehabilitation. Using an array of flex sensors, the glove measures finger flexion and extension angles in real-time. Data is processed through a microcontroller, translating sensor readings into accurate angular measurements, while Bluetooth communication ensures low-latency and stable transmission. A Butterworth filter is applied to minimize noise. The presented device shows potential for further improvements through automatic calibration and user-specific customization.
**Key words:** data glove, prototype

## 1. INTRODUCTION

Hands are very delicate and complex structures with over 30 muscles and tendons working together to facilitate the flexion or extension of the hand and fingers [1]. Since their inception in the 1980s, data gloves have revolutionized human-computer interaction, with early models like the Sayre Glove and the Power Glove paving the way for advancements in virtual reality and motion capture. These initial devices allowed users to interact with virtual environments through hand movements, laying the foundation for more sophisticated applications [2].

A data glove contains strategically placed sensors that communicate finger joint movement to an end device. The most popular sensors used in data gloves include flex sensors (resistant transducers), due to their low cost, optical sensor that use infrared light to detect the position based on intensity of light [3], Hall effect sensors, due to their small size and ability to smoothly prevent frictional resistance [4] and capacitive bend sensors [5]. Additionally, a gyroscope can be added to also measure the orientation of the hand and to improve the accuracy of finger dynamic.

Good control devices are described by low latency and high accuracy of the system response. Both characteristics are evaluated under the constraints of the applications, be they interactions in virtual environments (VR), control of remote devices or used in medical context, such as rehabilitation, assistance with disabilities or investigation [6][8][9]. A good example of using a data glove in the field of medicine is early detection of rheumatoid arthritis and other neurological conditions [7][10]. Rheumatoid arthritis is a chronic systematic inflammatory disease with peripheral synovitis as its main manifestation. Although there is no cure, it is commonly treated using physical therapy exercises that reduce disease progression. Another example of using it is to detect the early onset of Parkinson's Disease measuring the speed of finger movement, range and the amplitude of any abnormal movement. The data glove can be used for these exercises and monitoring progress, replacing the current method of measuring using universal goniometer [11].

The current paper presents a low-cost prototype of a glove that could measure the angle of flexion and extension of the fingers, connected to a custom mechanical hand capable of replicating the movements measured by the glove. The mechanical part could also be replaced with a mechanical exoskeleton, if necessary.

The remainder of the paper is organized as follows: Section 2 presents the proposed system, emphasizing the particularities in the implementation and the communication between the glove and the mechanical device. Section 3 contains the experiments, while the concluding remarks and perspectives are explored in Section 4.

## 2. SYSTEM IMPLEMENTATION

*Figure 1* shows the block diagram of the system communication between the glove and the mechanical hand. The glove gathers data from the flex sensors and transforms it into a digital signal that can be transmitted via Bluetooth to the mechanical replica.

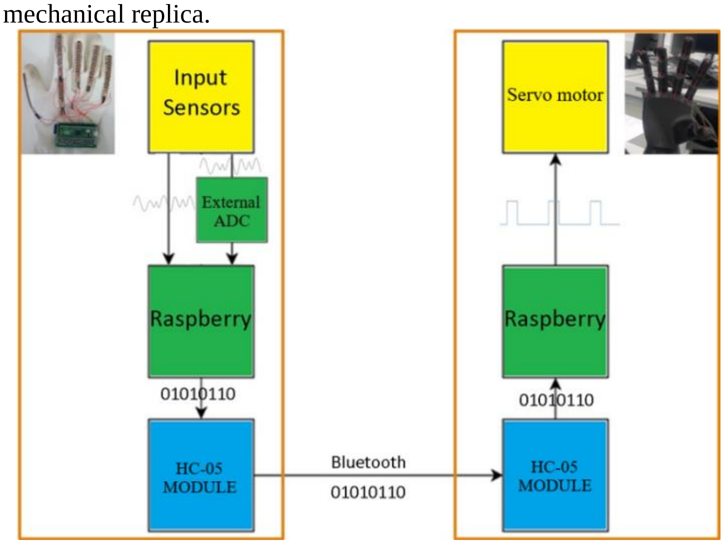


**Fig. 1.** Block diagram of the system

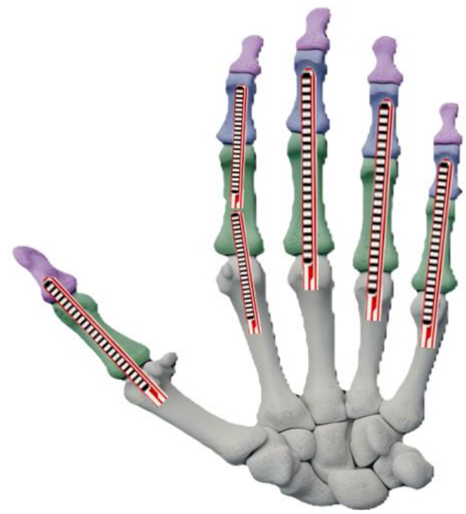

**Fig. 2.** Positioning of flexible sensors

### 2.1. Input sensors

The proposed input sensor block is formed from resistant transducers for the purpose of identifying flexions and extensions of each of the fingers. This type of the sensor measures the deviation from the initial position as a resistive indication, which can be then transformed into degree measure of the finger. The flexible sensor is connected to a voltage divider circuit, the output being the voltage across the resistor [7,12].

Most data gloves use a single flexible resistor for each finger, making it possible to measure the angle resulting from the flexion of the entire finger, rather than the individual angles formed between the three phalanges. For this project, 6 flex sensors were used: 2 for the index and 1 for each of the other fingers, as shown in Figure 2. Regarding the index measurements, one sensor was used for measuring the angle between proximal phalanx (green) and palm (gray) and one for the angle between the middle phalanx (blue) and the proximal phalanx. For a finger equipped with two flexible sensors, this approach increases the range of movements that the glove can capture, shown in Figure 3, as well as enhancing the accuracy of reproduction on the 3D model.

a) b)

**Fig. 3.** a) Possible movements of the index finger (two sensors)
b) Possible movement of the pinky finger (a single sensor)

### 2.2. ADCs and microcontroller processing

To convert the data, 6 ADCs were needed, 3 of them from the microcontroller and the other 3 attached as external modules. The microcontroller in use is RP2350, on the development board Raspberry Pi Pico. It has reduced dimensions, the operating frequency up to 150MHz and 26 GPIO pins with 24 controllable PWM channels.

After acquiring data from fingers in the form of voltage levels, in order to remove undesired noise and avoid unrealistic sequences of measured angles, a Butterworth filter was used with a cutoff frequency of 20Hz. The transfer function of the filter is shown in *eq. 1*.

$$H(z) = \frac{10^{-7}(1.39+8.097z-1+2.024\cdot 10z-2+2.699\cdot 10z-3+2.024\cdot 10z-4+8.097z-5+1.349z-6)}{1-5.422z-1+12.28z-2-14.85z-3+10.12z-4-3.688z-5+0.5606z-6} \tag{1}$$

### 2.3. The wireless transmission

For the wireless transmission, the two HC-05 modules were used in the Master-Slave configuration, ensuring a good and stable connection to transfer data between the two microcontrollers. Data packets are sent through UART to the Master HC-05 module in the glove, then via Bluetooth to the Slave HC-05 module in the mechanical model.

The data package consists of 48 bits with a resolution of 1 degree/finger. For a high-speed transmission, the 8-bit values were converted to 5-bit values and a resolution of 5 degrees resulting in 30-bit data packets. Once the packet transmission was completed and the data reached the second HC-05 module, it was forwarded via UART to the Slave microcontroller.

### 2.4. Mechanical 3D model

For simulating the hand muscles, MG995 servomotors were used, each capable of 10kgf·cm (6V) torque and a rotation angle of 180degrees. It works as a muscle that pulls on the tendons (simulated using wire with metal insertion) to actuate the flexion and extension of the fingers. The control for servomotor is realized with a variable duty-cycle PWM. The 3D model is just an example to demonstrate visible how data glove works, but it can be replaced by a rehabilitation skeleton or a remote robotic arm to be controlled from a safe distance.

## 3. RESULTS

The experiments tested the accuracy and latency of the presented system. To evaluate the performance of the glove, an accuracy test was performed. For each finger, multiple measurements of the deviation were taken, and the average was calculated. The response time between the moment when one or more fingers changed their position by performing a flexion or extension and the moment when the 3D model reproduced that flexion or extension was measured. Similarly, multiple measurements were taken for each finger and the average was calculated. The measurement results for both can be observed in *Table 1*.

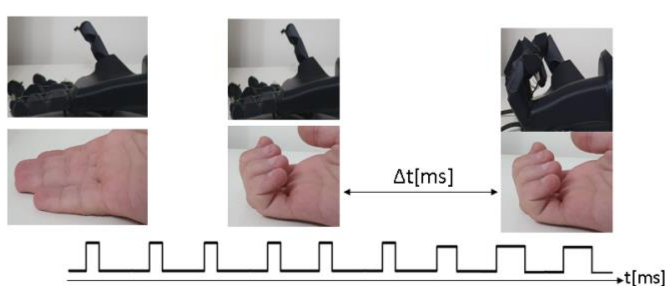


**Fig. 4.** Latency measurement

Table 1. Average deviation and latency

| Measured finger | Average deviation [°] | Average latency [ms] |
|---|---|---|
| Thumb | 25.37 | 154.17 |
| Index | 25.92 | 123.12 |
| Middle | 26.73 | 143.82 |
| Ring | 22.35 | 165.16 |
| Pinky | 24.77 | 127.94 |
| *Overall Mean* | *25* | *142.84* |

## 4. CONCLUSIONS

This project demonstrates the potential of using a data glove for capturing and reproducing finger movements in various applications, such as virtual reality, medical rehabilitation, and assistive technologies. By designing a system with strategically placed sensors, efficient microcontrollers and a robust communication interface, the glove can translate finger motions into precise control for a robotic hand. The integration of Bluetooth communication and real-time filtering techniques ensures that the glove delivers low latency and accurate gesture recognition, essential for an immersive and responsive user experience.

With the results indicate that the data glove achieves reasonable accuracy and latency, and while the project utilized low-cost components, further improvements could be made to reduce deviation using more expensive components and particularly by customizing the glove fit to the user's hand. Additionally, implementing an automatic calibration upon startup of the glove could further enhance performance.

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