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Remote Control of Hand Actuators via Glove Sensors for Medical Care Applications

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ABSTRACT

Early diagnosis of psychomotor diseases such as Parkinson's requires timely and effective medical care, which is often expensive and resource-intensive. This study proposes a remote-control system for assisting medical care related to hand movement. Human hand motion is captured using a comfortable, wearable sensory glove, while actuation is achieved via a fabric-based pneumatic system that drives finger bending. Finite element modeling is conducted to examine how the ratio of the stiff to soft sheet's Young's modulus affects actuator performance, showing that increased ratios lead to greater bending angles. A machine learning model is developed to relate finger angle to actuator pressure. For remote operation, data from the glove are transmitted—physically or virtually—to a separate system, where a medical professional controls the actuator using MATLAB-based algorithms. This teleoperation method for healthcare is relatively unexplored in current literature. In addition to medical applications such as rehabilitation or Parkinson's monitoring, the system offers the potential for reducing human risk in hazardous settings—such as operating heavy industrial machinery, handling high-risk lab chemicals, or performing maintenance in contaminated environments.

1 | Introduction

With the generalization of soft robotics [1], computers, and machines in recent years, the human–machine interface (HMI), similar to the bridge between machine and human, has shown tremendous importance and obtained great attention [2]. Conventional HMIs, like touchpads, keyboards, and joysticks, could provide the necessities in most applications but yet have their restrictions, particularly when a more intuitive and natural manipulating method is required for reality and virtual reality [3]. Novel kinds of HML which immediately express human intents were emerging as necessary alternatives by leveraging other human characteristics [2] for example; voice [4], the electromyogram [5], facial expression, and electromyography [6]. Between them, the HMI based on the movements of a finger has attracted importance and fondness from society because of its multiple degrees of freedom control and great accuracy [7, 8]. Particularly, movement, principally from finger phalanxes, could be identified by glove-base HMI and schemed into various machine commands, enabling immersive control in production, hobby, and healthcare systems [9]. For this purpose, different sensors are customized to gather such data, such as the capacitive sensors [10–15], piezo-resistive sensors [16–22], and internal measurement units [23–25]. These sensors obtain great correctness in identifying finger movements [26, 27], yet different challenges remain to be solved, like complex manufacturing, temperature dependence, and small yields [28]. In addition, for long-term and lightweight connectivity, the HML energy consumption shall also be minimized and optimized at the level of the system [28]. Quantitative identification of hand finger movements could support us in quantifying finger impairments and realizing pathophysiological features of finger neural control.

The primary performance of the soft rehabilitation glove was detected by its artificial hand actuator [29]. The design of an artificial hand actuator is very significant for the design of an appropriate sensor glove–artificial hand actuator system. A large number of soft artificial hands have been designed and manufactured ranging from the one finger to the five fingers gripper [30–33]. Kunal Singh [34] studied the bending behavior of soft artificial fingers manufactured by Elastosil M4601 and Smoothsil 950. They used Yoeh and Neo-Hookean models for importing the mechanical behavior of the actuator parent material into the simulation software. The effect of internal pneumatic pressure variation on the bending angle was studied numerically. Some researchers use fabric material to produce artificial hand actuators, and the movement of fingers is provided by rotation of the actuator finger [35]. The mechanism of the bending is due to the use of two different structures on both sides of the finger, which causes bending in the fingers of the actuator due to the different amounts of increase in the length of the two sides.

Zheng et al. [36] developed a piezo-resistive sensor glove for finger joint angle monitoring. They suggested a new approach to quantify and visualize the abnormality of the inter-joint harmony. The participation of the sensors and the ability to reflect inter-joint harmony make their glove more complete for hand movement detection. Tran et al. [37] presented a voice-controlled artificial hand actuator to assist people with hand mobility impairments in doing daily living activities. They used a new manufacturing approach for the wearable glove implementing biomimetic tendon routing and huge stability rubber silicone and developed a smartphone app-based voice user interface to supply a correctly intuitive and portable control system.

Here, the developed sensor glove was used to identify the finger's movements. Furthermore, a pneumatic artificial hand as an actuator was utilized to imitate the sensor glove movements to assist patients in their daily lives. A glove equipped with textile-based flexible soft sensors on each finger was used as the controller. A pneumatic glove consists of actuators integrated into each glove finger that is worn by the patient. Data gathered from five fingers were used to predict each finger's label. The motion label of each finger of the sensor glove is recognized in real time and transmitted to the control system via a socket connection. Figure 1 schematically shows the article's idea; by using the glove–actuator system, the patient wears the sensor glove at home and has hand movements that could be examined by the doctor in the hospital. By implementing the remote-control idea, it is possible to have more accurate and less expensive care for diseases related to the elderly such as Parkinson's disease. This idea could be essential for societies with an old population.

2 | Materials and Methods

The construction of different parts of the glove–actuator system includes the construction of sensory gloves, the construction of the hand actuator, and how to connect these two parts. This section focuses on the conceptual design of the integrated system for the sensory glove and hand actuator, materials, and finally, the idea of remote control.

2.1 | Sensor Glove Preparation

To make sensory gloves, a cloth glove made of fabric was prepared to be suitable for the patient to wear. Then, five capacitive sensors were designed to be placed on each finger to detect the movements. The construction of capacitive sensors is such that a non-conductive (dielectric) sheet is placed between two conductive sheets. The mechanism of these sensors is that when the sensor is subjected to a tensile load, the middle layer becomes thinner and causes the two capacitor sheets to be closer together, and the capacitance of the capacitor changes. The capacity of the sensor [38] is determined from Equation (1).

$$C = K\frac{A}{d} \tag{1}$$

where A is the area of the capacitor sheets, and d is the thickness of the dielectric. In this article, the upper and lower layers of the sensor are made of a commercial 235 f/36 dtex 2-ply HC þ B silver-plated nylon conductive yarn (Shieldex, Bremen, Germany), and the dielectric layer was made of polyurethane which was prepared using a knitting machine and then the layers were sewn together to manufacture the sensors. The sensors were attached to the fingers of the gloves. It is worth noting that the glove must fit the human hand perfectly so that the sensors can

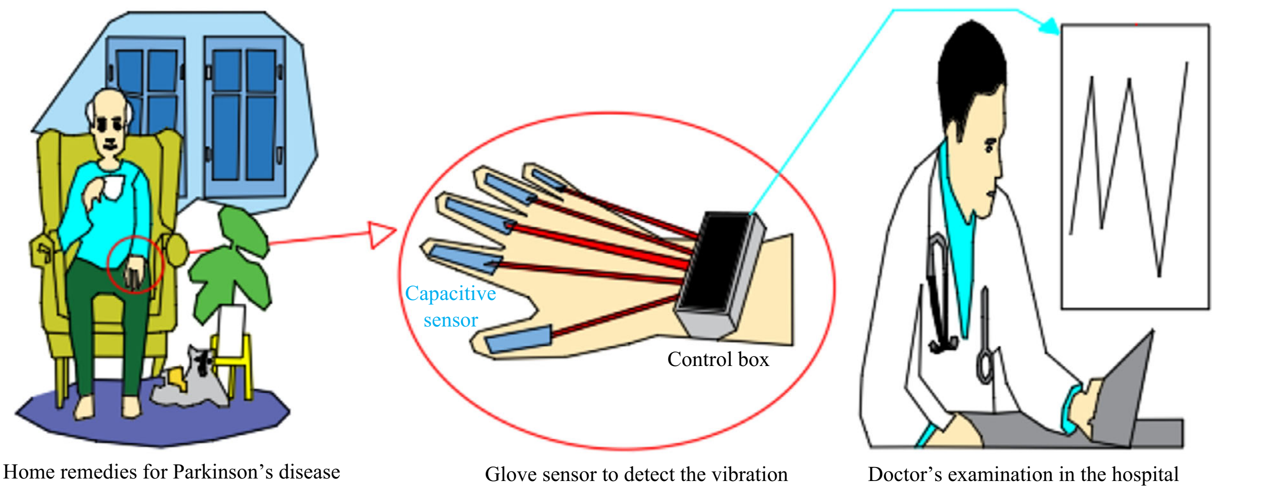

FIGURE 1 | Components of remote-control glove–hand actuator system. The patient could be controlled at home by a doctor in the hospital.

FIGURE 2 | Schematic view of the (a) sensor glove. Reproduced (Adapted) under the terms of the Creative Commons Attribution-Non Commercial License (CC-BY-NC) [40]. 2025, Wiley. (b) Artificial hand actuator preparation. Reproduced (Adapted) under the terms of the Creative Commons Attribution-Non Commercial License (CC-BY-NC) [40]. 2025, Wiley.

correctly detect the movements of the fingers, and this issue limits the use of gloves to one person. In the next work, we want to use an image processing method to make it possible to provide gloves according to the size of each person's hand by showing the hand using a knitting machine. To install the circuit box on the glove, some magnetic buttons are placed on the glove fabric. The sensory performance of this sensory glove was evaluated [39]. In this application, it is necessary to transfer one-to-one information from the sensory glove to the hand actuator, the sensory glove has a linear function during bending. Figure 2 schematically shows the preparation of the glove sensor (a) as well as the artificial hand actuator (b).

2.2 | Artificial Hand Actuator Preparation

In this part, the details of the construction of the artificial hand actuator were provided. A pneumatic system was used to provide force to create bending in the fingers. To provide bending, two different layers (material or structure) must be placed on both sides of the glove fingers so that they have different elongations under equal force to create bending. Like this mechanism, there is also a thermostat in which two different materials (different thermal expansion) cause bending. The artificial hand operator is manufactured of fabric. TPU material was used to trap air inside the actuator. Robot hands must be able to bend and then straighten. For this purpose, bending and elongation actuators were used, which have a mutual layer on top of each other. By applying air pressure to each actuator, its corresponding movement is activated (see Figure 2).

2.3 | Control of Artificial Hand Actuator via Sensor Glove

Here, an actuator was activated using a sensor in such a way that the application of pressure inside each of the actuator's fingers occurs upon receiving a command from the sensor. A wire, Bluetooth, or the Internet can connect the actuator to the sensor, depending on the distance between the two and its application. A neural network prepared in MATLAB2024 software sent commands from the sensor to the actuator. As each finger was bent, the corresponding sensor was activated and sent commands to the corresponding finger in the artificial hand actuator.

3 | Results and Discussion

In this section, the performance of the components of the sensory glove system and the artificial hand actuator were examined, and their possible applications were described. A finite element simulation of a finger was performed to better understand how to design a finger to bend and straighten.

3.1 | Sensor Glove Performance

Figure 3 shows the performance of a glove sensor over time for (a) 300 and (b) 11 repetitions of flexing and straightening the index finger. The performance of the other finger sensors is the same. For a sensory glove, the sensors must have linear performance throughout the angle change to transmit a one-to-one ratio to the actuator. As shown in Figure 3c, the sensor has an almost linear performance at different angles.

3.2 | Finite Element Simulation for Artificial Hand Actuator Performance

To perform finite element analysis, the commercially available ABAQUS 2024 software, integrated with Python 2024, was used. The actuator finger model consisted of three identical shell sheets, with mechanical properties imported linearly. Due to the large deformations associated with pneumatic actuation,

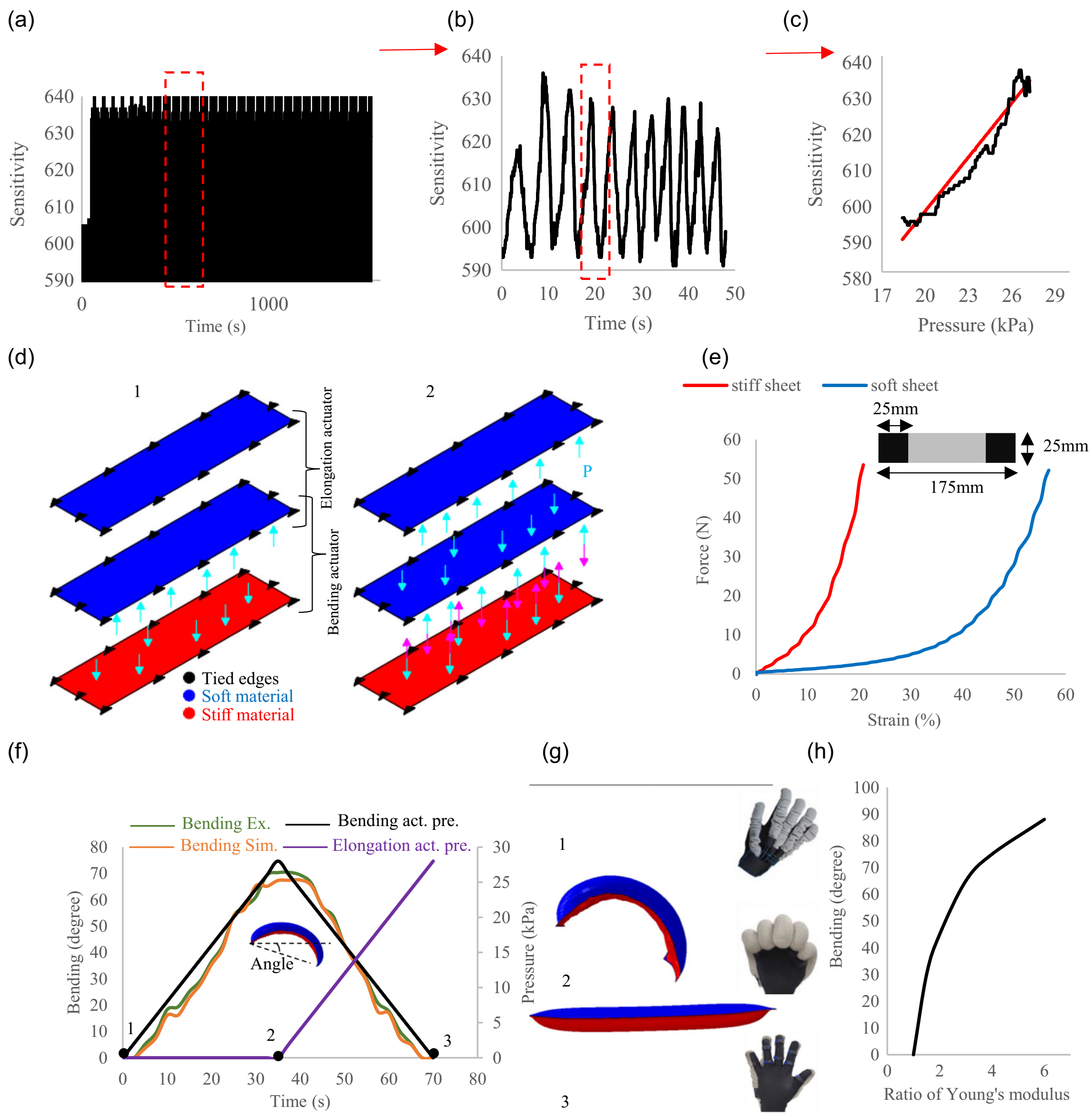

FIGURE 3 | Sensitivity in terms of the time for (a) 300 and (b) 11 cycles. (c) The performance of the sensor is linear. (d) Simulation procedure for the artificial finger. It consists of one bending actuator for finger bending and one elongation actuator for finger strengthening. It contains three sheets with stiff and soft materials. The problem consists of three shells with two different stiff and soft materials. The sheets are coupled to each other on all edges, and (e) the stress–strain curve for the stiff and soft materials are presented. (f) Bending angle in terms of the pressure for artificial fingers as well as sequence images of the finger deformation during the pressure (g) numerically and experimentally. Reproduced (Adapted) under the terms of the Creative Commons Attribution-Non Commercial License (CC-BY-NC) [40]. 2025, Wiley. (h) The relation between ratio of Young's modulus of stiff sheet to soft sheet.

static solvers were found to be unsuitable. Instead, among available dynamic solvers, the implicit dynamic solver (quasi-static) provided the most stable and accurate results and was therefore selected for this study. A step time of 10^{-5} seconds was applied. Model convergence was significantly improved by fine-tuning parameters such as material density and geometrical dimensions at the millimeter scale. The simulation consists of two steps, including the initial bending to bend the finger by applying the pressure into the bending actuator. Then, by deflating the bending actuator by applying the negative pressure and at the same time applying the pressure inside the elongation actuator happen. By repeating these two steps, the bending and straighten of the finger for several times will be visible. All the edges of each sheet were coupled the edges of upper sheet. The right edge was completely fixed. The total number of mesh was 10,321 of type S3. Figure 3d shows the simulation procedure and Figure 3e illustrates the stress–strain curve for soft and stiff materials.

Figure 3f shows the deformation behavior of the finger in terms of pressure. As can be seen, initially the pressure in the bending actuator reaches 28 kPa (maximum pressure), and complete bending occurs at 70°. Then, the pressure in this actuator decreases and is added to the pressure in the elongation actuator, such that the total pressure in the two actuators is always constant, and then the finger straightens. The reason why an elongation actuator was used to straighten the finger was that if there was no pressure inside the fabric, the fabric would lose its shape and could not have the stretched finger shape. The finite element deformation and the experiment images of the finger during the pressures are shown in Figure 3g [40]. Figure 3h reveals the relation between the ratio of Yong's modulus of stiff sheet to Young's modulus of soft sheet. The bending angle increases by increasing this parameter. It is found to be an important parameter affecting the bending angle.

In the elongation actuator, the lower the Young modulus of the material, the greater the elongation. The physics of the problem for bending actuators is that when two materials with two different Young's moduli are placed on top of each other, the effect of applying the same pressure to both cause different elongations, causing bending in the actuator. The greater the difference in Young's modulus between the two sheets, the greater the amount of bending that occurs. Because bending requires that both sheets be able to elongate, and this difference in elongation causes bending. However, if one sheet cannot elongate due to an excessive increase in Young's modulus, it is natural that the expected bending will also be eliminated.

3.3 | Application

The glove–actuator system has many applications, including Parkinson, remote workers [41], and physiotherapy (rehabilitation) [42, 43]. Haptic [44], remote, integrated sensor–actuator system to be scientifically used in the paper. The best usage for this system is the last one, for medical treatment of people who have had a stroke or have problems moving their hands and need to be under the supervision of a doctor. This application can reduce the costs of treatment and hospitalization, and the sick person can be examined by a doctor more easily at home (remotely). Depending on the distance between the sensory glove and the prosthetic hand actuator, this system can be used in three ways: wirelessly utilizing the Internet, wirelessly using Bluetooth, and wired. It is also possible to transfer motion from the sensory glove virtually so that hand movement can be seen inside the monitor.

For example, the idea could be used for physical therapy for someone who has a broken hand and wants to start recovering. This way, the amount of air entering is determined according to the sensor. At first, when a person has difficulty opening and closing their fingers, this sensor will have a harder time deforming, and as a result, the air pressure applied to it will be greater. But after some days, when the patient's hand has become better and stronger and needs less help, the sensor can command less air pressure, and as a result, the energy of the patient's hand will play a greater role in moving her fingers. All details of the experimental test were provided in the work of Kadir et al. [40].

4 | Conclusion

In this study, a glove-actuated remote-control system was developed to enhance telemedicine capabilities for patients with motor impairments, particularly elderly individuals affected by conditions like Parkinson's disease. The system integrates a fabric-based sensor glove with a pneumatic hand actuator, enabling remote monitoring and control of finger movements via MATLAB-based algorithms. Finite element analysis demonstrated the impact of material properties on actuator performance, while machine learning enabled precise translation of sensor data into actuator response. The glove's comfortable textile design ensures wearability, and the system's flexible communication options—wired, Bluetooth, or internet—allow for scalable deployment. Beyond medical rehabilitation, the proposed system shows promise in hazardous applications where direct human involvement poses safety risks. This work provides a foundation for future development of cost-effective, wearable human–machine interfaces for remote care and robotic control.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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