POF Sensor for Angle Measurement in a Textile-based Soft Hand Exoskeleton

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***Abstract*—Soft robotics hand exoskeletons have proven to be effective in recovering hand function due to features such as lightweight, portability, and comfort. These devices incorporate user interfaces to identify the intention of the user's movement to control the exoskeletons. However, the monitoring of the physical variables of the device is still limited. Some devices have included resistive and capacitive sensors for angle or grip force detection but increased the complexity of the systems. Research in optical sensors for robotic hands and prostheses presents an alternative to the development of sensors for soft robotics. This work presents the development and validation of an optic sensor for angle measurement of a textile-based hand exoskeleton. The results show that the optical fiber sensor is an option for an angle sensor for a soft hand exoskeleton by obtaining a correlation coefficient of 99% between the sensor and software data.**

***Index Terms*—Soft Robotics, Hand Exoskeleton, Optical Fiber Sensor**

I. Introduction

Soft hand exoskeletons have demonstrated their potential to aid in the stroke rehabilitation process [1]. Particularly, soft robotic hand exoskeletons are comfortable, portable, and user-friendly. Likewise, soft hand exoskeletons reach sufficient force to aid the patient in manipulating objects used in daily life [2]. However, the implementation of sensors to monitor the physical variables of these devices is still limited.

Some exoskeletons have implemented resistive or capacitive sensors in their devices, such as those developed by Zhou *et al.* that track finger flexion via strain and detect contact with objects via force [3]. Nevertheless, the detection of angle or grip force requires complex sensor design, fabrication, and assembly, which increases the complexity of the system.

Sensors based on optical fibers are an emerging sensor technology due to their immunity to electromagnetic fields, multiplexing capability, compactness, and low-cost properties. An example of optical sensors is sensors based on polymer optical fibers (POF). High flexibility, low cost, ease of application, and data acquisition are some advantages of these sensors. POF sensors employ the variation of light intensity to measure stretch, bend, or press variables [4]. Furthermore, POF sensors for angle monitoring have been implemented in other devices such as soft prostheses [5]. In this context, this research proposes the development of a POF sensor for angle monitoring of a textile-based soft hand exoskeleton.

II. Materials and Methods

In this section, the textile-based soft hand exoskeleton is presented. In addition, the fabrication, and placement of the sensor on the hand exoskeleton are described.

A. Textile-based Soft Hand Exoskeleton

The hand exoskeleton used is the ExHand Exoskeleton developed by Maldonado-Mejía *et al.* [6]. ExHand is a textile-based exoskeleton for stroke rehabilitation. Their actuators are made with layers of fabric and a thermoplastic elastomer balloon between the layers of fabric. Thus, the pressurization of each balloon performs the flexion and extension movements.

B. Angle Sensor: Fabrication and Characterization

The functionality of the sensor is based on the variation of the light intensity while the fiber is bent. The angle is associated with the variation of the optical power due to radiation losses [5]. For ease, photodiodes or phototransistors are used for the optical power variation measurement. Thus, the optical power variation is associated with a voltage value. POF (SH4001, Mitsubishi Chemical Corporation, USA) was employed to fabricate the sensor. In addition, a sensitive zone was created by removing part of the fiber core to enhance sensor sensitivity. Then, the sensor is sewn around the index finger to keep it fixed on the exoskeleton, and the sensitive area is placed upwards near a finger joint (see Figure 1).

Fig. 1. POF sensor placed on ExHand Exoskeleton.

To characterize the sensor, a test was carried out by pressurizing and depressurizing the index finger actuator to perform the flexion motion. The acquisition voltage values are obtained using a microcontroller's internal Analog-To-Digital Converter (ADC). Moreover, the test was recorded to

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compare the value of the ADC with the angle obtained by an open-source video analysis software (Kinovea). Likewise, three markers were placed on the exoskeleton (Figure 2) to avoid wrong information during the video analysis. The test was recorded at the same time that the data of the ADC was stored, and was performed eight times to analyze repeatability.

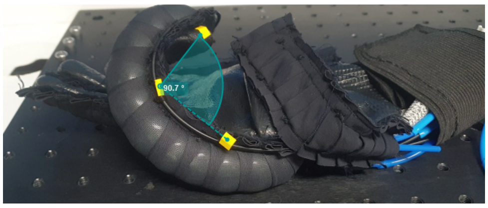

Fig. 2. Markers placed on the Exoskeleton ExHand and an example of the angle measurement provided by the software.

As a light source, a red light-emitting diode (IF-E97, Industrial Fiber Optics, USA) is implemented, and a phototransistor IF-D93 (Industrial Fiber Optics, USA) is employed to measure the voltage value associated with the optical power variation. For processing, control, and data acquisition, a USB-based microcontroller development system (Teensy 3.6, PJRC: Electronic Projects, USA) with an ADC of 16-bits of resolution was used, and 997.5 samples per second were collected.

III. Results and Discussion

The data obtained by the ADC was a noisy signal. Accordingly, a digital Butterworth filter with a cutoff frequency of 10 Hz was applied. Then, the mean and the standard deviation of the eight tests were obtained to verify the repeatability of the tests. For characterization, the sensor and software data were interpolated to ensure that both sets of data shared the same time axis. The interpolation, the mean, and the standard deviation of the sensor and software data are presented in Figure 3.

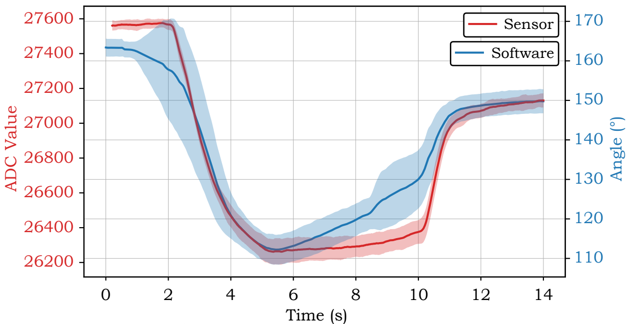

Fig. 3. Comparison of the POF sensor graph and the angle obtained by the open-source video analysis software.

Figure 3 shows that sensor and software data have similar behaviour. In addition, repeatability was demonstrated in the tests as the highest standard deviation of the sensor data was 88.73 at 10.13 seconds, and the highest standard deviation of the software data was 14.71 at 2.43 seconds. In addition, the behavior of both graphs is nearly equal between 2 and 5 seconds (The time in which the actuator is inflating) as opposed to the rest of the time. This occurs because of the viscoelastic material of the POF [4].

To finish the characterization, a partitioning of the data is performed to analyze the pressurization and depressurization of the actuator. With each data set, the correlation coefficient (R) between the sensor and the software data is calculated. The characteristic equation of each curve is shown in Figure 4.

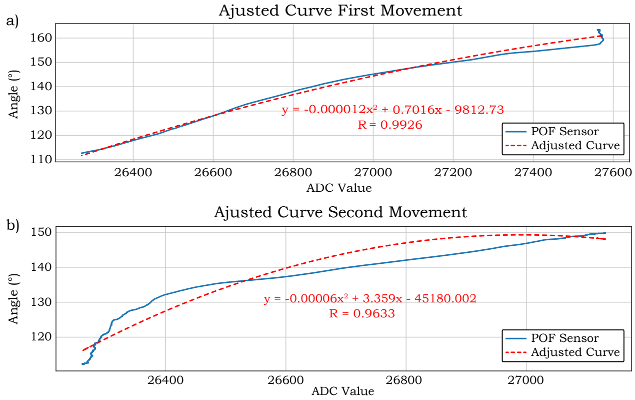

Fig. 4. Characteristic equation of POF sensor for the moment when a) the actuator is pressurized and b) the moment when the actuator is depressurized.

The best correlation coefficient was 99% and was for the moment of pressurizing the exoskeleton (Figure 4a). An R close to 1 indicates that the sensor data fits with the software data. Therefore, the POF sensor is an option for an angle sensor for a hand exoskeleton based on soft robotics. However, testing with another type of sensor such as an IMU sensor is still required. Also, it is required to verify the performance of the sensor while a user wears the hand exoskeleton.

IV. Conclusions and Future Works

A POF sensor for angle measurement of a textile-based soft hand exoskeleton was developed. Also, a regression was applied to obtain an association between the ADC values and the angle, and a correlation coefficient greater than 99% was obtained. Therefore, several future works are proposed to improve the evaluation of the POF sensor performance. More sensitive areas will be created on the POF sensor to further improve the sensitivity of the sensor. An IMU sensor will be implemented on the index finger of the ExHand Exoskeleton to carry out a comparison with another sensor. Finally, tests with patients will be carried out.

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