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WEARABLE TEXTILE ELONGATION SENSOR

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ABSTRACT

This work shows a developed wearable elongation sensor based on an optical fiber. The presented approach to sew a fiber optic into a lycra textile enables the modulation of light amplitude in respect to textile strain. This apparatus in combination with small-size instrumentation enables the development of a wearable textile garment capable of monitoring and acquiring strain data, and send it wirelessly to a base station. The light amplitude increases with the increment of textile strain. The output voltage remains stable over time for the resting and maximum textile strain position.

Keywords: Wearable applications, fiber optic sensors, elongation sensor.

INTRODUCTION

In this paper it is reported the design and fabrication of a wearable elongation sensor based on optical fibers. The optical fiber is sewed on the top of a lycra textile surface. This kind of sensors can be used for posture and motion analysis in sports, medicine and rehabilitation.

The unique properties of an optical fiber contribute to enhance the performance of elongation sensors making them capable of providing reliable solutions for those applications where conventional sensors are not suitable. Glass optical fibers have some good properties, such as lightweight, small diameter and no threat of electrical risk [1]. A typical single mode fiber (SMF) has an outer diameter of only 125 μm (62 μm inner core more cladding). Additional protective layers will increase dimensions, up to 900 μm for the outer diameter. Glass optical fibers are made of SiO_2 with a density (2200 kg m^{-3}) approximately four times lighter than copper, which also facilitates miniaturization [2, 3].

The geometrical versatility of optical fibers allows them to bend in textiles to diameters of 10 mm, which make them suitable to adapt to complex surfaces, such as skin surfaces and body joints [4]. They also offer an excellent measurand-type range and can be used as a generic sensing element to quantify other physical quantities such as force, acceleration, pressure, vibration, electromagnetic field and certain chemical quantities [5-7].

During the past few years many successful attempts have been done in order to integrate optical fibers into wearable textiles. Dunne *et al.* developed a wearable plastic optical fiber (POF) sensor for monitoring seated spinal posture [8]. Li *et al.* developed a novel wearable sensor for human body temperature measurement, with the goal of integrate optical Fiber Bragg Grating (FBG)-based sensors into functional textiles, extending the capabilities of wearable solutions for body temperature monitoring [9]. Fujiwara *et al.* developed a glove-based sensor using flexible optical fiber microbending transducers for applications in biomechatronics. The devices are attached onto the dorsal surface of monitored joint, which detects variations of ~4° in angular displacements [10].

In this paper it is possible to read a short description of the developed elongation sensor. The hardware/software needed to operate the sensor is also reported. The results describe how the test was performed and discuss the plots from the elongation tests. Final section in this paper is a conclusion about the elongation sensor where the results and possible applications are synthetize.

SENSOR DESCRIPTION

The elongation sensor is made of a single mode optical fiber (ø = 900 µm) sewn into a lycra textile in a double wave shape as shown in figure 1. SC fiber optic connectors are used for pass light through the optical fiber. Those connectors were chosen due to their small dimensions that make easier textile integration. One connector connects with a photodetector and the other end connects with a light emitter. The optical fiber is sewn into 22 wave shapes, with a maximum diameter of 1.2 cm, which together decrease the resting sensed voltage in the photodetector down to 1.5 V after amplification. At the same time the wave shapes and diameter allow to increase the sensed voltage up to 1.9 V after amplification when the sensor is stretched. Decreasing the optical fiber wave diameter can damage the optical fiber, which will stop or decrease the amount of light passing through. Increasing the number of waves will also decrease the amount of light passing through the fiber.

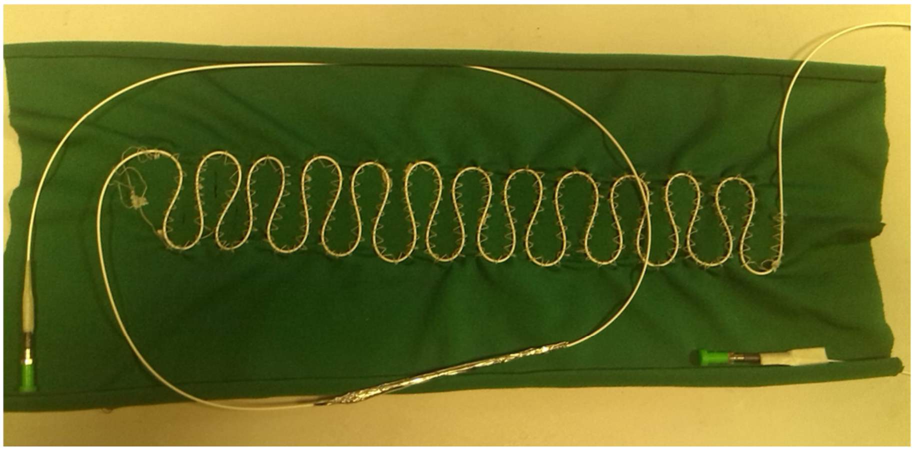


Fig. 1 - Elongation sensor.

HARDWARE

The fiber optic connectors couple with the light emitter and a photo detector. When the lycra is stretched, the light amplitude passing thought the fiber increases, which increases the output voltage coming out the photodetector. The output voltage from the photodetector was amplified and then digitalized from the analog to digital converter (ADC) of the microcontroller. The digital value was sent to a computer by Bluetooth connection. The sampling ratio was 1 Hz. Figure 2 shows the printed circuit board (PCB) where the fiber optic connectors are plugged. The circuit can be powered by a battery or plugged into a 5 V power supply.

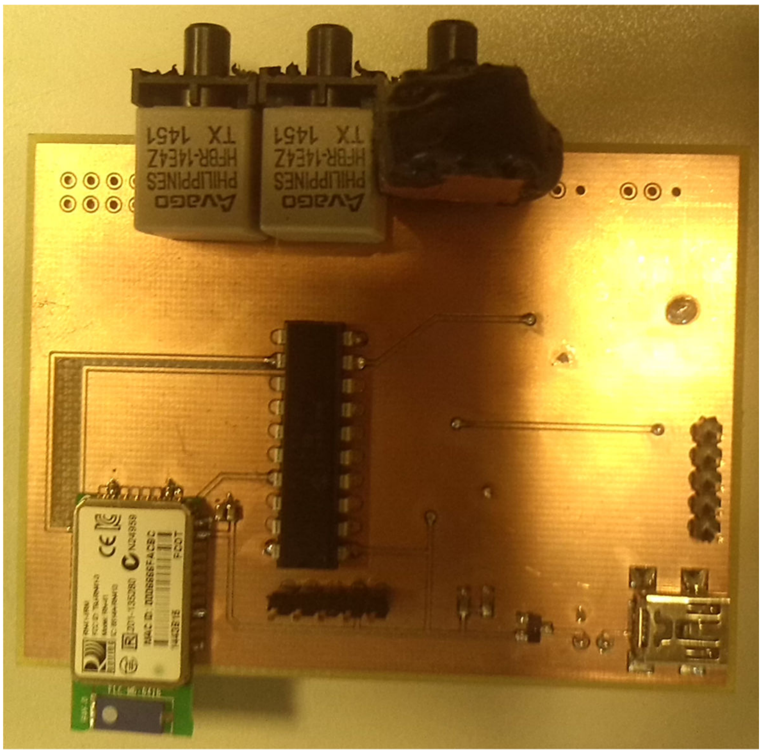
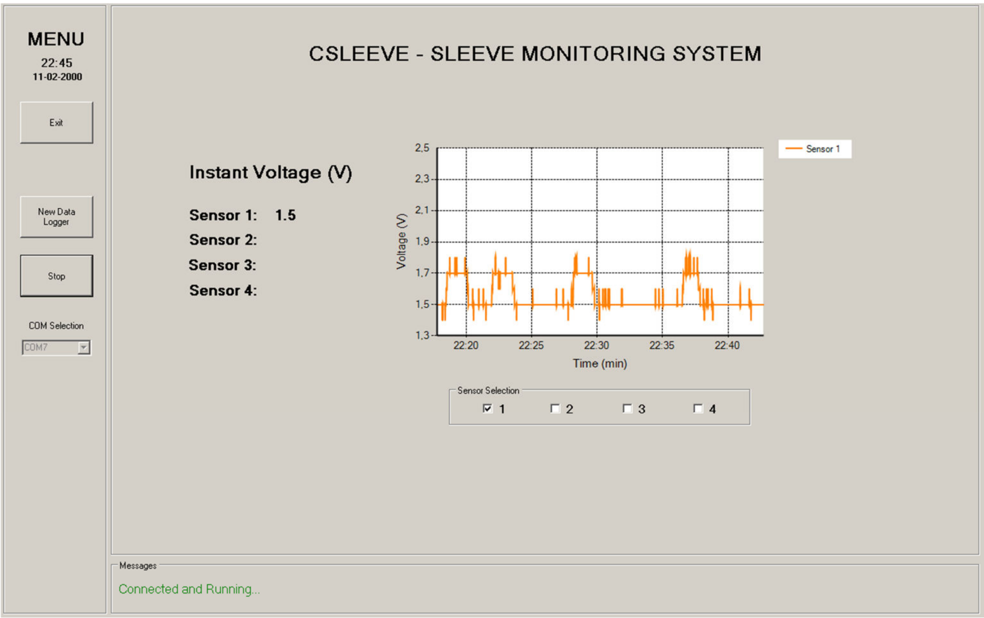


Fig. 2 - Control board.

SOFTWARE

A data acquisition software interface was built in order to get the output values from the sensor in real time and them save it in a log file for later analysis. A graph is done at the same time with the received values. Figure 3 shows a data acquisition software interface.



CSLEEVE - SLEEVE MONITORING SYSTEM

22:45
11-02-2000

Instant Voltage (V)

Sensor 1: 1.5
Sensor 2:
Sensor 3:
Sensor 4:

Sensor Selection: ☑ 1 ☐ 2 ☐ 3 ☐ 4

COM Selection: COM7

Messages

Connected and Running...

Fig. 3 - Data acquisition software interface.

RESULTS

The results from the elongation tests explained in this paper were taken with an extensometer. The sensor was tested in extensometer Shimadzu Autograph IG-IS 500N (Figure 4). Four velocities were used (1, 5, 10, 15 mm/min) to stretch the sensor up to 50 mm. In all the graphs presented bellow, the red curve represents the raw data, the blue line the spline curve and the green line the extensometer displacement. Two cycles at 1 Hz sampling rate were taken for each tested velocity.

Fig. 4 - Elongation test approach.

Figure 5 shows the elongation profiles from the sensor at 1 mm/min. The output voltage from the sensor increased when the displacement increase and it remained stable when the extensometer stops at the maximum displacement (50 mm). Reverse behavior is shown when the extensometer decreases the displacement from 50 mm to resting position. At this point, the sensor decreases the output voltage until the initial value. The little resting time at the maximum extension and resting point justify the curve sloop shape. Similar behavior is presented in the second cycle.

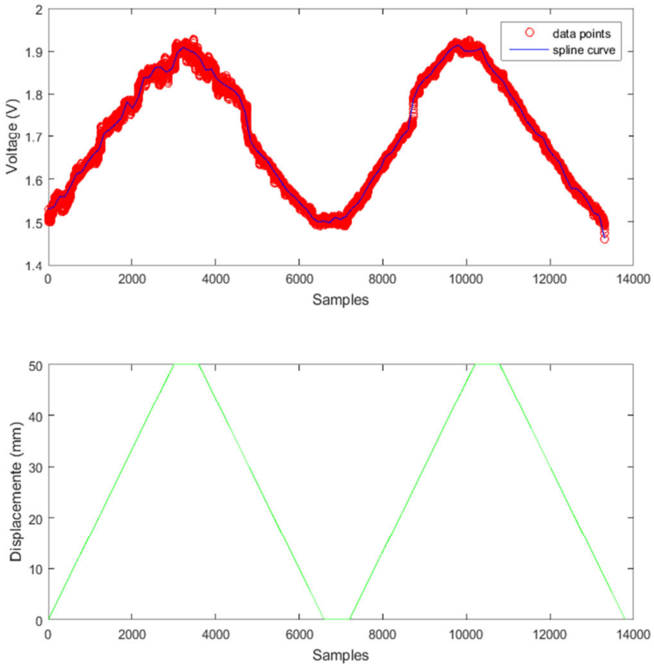


Fig. 5 - Elongation profile at 1 mm min^{-1}

Figure 6 shows the elongation profiles from the sensor at 5 mm/min. The output voltage from the sensor increased when the displacement increase. No resting time was set for this experiment, which justify the sloop peaks in the graph. The absolute gradient sloops are the same for the stretching and de-stretching sensor. For the stretching, there is a positive gradient sloop and for the de-stretching the gradient sloop is negative. Similar behavior is shown in both cycles.

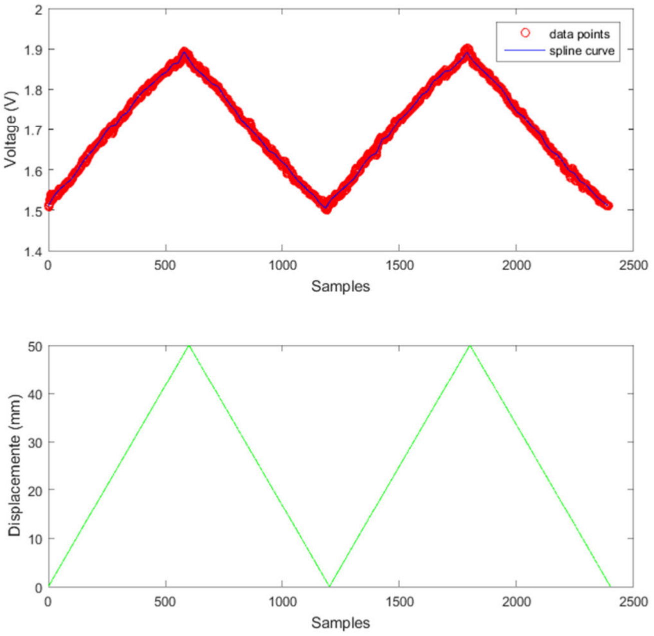


Fig. 6 - Elongation profile at 5 mm min^{-1}

Figure 7 shows the elongation profiles from the sensor at 10 mm/min. Comparing the results performed at 5 and 10 mm/min, the main difference is the absolute gradient sloops. As expected the absolute gradient sloop is higher for the higher velocity. The absolute gradient sloops are the same for the stretching and de-stretching sensor. For the stretching there is a positive gradient sloop and for the de-stretching the gradient sloop is negative. Once again, no resting time was set, which justify the peaks. Similar behavior is shown in both cycles.

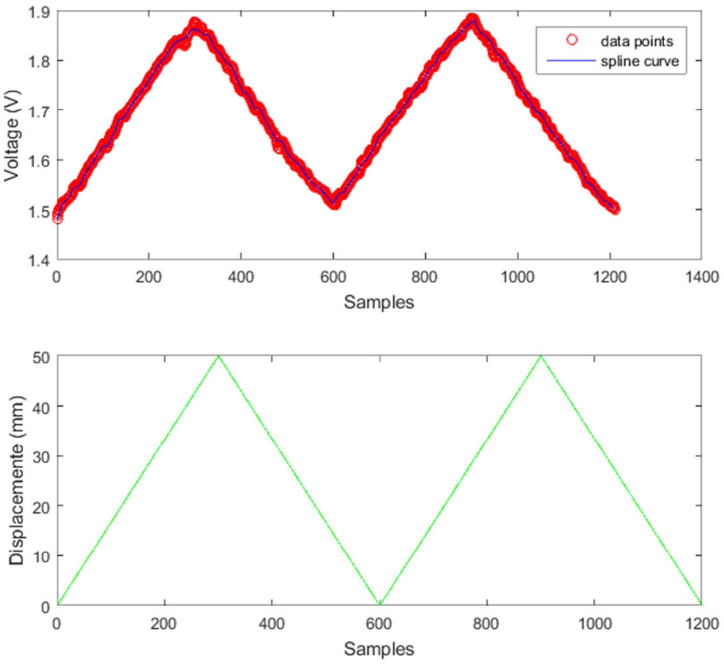


Fig. 7 - Elongation profile at 10 mm min^{-1}

Figure 8 shows the elongation profiles from the sensor at 15 mm/min. The square shape seen in the graph can be justify due to the short time needed to reach 50 mm elongation and the longer resting time. Once again, when the sensor reaches the 50 mm extension, the output voltage remains stable and the same behavior is noticed when the sensor returns to the resting position. Similar behavior is presented in the second cycle.

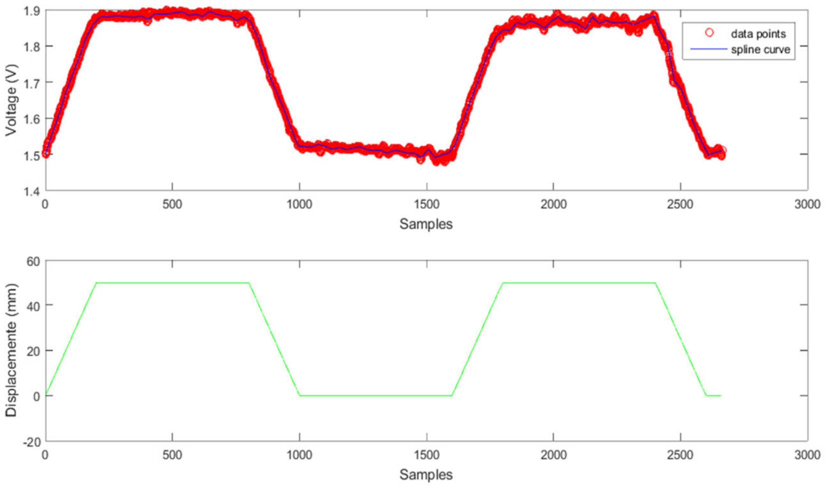


Fig. 8 - Elongation profile at 15 mm min^{-1}

CONCLUSION

With the performed work to this paper it is possible to prove that optical fibers can be embedded into wearable textiles in order to measure displacements induced by applied forces into the textiles. The results show a direct correlation between the sensor displacement and the output voltage sensed in the optical sensor. In all the performed tests the sensor increase the output voltage when the displacement increase. The same output voltage at resting position and maximum displacement (50 mm) it is always verified remaining stable over time. With the collected data it is possible to calculate a sensibility of 1 mm and a resolution of 8 mV/mm. This work can be applied in the field of compression garments for sports and healthcare, enabling the sensing of an active compression control in real time.

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