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# Development of flexible glove sensors for virtual reality (VR) applications

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ABSTRACT

Virtual reality (VR) technology has catalyzed the development of flexible sensors to interact with objects in a virtual environment. Current solutions for smart glove sensors are limited by rigid factors. In this article, a novel smart glove is developed that utilizes a flexible sensor made from a polyethylene-carbon composite (Velostat) to manipulate a hand model in a 3-dimensional (3D) virtual reality (VR) environment. The sensors are specifically designed to measure the angle of finger joint flexion, and an interface circuit has been developed to process the joint angle data. The strain sensors attached to the smart glove show a high sensitivity of 59.8 % $rad^{-1}$, with a response time of 15.8 ms when the joint angle increases from 0° to 30° under the dynamic response test. The fabricated smart glove successfully controls a 3D hand in a VR environment. This proof-of-concept experiment explores the potential application of the smart glove for VR telerehabilitation.



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## 1. Introduction

Recent advancements in virtual reality (VR) and augmented reality (AR) technology are closely tied to materials science. To enhance the sensory experience of users, the development of materials has become a key challenge. Research has been dedicated to creating lightweight, durable, and flexible materials, including stretchable materials, for use in wearable VR/AR devices [1,2]. A flexible sensor acts as an electronic transducer, mimicking human skin to perceive external stimuli. This sensor is constructed by integrating several advanced polymers into stretchable materials, such as Ecoflex [3,4] and polydimethylsiloxane (PDMS) [5,6], for throat muscle movement detection [7], gait monitoring [8], and electronic skin applications [5]. With its conformal contact with human skin, flexible sensor technology has recently been explored for VR applications. For example, the smart glove that acts as a human–computer interface can identify the number of degrees of freedom (DOF) in hand movements, allowing the manipulation of an object in a virtual environment [9–11]. Joint angle measurement plays a significant role in hand movement sensing.

Numerous sensing principles have been developed to measure joint angle flexion. An optical sensor has been utilized to detect the curvature of joint angle bending via variations in light intensity. This sensor is advantageous due to its being lightweight, flexible, and free from electromagnetic interfaces [12,13]. This approach, however, is sensitive to the additional stress induced in the fiber in a bending movement and causes light attenuation. Integration of a hall effect sensor could potentially address this constraint by locating it at the tip of the fingers with a permanent magnet attached to the palm. It acts as a switch to identify finger movement by detecting changes in proximity [14,15]. However, this sensing approach has a limitation as it can only detect movement along one DOF and is unable to capture intricate finger movements. Another alternative is integrating accelerometers on the joint of each finger [16,17]. However, the flexibility and conformability of the glove reduce as the accelerometers are constructed in a rigid integrated circuit (IC) form factor. Flexible transistor pressure sensors have been used to monitor joint bending. However, concerns regarding their low durability and complex manufacturing process in sensor fabrication need to be considered [18,19]. Recently, a single-skin sensor has been proposed for 3-dimensional (3D) hand control in VR environments with the aid of machine learning [20–23]. It provides the advantages of being lightweight, simple, and skin-conformal to the user. However,

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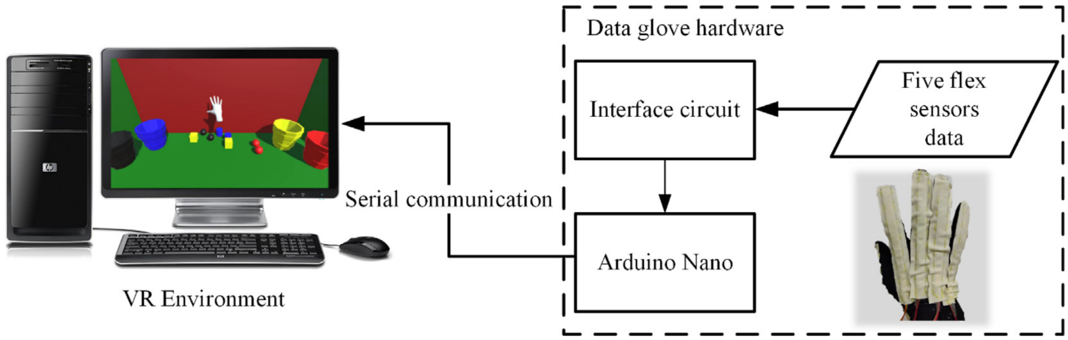


**Fig. 1.** The design of the smart glove architecture.

the performance of this sensor in detecting movements from multiple fingers simultaneously remains unknown.

This paper outlines a smart glove that can detect joint bending in real-time, fabricated from polyethylene-carbon composite (Velostat) material. Velostat is a type of electrically conductive plastic film made by combining polyethylene with carbon black nanoparticles. The manufacturing process involves mixing carbon particles with polyethylene pellets, which are then extruded and stretched to produce a thin film. The exact composition of Velostat may vary depending on the manufacturer and intended conductivity and sensitivity, but most formulations contain 10–20% carbon black nanoparticles by weight. It is commonly used in pressure-sensitive applications such as touch-sensitive switches and force sensors. It exhibits a change in resistance when a force is applied, based on the principles of quantum tunneling and percolation [24].

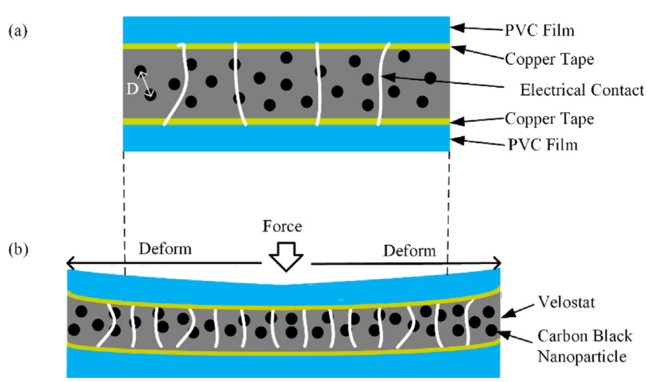


**Fig. 2.** (a) Sensor structure; (b) Sensor deformation under an applied force.

We study the strain-sensing behavior and correlate the output with the bending angle of the joint for five different fingers. The result shows that bending the finger of the smart glove can derive the bending of the corresponding finger of a 3D hand in a VR environment.

## 2. Research methodology

### 2.1. Overview of the smart glove

In this project, a smart glove that integrates five strain sensors made of polyethylene-carbon composite Velostat, which served as a human–machine interface (HMI) was developed for controlling a virtual 3D hand model. Fig. 1 illustrates the design of a system for the smart glove. The bending angle data obtained from the Velostat strain sensors were transmitted to an Arduino Nano, a miniature microcontroller. The output signal from the Arduino Nano was then sent to the personal computer via serial communication, which was used for object manipulation in a VR environment developed using Unity Editor.

### 2.2. Working principle of the strain sensor based on Velostat material

Velostat was chosen as the strain sensing material due to its thin (<0.1 mm), lightweight, and flexible properties, making it an ideal candidate to be integrated into the wearable glove. This polymeric film is made from a blend of polyethylene and carbon black, with carbon black nanoparticles dispersed throughout the film to create a conductive pathway for electricity to flow through [25]. Under free-strain conditions, the carbon black nanoparticles in the Velostat are randomly distributed, with no continuous conducting path between them, as shown in Fig. 2(a). As a result,

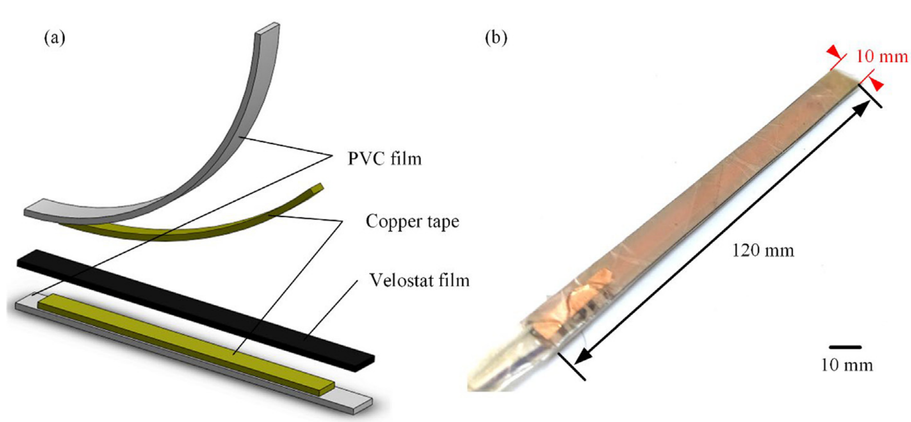


**Fig. 3.** (a) Composite layer of the strain sensor; (b) Prototype of strain sensor.

the sensor has a high resistance. When an external force is exerted on the sensor, the percolation network deforms, causing the distance (D) between the conducting particles to decrease and resulting in a decrease in resistance, as depicted in Fig. 2(b).

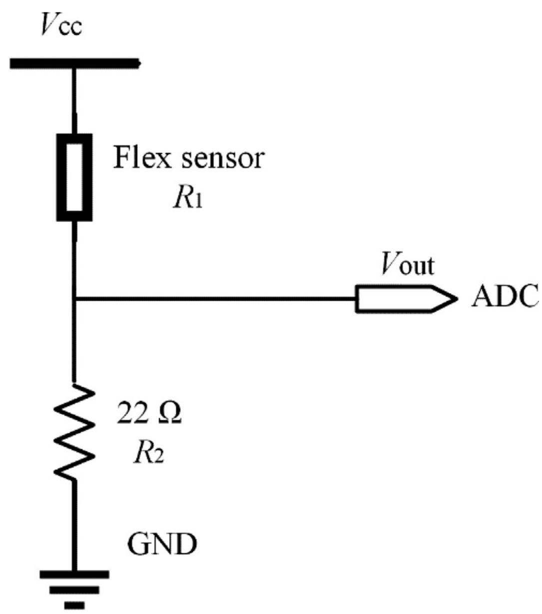


**Fig. 4.** Voltage divider circuit for strain sensors characterization.

### 2.3. Fabrication of the strain sensor

To measure bending angle, a strain sensor was fabricated by laminating Velostat film between adhesive copper electrodes. The strain sensor was encapsulated in PVC film for compatibility with the textile glove. Fig. 3(a) shows the buildup components of the strain sensor while Fig. 3(b) illustrates the fabricated strain sensor.

### 2.4. Experimental setup for the strain sensor

In Fig. 4, a voltage divider circuit was built to analyze the joint bending responses. The strain sensor output was converted to a microcontroller-readable value. The voltage output ($V_{out}$) of the voltage divider circuit was determined by the following equation:

$$V_{out} = \frac{R_2}{R_1 + R_2}(V_{cc}) \quad (1)$$

where $R_1$, $R_2$, and $V_{cc}$ are the resistance of the strain sensor, the shunt resistance of 22 Ω, and the supply voltage, respectively.

## 3. Results and discussion

### 3.1. Strain sensor characterization

The fabricated resistive-based strain sensor was attached to a commercial glove. Fig. 5 (a) illustrates the change in resistance over time as the angle of bending increases from 0° to 90°. As shown in Fig. 5(a), the strain sensor exhibited changes in relative resistance within 15.8 ms during the dynamic test as the bending angle increased from 0° to 30°, indicating a rapid response time

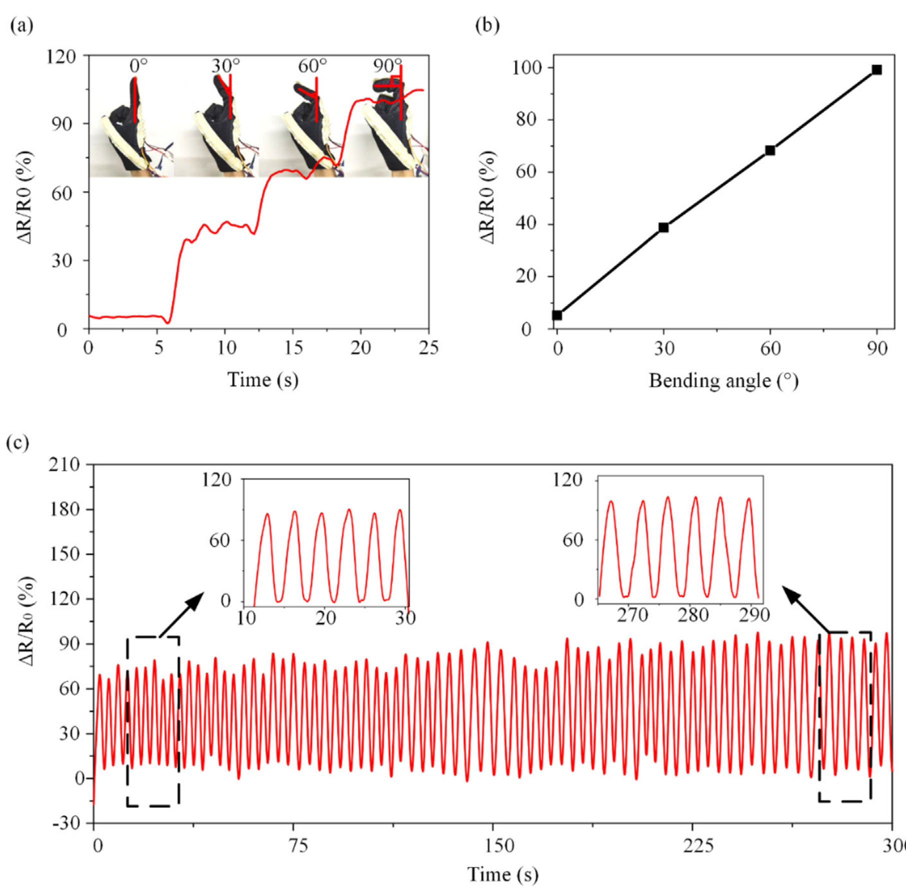


**Fig. 5.** (a) The time-dependent behavior of the finger bending motion; (b) Sensitivity of the developed strain sensor; (c) Repeatability test of the strain sensor.

that can detect finger movements. It is noteworthy that the change in resistance increases linearly with the bending angle, exhibiting a sensitivity of 59.8% $rad^{-1}$, as illustrated in Fig. 5(b). This linear behavior may be attributed to the applied strain falling within its elastic region, where the sensor can revert to its initial state once the external force is eliminated. To further investigate the hysteresis and repeatability of the sensor, the sensor was continuously bent from 0° to 90°, as depicted in Fig. 5(c). As can be seen in the figure, no hysteresis or signal distortion was observed during flexion movement, ensuring its repeatability. However, it is important to note that the adhesive on the copper tape may degrade over time, potentially resulting in weakened or failed connections. Therefore, alternative connection methods, such as attaching the resistive-based strain sensor to a conductive thread or wire, could be a good option to ensure the Velostat sensor's reliability when subjected to cyclic bending and stretching movements. Table. 1 presents a comparison of sensor characteristics in terms of response time and sensitivity with their respective counterparts. Among the sensors listed in the table, the use of Velostat as the sensing material exhibits the best response time and sensitivity.

**Table 1**
Piezoresistive sensors design and their characteristics.

| Sensing Element | Response time (ms) | Sensitivity (% $rad^{-1}$) | Citation |
|---|---|---|---|
| Graphene | < 100 | 19 | [26] |
| Graphene/Silver Nanowires | < 78 | 26 | [27] |
| Graphene/Sodium Alginate | – | 17.2 | [28] |
| Platinum | – | 0.86 | [29] |
| Silver Nanowires | < 120.0 | 16.0 | [30] |
| Velostat | < 15.8 | 59.8 | This work |

### 3.2. 3D hand modeling

An open-source 3D hand model was obtained from Sketchfab. The top view and side view of the 3D hand model are shown in Fig. 6 (a) and (b), respectively. Blender software was used to fit the 3D hand model with an armature. To simulate the movement of human fingers, the index finger, middle finger, ring finger, and pinkie finger of the 3D hand model were subdivided into three segments, while the thumb was subdivided into two segments. The 3D hand model with armature was then exported to Unity for VR application.

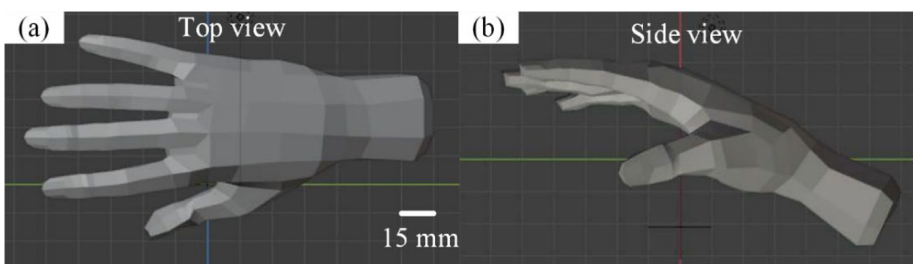


**Fig. 6.** (a) Top view of the 3D hand model; (b) Side view of the 3D hand model.

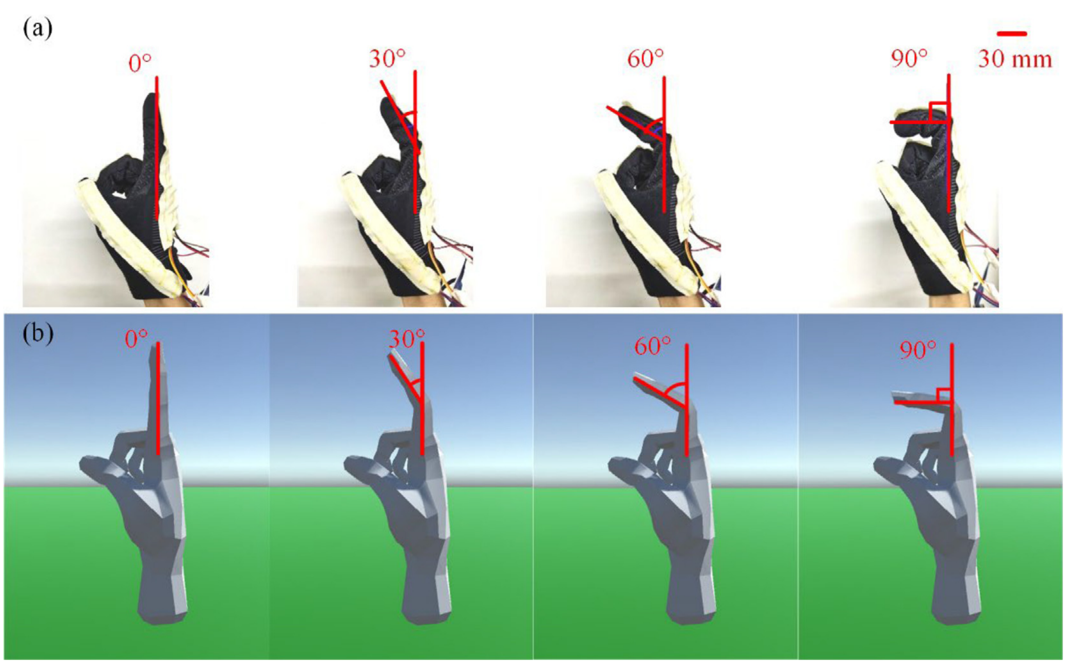


**Fig. 7.** (a) The index finger of the smart glove bends from 0° to 90° in the real world; (b) The index finger of the 3D hand model bends from 0° to 90° in the virtual environment.

### *3.3. Controlling a 3D hand model in a virtual environment*

The virtual 3D hand model's fingers bend following the signals received from the smart glove. The index finger movement of the smart glove in Fig. 7(a) (from 0° to 90°) shows excellent equality in the 3D hand model, as shown in Fig. 7(b). When a new user is introduced, he will be asked to perform a grip and release hand gesture, and the output of all the strain sensors will be recorded. The value calculated for calibration will then be fed into the microcontroller.

## 4. Conclusion

In this paper, a smart glove was developed based on Velostat sensors for a VR interface. The smart glove includes a Velostat piezoresistive sensor and a data acquisition microcontroller. The sensing behavior of the strain sensor is examined when it is attached to the smart glove. It demonstrates a quick response time of 15.8 ms and a sensitivity of 59.8 % $rad^{-1}$ when the joint angle increases from 0° to 30°. The 3D hand model, created with Unity, accurately mimics the movements of an actual hand. With this smart glove, the user can effectively control the bending motion of a virtual 3D hand finger within a VR environment, expanding the range of VR control. Future improvements to the smart glove include adding haptic feedback to enhance the user's experience.

## Data availability

Data will be made available on request.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Pei Song Chee reports financial support was provided by CREST fund. Pei Song Chee reports a relationship with CREST that includes: funding grants.

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