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Original Article

Development of Physical Therapy for Hand Neuro-Rehabilitation by Mechatronics

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ABSTRACT

Background: One of the basic matters of communication in our daily life is interaction and communication with others. So, Communication is very important in the life of all human beings alike. The problem begins with the hands-on rehabilitation to restore function, improve movement, and alleviate pain and spasms in individuals with hand impairments, as they face many problems in expressing their feelings and communication to others**. Objective**: The article aims to developed a new designing for Hand rehabilitation to restore function, improve movement, and alleviate pain and spasms in individuals with hand impairments. **Materials and Methods:** The traditional rehabilitation methods often require specialized equipment and clinic visits. The article has proposed a novel design, with low-cost, and portable wearable rehabilitation glove designed to enhance hand functions. The glove is custom-made for each individual by measuring finger joint angles, with personalized rings printed using 3D printing technology. Servo motors are connected to Kevlar yarn to assist in finger movement, enabling users to perform repetitive rehabilitation exercises. **Conclusion:** Through the implementation of this work, it is possible to know the extent of the importance of the various sensors and control systems and their relationship to facilitating our lives and solving some complex and different problems. The glove demonstrated the ability to facilitate the flexion and extension movements of the fingers, supporting hand training. Based on the findings, it is clear that while the glove shows promise in its intended function, further refinement of the sensor calibration and the glove's design is necessary to minimize interference and ensure more reliable data collection.

Keywords: Physical Therapy, Hand Neuro-Rehabilitation, Mechatronics, Biomedical Robotics.

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INTRODUCTION

Over the past decade, we have witnessed the rise of numerous interdisciplinary and multidisciplinary fields as the boundaries between traditional disciplines have become increasingly blurred [1]. The integration of previously separate fields has led to the development of innovative technologies that are now deeply embedded in our daily lives. One notable example is mechatronics, an interdisciplinary domain that merges mechanical, electronic, control, and computer engineering. Today, another multidisciplinary field is gaining significant momentum, opening new frontiers in science and technology: (Biomedical Mechatronics), which combines mechatronics, medicine, and biology [1,2]. In particular, the field of physical medicine and rehabilitation has already begun to incorporate mechatronic systems in clinical practice. Advances in robotics and clinical neuroscience have made it possible to use robotic systems as therapeutic tools for physical rehabilitation. Robotics, especially in motor retraining, is highly effective due to the repetitive nature of rehabilitation exercises. Moreover, the application of robotic technology is paving the way for new rehabilitation possibilities that were once out of reach [3,4]. For patients with conditions such as hemiplegia or stroke, robotic therapy can help restore lost functions or strengthen weakened muscles. Occupational therapy, which is commonly used for the hand, arm, shoulder, and torso after stroke or hemiplegia, is often combined with mechatronic devices or electrotherapy to improve physical function [4,5]. Occupational therapy also addresses the physical, cognitive, and emotional challenges that accompany stroke recovery, helping patients regain independence or adapt to new ways of performing daily activities [6]. The article aims to support stroke patients and others undergoing hand therapy by providing assistive rehabilitation for the upper limbs by Using inertial sensors and the system accurately tracks hand movements and adjusts the therapy in real time, allowing for personalized and responsive rehabilitation.

MATERIAL AND METHODS

1. *The system consists of Three key sections:*

1.1. Glove (Mirror Technology Mode):

The glove is worn on the patient's non-affected hand and is equipped with sensors to track its movements. The device then mimics these movements on the patient's injured hand using mirror technology, promoting motor learning and recovery [7].

1.2. Control Box with Circuitry and Mode Switcher:

The control box houses the system's electronics, including circuitry that manages the device's functions. It also features a mode switcher, allowing the user to toggle between different modes of operation (Mirror Mode and Auto Mode) [7,8,9].

1.3. Exoskeleton for Hand Movement:

The exoskeleton is a mechanical structure that physically assists in the movement of the patient's injured hand. It uses actuators or motors to perform controlled, therapeutic movements based on the mode selected, helping the patient regain strength and mobility.

2. *Operation Modes:*

2.1. Mirror Mode:

This mode synchronizes the movement of the non-affected hand with the injured hand, promoting neurological rehabilitation through the concept of mirror therapy, which has been shown to improve motor function [10].

2.2. Auto Mode:

The auto mode automatically guides the patient's hand through predefined therapeutic motions to aid in rehabilitation. This mode is designed to provide consistent, controlled therapy based on the patient's condition and recovery stage [10,11].

2.3. Experimental procedure:

The experimental setup will involve evaluating the device in both Mirror Mode and Auto Mode under various conditions, with a focus on the following aspects:

2.3.1. User Interaction:

Understanding how patients interact with the system, their comfort, and the ease of switching between modes. Feedback from users is essential for assessing the system's practicality in a clinical setting [12].

2.3.2. Sensor Data Collection:

Monitoring and analyzing the data provided by the inertial sensors to evaluate the range, accuracy, and effectiveness of the movement tracking. This data will also help fine-tune the system's feedback mechanisms for optimal rehabilitation outcomes [13].

2.3.3. System Performance and Response:

Assessing how the glove, control box, and exoskeleton work together to provide accurate and effective movement assistance. Testing different movement scenarios will ensure the system can adapt to the specific needs of each patient [13,14].

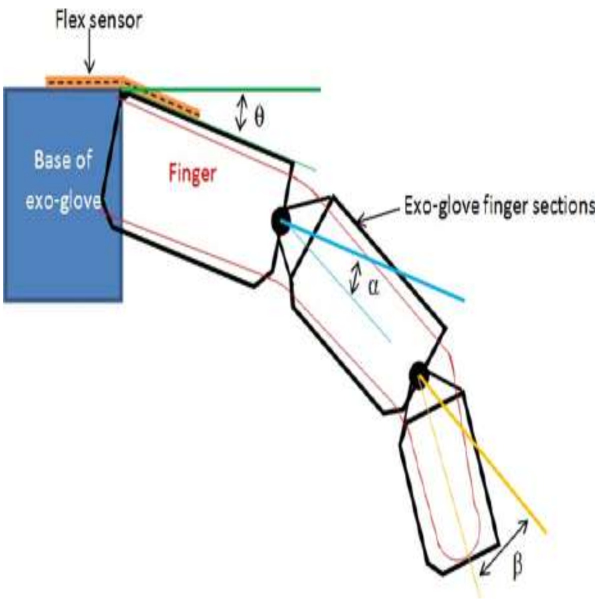


Figure 1. Glove sensor angles

2.4. Process Description:

These Three different parts consists of a variety of components. Therefore, this works on the bending strip principle which means whenever the strip is twisted then its resistance will be changed. so that, can be measured with the help of any controller. This sensor works similar to a variable resistance because when it twists then the resistance will be changed. The resistance change can depend on the linearity of the surface because the resistance will be dissimilar when it is level. When the sensor is twisted 45° then the resistance would be dissimilar. Similarly, when this sensor is twisted to 90° then the resistance would be dissimilar. These three are the flex sensor's bending conditions as shown in Figure 1. According to these three cases, the resistance will be normal in the first case, the resistance will be double as contrasted with the second case, and the resistance will be four times when compared with the third case. So that, resistance will be increased when the angle is increased [15,16]. The specifications and features of this sensor include the following:

- The operating voltage of this sensor ranges from 0V to 5V.
- It can function on low voltage.
- Power rating is 1 Watt for peak & 0.5 Watt for continuous.
- Operating temperature ranges from -20ºC to +80ºC.
- Flat resistance is 25K Ohms.
- The range of bend resistance will range from 45K Ohms to 125 K Ohms.

2.5. Mechatronic Structure:

The MG-90S Micro Servo is a 13.5g servo motor that is great for applications in low-cost robotics and automation as showed in Figure 2. The MG-90S can be powered directly from any 5.0V Arduino board, and can be controlled using the servo library included in most Arduino IDEs.

Figure 2. The MG-90S Micro Servo with components

The components of MG-90S Micro Servo and functions:

- Red wire: Powers the motor typically +5V is used.
- Brown wire: Ground wire connected to the ground of system.
- Orange wire: PWM signal is given in through this wire to drive the motor.

- Operating Voltage: 4.8V to 6.1V (Typically 5V).
- Stall Torque: 1.8 kg/cm (4.8V).
- Max Stall Torque: 2.2 kg/cm (6.1V).
- Operating speed is 0.1s/60° (4.8V).
- Gear Type: Iron Metal.
- Rotation: 0°-180° Degree.
- Weight of motor: 13.5gm.
- Package includes gear horns and screws.

A servo consists of a Motor (DC or AC), a potentiometer, a gear assembly, and a controlling circuit. First of all, we use gear assembly to reduce RPM and to increase the torque of the motor. Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. Now, an electrical signal is given to another input terminal of the error detector amplifier. Now the difference between these two signals, one comes from the potentiometer and another comes from other sources, will be processed in a feedback mechanism, and the output will be provided in terms of an error signal [17,18,19].
This error signal acts as the input for the motor, and the motor starts rotating. Now the motor shaft is connected with the potentiometer, and as the motor rotates so the potentiometer generates a signal [19]. So as the potentiometer's angular position changes, its output feedback signal changes. After some time, the position of the potentiometer reaches a position where the output of the potentiometer is the same as the external signal provided. Under these conditions, there will be no output signal from the amplifier to the motor input as there is no difference between the externally applied signal and the signal generated at the potentiometer, and in this situation, the motor stops rotating [20,21,23].

2.6. Arduino Code System:

Arduino Code to Control 5 Servo Motors Using 5 Flex Sensors, each flex sensor will provide an analog value that is used to adjust the position of the corresponding servo motor [23,24]. Here's a structure of Arduino code to accomplish this study.

2.6.1. Structure of the Code system:

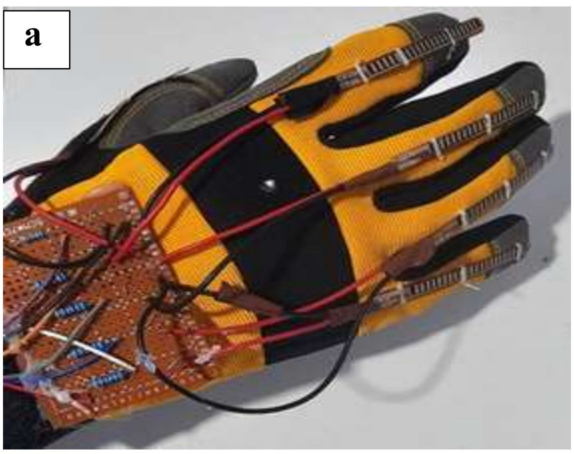
- Servo Library: The code uses the Servo library to control the servos.
- Flex Sensors: Five flex sensors are connected to the analog pins A_0 to A_4.
- Servo Motors: Five servo motors are controlled via pins 9 to 13.
- Mapping Flex Values: The analog Read function reads the flex sensor's value (ranging from 0 to 1023). This value is then mapped to the servo motor's angle range (0° to 180° ° degrees) using the map function.
- Servo Control: The servo. The write function sets the servo position based on the mapped angle value.
- Serial Output: The code prints the flex sensor values and corresponding servo angles to the serial monitor for debugging.
- Delay: A small delay of 100ms is added to allow the servos to stabilize between movements.

2.6.2. Hardware Connections:

- Flex Sensors: Connect one end of each flex sensor to the analog pins A0 to A4 and the other end to ground, with a pull-down resistor (10k Ohms) connected between the analog pin and ground.
- Servo Motors: Connect each servo's control wire (usually yellow or white) to one of the digital pins (9, 10, 11, 12, and 13) on the Arduino. The power (red) and ground (black or brown) wires should be connected to a suitable power source.

RESULTS:

The first posture tested was the glove placed in the initial relaxed position, resulting in the fingers being nearly flat across the joints. Generally, a person does not hold their hand, when relaxed, perfectly straight, which would mean their finger joints are already angled. This posture was tested first to set reference values the additional postures could be measured.



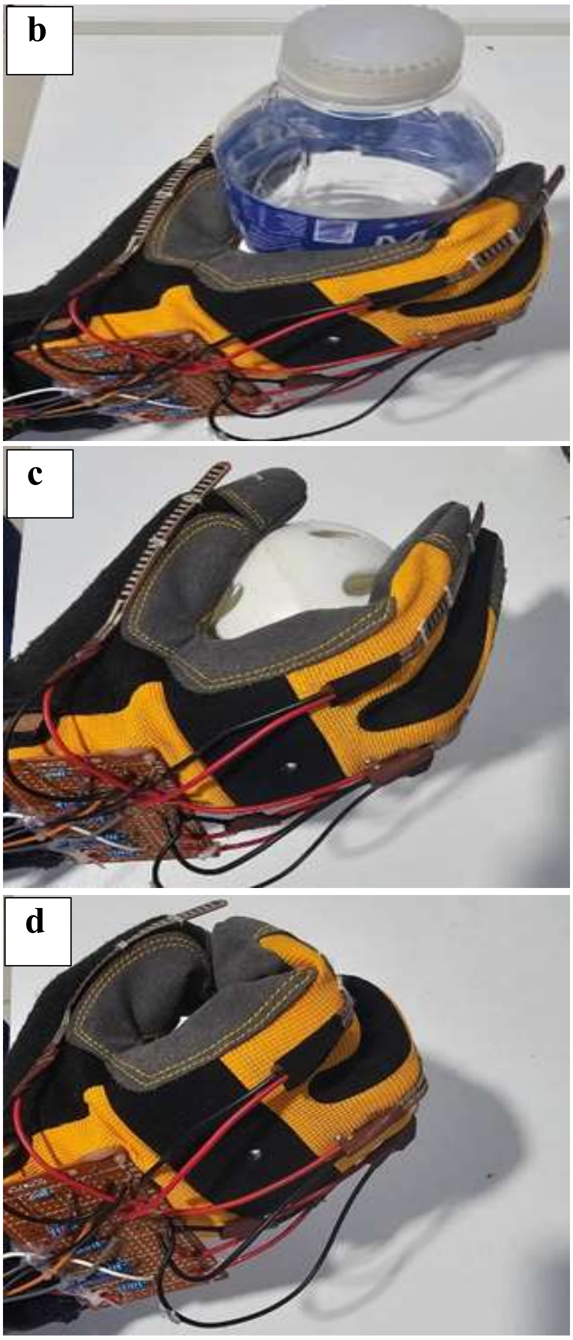


Figure 3. Glove postures: (a) Relaxed sensors, (b) Grasping water bottle, (c) Holding A ball, (d) Clenched fist

In this position 15 seconds was allowed to pass before retrieving data to ensure the sensors reached steady state equilibrium. Data was logged from the serial connection of the Arduino Mega using the Serial data monitor.
The information was gathered of the sensors from the Arduino serial port and transferred them to a Microsoft Excel spreadsheet. The data logged for the relaxed sensors was obtained in bits ranging from 0 to 1024 due to the 10-bit ADC on the Arduino Mega. Using the serial monitor data taken from each sensor reading during the calibration process, each column of sensor data was evaluated for accuracy at steady state as observed on Four cases in Figure 3.

Table 1. The glove posture angles

Posture	Middle Finger MP	Index Finger MP	Thumb MP	Ring Finger	Little Finger
Bottle	22	18	15	26	62
Fist	22	25	13	60	68
Ball	15	12	15	34	62

In Table 1. Once the reference postures were acquired, each of the five remaining postures underwent the same process for data acquisition. Using the resolution found during the sensor calibration, we were able to take the difference between the reference posture and the alternative posture to obtain a difference in bit values sensor by sensor. The difference in bit values was then multiplied by the resolution to find the change in flexion angles for each finger joint as showing in Figure 4.

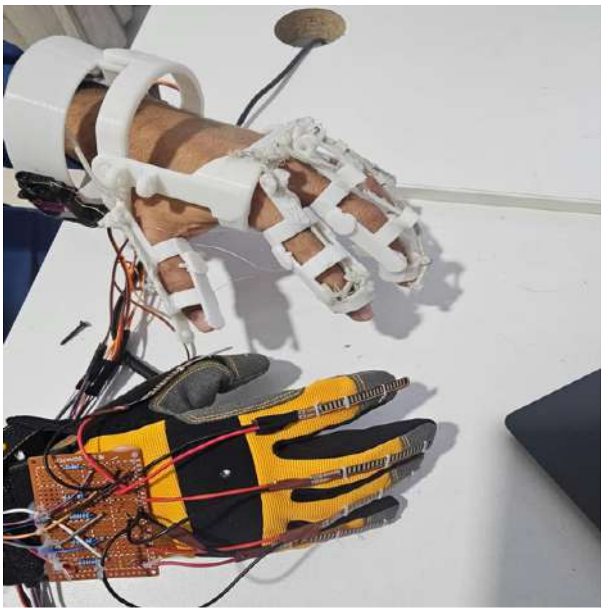


Figure 4. Relaxed posture with robotic hand

Rehabilitation gloves are commonly used to help patients recover such as stroke or spinal cord injury patients, so these gloves must have appropriate features for patients, the most important of which is their effectiveness for the purpose of rehabilitating the patient to benefit them. In addition to being lightweight so that it is not heavy on the affected limbs when used by the patient, the use of materials with low manufacturing density is avoided as much as possible. The cost of manufacturing it is not high, so the patient can use it or obtain it, and this means that it is cheap. It also turns out that there are multiple models of this robotic glove designed to be suitable for use by patients. Therefore, these gloves can be combined with certain systems such as virtual reality systems or some video games that will help the patient improve communication between the brain and the affected limb and train the brain to regain the ability to control the damaged tree branch. As for the patient's need for the stages of the rehabilitation process, this will be determined by the specialist doctor and depends on the patient's age group and the level of injury. While the robotic glove is powered several times during the rehabilitation process, it needs a portable power supply for hours suitable for operating for long periods of time at the same time. Time to design the system, such as a rechargeable battery, must or can be lightweight. They are placed in a box away from the robotic glove and are connected via wires to the glove.

DISCUSSION:

During the results we illustrated that, the experiments on the glove system for hand rehabilitation highlight several important aspects of the device's functionality with the challenges encountered during the testing process:

1. Effectiveness in rehabilitation:
   The glove demonstrated the ability to facilitate the flexion and extension movements of the fingers, supporting hand training. The device, which uses a fiber-reinforced soft electronic actuator, effectively assisted the hand in performing both typical gestures and grasping tasks. This suggests that the glove could help individuals regain hand movement and control.
2. Grip assistance:
   The glove was shown to help the wearer grip objects of various shapes securely. This indicates its potential for improving the strength and dexterity of the user's hand, which is important for restoring functionality in hand rehabilitation.
3. Sensor variability and interference:
   One of the major challenges identified in the study is the inconsistency in the sensor readings. Specifically, there was noticeable variation in the data from the flex and rotary position sensors, particularly with one flex sensor providing values significantly different from the others. This could have been due to the natural movements of the fingers and the glove's frame, which potentially interfered with the sensors, leading to fluctuations in readings. Even though, under controlled conditions, some factors such as blood flow, small finger movements, and sensor calibration inconsistencies contributed to data variability.
4. Challenges in data consistency:
   The result value also pointed out that even with careful repetitions of the experiments, slight fluctuations in sensor readings were observed. These fluctuations might have been caused by subtle finger movements, pressure from the glove, or even changes in posture during the testing phase. This highlights the difficulty in achieving perfect consistency when conducting sensor-based experiments with wearable devices.
5. Improved calibration and design:
   Based on the findings, it is clear that while the glove shows promise in its intended function, further refinement of the sensor calibration and the glove's design is necessary to minimize interference and ensure more reliable data collection. The minor variances observed in sensor readings could be mitigated with more precise calibration or adjustments to the glove's fit and pressure distribution.

CONCLUSIONS:

The conclusion observed from the experiments on the glove system for hand rehabilitation highlight several important aspects of the device's functionality. which as, Through the implementation of this work, it is possible to know the extent of the importance of the various sensors and control systems and their relationship to facilitating our lives and solving some complex and different problems. The glove demonstrated the ability to facilitate the flexion and extension movements of the fingers, supporting hand training.

This suggests that the glove could help individuals regain hand movement and control. There was noticeable variation in the data from the flex and rotary position sensors, particularly with one flex sensor providing values significantly different from the others. This could have been due to the natural movements of the fingers and the glove's frame, which potentially interfered with the sensors, leading to fluctuations in readings. Even though, under controlled conditions, some factors such as blood flow, small finger movements, and sensor calibration inconsistencies contributed to data variability. These fluctuations might have been caused by subtle finger movements, pressure from the glove, or even changes in posture during the testing phase. This highlights the difficulty in achieving perfect consistency when conducting sensor-based experiments with wearable devices. Based on the findings, it is clear that while the glove shows promise in its intended function, further refinement of the sensor calibration and the glove's design is necessary to minimize interference and ensure more reliable data collection. During our experimental work we recommended that, while the glove system offers promising rehabilitation benefits, the sensor variability and interference require more attention to optimize its performance. However, Future research could focus on enhancing the consistency of the data and improving the overall user experience during rehabilitation exercises.

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