DEVELOPMENT OF FABRIC-TYPE OF TENSIONAL FORCE SENSOR

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ABSTRACT

We developed a tensional force sensor by applying artificial tetrafluoroethylene-perfluoroalkylvinyl ether copolymer (PFA) hollow fibers. The fibers were fabricated by depositing thin metal and an insulation layer on the PFA tube, and the fabric sensor was made by weaving the decorated PFA tube and the conventional cotton yarns together. The sensor was 57.0 x 4.0 mm. The sensor output linearly increased with the increase of the tension. We confirmed that the sensor output increased with applied tension at a rate of 2.1 %/N.

1. INTRODUCTION

Many physical sensors, for example pressure, acceleration, gyro, and tactile ones used in micro Electro Mechanical Systems (MEMS), have been developed for applications in the automotive and medical industries [1-4]. These sensors now come into usage for recording human behavior. They are attached to the surface of clothes . To be fitted in the surface of the clothes, these sensors need to have a flexible structure. Furthermore, they have to be enlarged to be used in applications used by people and those designed for robots. Therefore, flexible resin materials, such as PDMS and polyimide films, used as a substrate for their structures [5, 6]. As film-based sensors can bend along one axis, they can be attached to applications that are cylindrical. However, they are difficult to fit on any 3-dimensional arbitrary surfaces. To overcome these problems, J. Chen et al. proposed the use of a novel fabrication process that can produce an arbitrary bendable thin film structures that are similar to a fabric [7]. As this process involves the use of photolithography, it cannot be easily used to produce large (i.e., meter-sized) fabric structures. The sensor has to be enlarged to recognize human behaviors, as shown in Fig. 1.

We therefore propose an artificial hollow fiber structure as a new material for MEMS and applied this fiber to a fabric tactile sensor that detects a normal load [8]. This fiber was then made into a tensional force sensor, a sensor that has rarely been presented at a MEMS conference, with the goal of expanding the number of applications of fabric sensing devices and developing this field.

2. DESIGN AND PRINCIPLES

A schematic view of the fabric tensional force sensor and its detection mechanism are shown in Fig. 2(a). The surface of the hollow fiber is covered with thin metal and insulation layers. The fabric tactile sensor is formed by weaving the hollow fibers as shown in Fig. 2(a). The contact area at the intersection between warp and weft fibers is the part that senses force. As shown in Fig. 2(b), when a tensional force is applied to the end of the fabric tactile sensor, both the warp and weft fibers deform. As a result, the capacitance between them increases with applied force. The sensor can therefore be used to detect

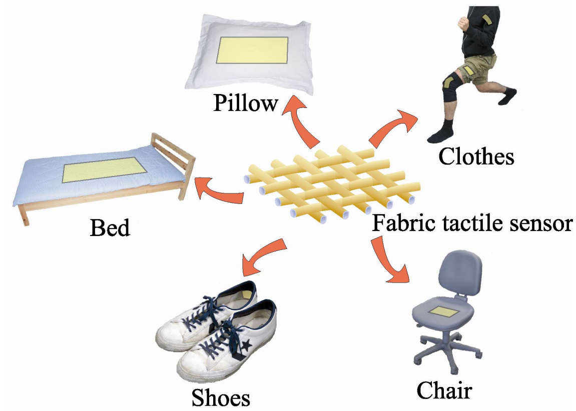

Fig. 1 Applications of a fabric tactile sensor.

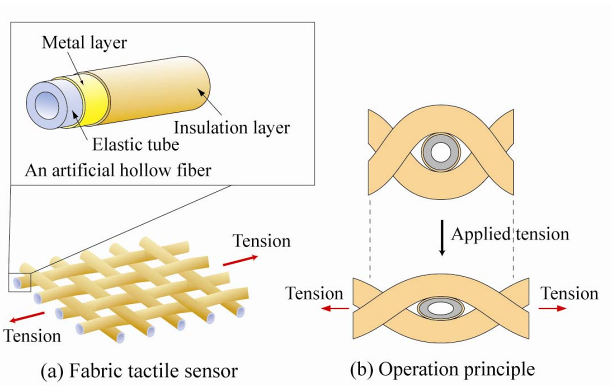

Fig. 2. Fabric sensor and its mechanism of detecting tension.

the tensional force by measuring the change of capacitance between the fibers.

3. FABRICATION

The fabrication of the sensor is shown in Fig. 3. We used commercially available tetrafluoroethylene-perfluoroalkylvinyl ether copolymer (PFA) tube as the elastic hollow fiber (Fig. 3(a)). Its external diameter and thickness were 0.3 and 0.1 mm, respectively, and it had a Young's modules of 28 MPa. To deposit Au film on the tube surface, we developed a rotating mechanism by which the PFA tube was rotated in a vacuum chamber during sputtering. The thickness of the deposited Au was 250 nm (Fig. 3(b)). The electrical wirings were then attached at the one end of the fiber by using silver paste, as shown in Fig. 3(c). We then evaporated 1.0-µm-thick parylene-C film on the surface as an insulating layer. Finally, the rectangular shaped fabric tension sensor was fabricated by weaving the hollow fibers and conventional cotton yarn (0.4 mm in diameter) manually(Fig. 3(d)). The total size was 57.0 x 4.0 mm, and the pitch of the warp was 3.5 mm. A single pair of the sensing fiber was knitted in the fabric sensor to evaluate the performance of the tensional force detection. A schematic

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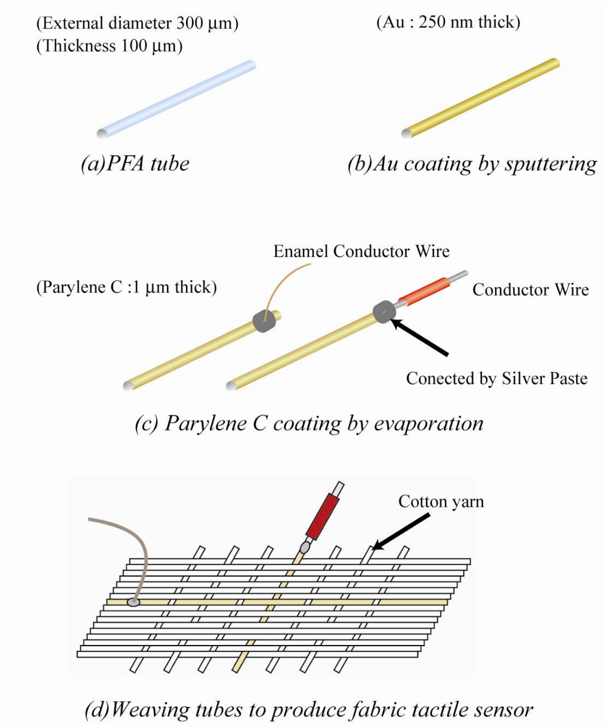

Fig. 3. Fabrication of fabric tactile sensor.

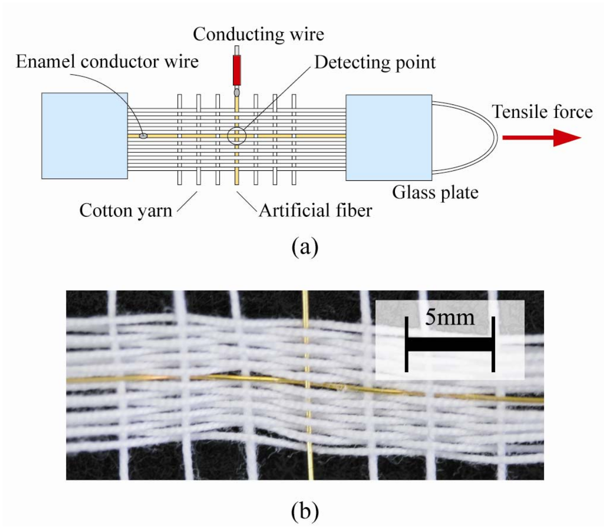

Fig. 4. Experimental device (a) Schematic (b) Photograph

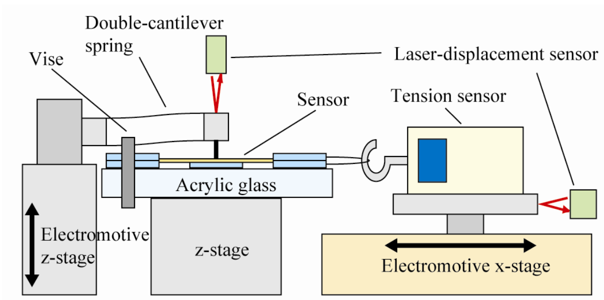

Fig. 5. Experimental setup for evaluating normal load, tension, and sensor output.

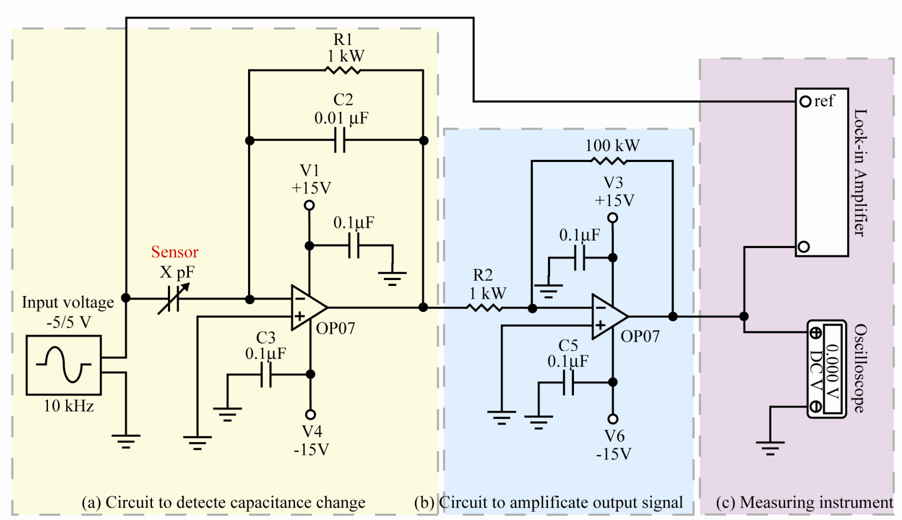

Fig. 6. Conventional CV circuit for evaluating sensor output.

view and a photograph of the fabricated fabric sensor are shown in Fig. 4. A 25-mm-square glass plate was attached at both end of the fabric to apply the tension.

4. RESULTS

The experimental setup and a detection circuit are shown in Figs. 5 and 6, respectively. The fabric sensor was placed on an acrylic plate in z-state, and one end of it was fixed on the plate. The other end was fixed on the head of the force sensor placed on the x-stage, and the tensional force was applied to the fabric sensor by automatically actuating the stage. The velocity of the movement of the x-stage was 0.30-1.35 mm/s. First, the capacitance value at the intersection between the warp and weft fibers was detected by the conventional CV circuit, and then it was synchronously-demodulated by a lock-in amplifier (Fig. 6). The signal of 10 kHz was used as the capacitance detection.

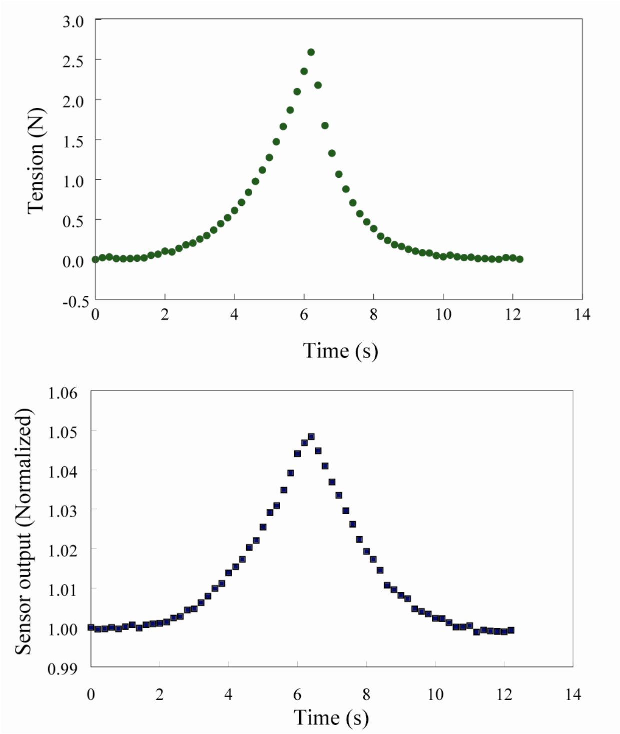

Fig. 7. Change of applied tension and sensor output with movement of x-stage.

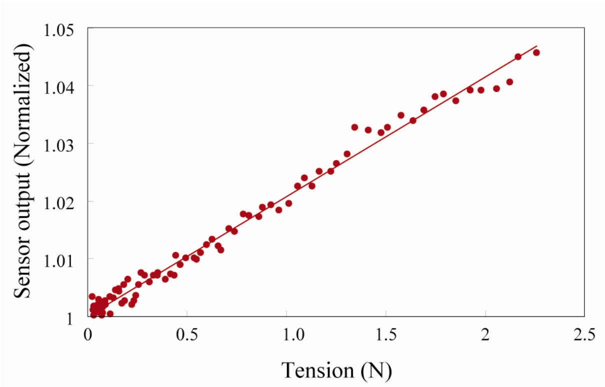

Fig. 8. Relationship between sensor output and applied tension.

Performance as Tensional Force Sensor

We first measured the changes of the applied tensional force and sensor output with the movement of x-stage, and the result was shown in Fig. 7. Both values were similarly changed with the back-and-forth motion of the x-stage. Therefore, we re-plotted the graph clearly showing the relationship between the applied tension and the sensor output (Fig. 8). The sensor output linearly increased with the tension. The increasing rate of the sensor output against the applied tension was 2.1 %/N, and the output changed 4.2 % when the applied tension was 2.0 N.

Influence of Pulling velocity

We also studied the influence of pulling velocity on the performance of the tension detection, and confirmed that it did not depend on the velocity in the range of 0.30-1.35 mm/s (Fig. 9).

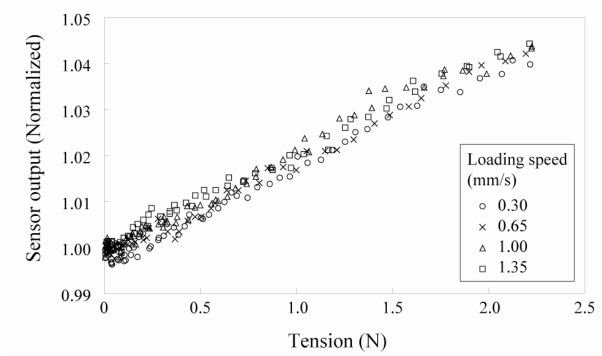

Fig. 9. of pulling speed on detecting tension.

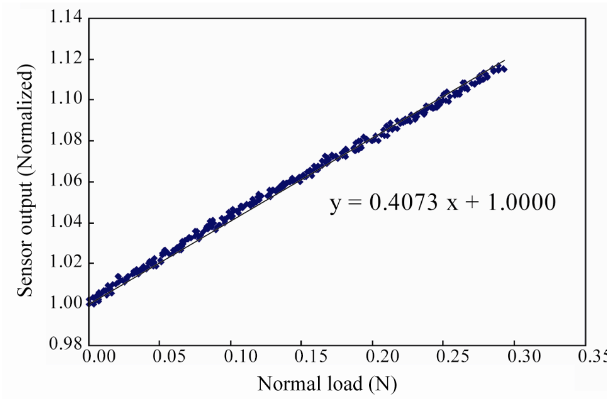

Fig. 10. Relationship between sensor output and applied normal load.

5. DISCUSSION

The fabric sensor stated above also has a high sensitivity to the normal force because, as described in Ref. 8, the fibers at the crossing point between the warp and the weft also deforms by the normal force. We therefore investigated the relationship between the applied normal force and the sensor output, and compared the sensitivity to both forces. The sensor output linearly increased with the increase of the normal load at the no-tensional force conditions (Fig. 10). The increasing rate of the sensor output against the applied normal load was 40.7 %/N. This result means that the sensitivity of the normal force was 20 times higher than that of the tensional force.

Therefore the fabric sensor has to be used for detecting the two forces as follows.

(1) Tensional force detection: As the sensor has a much high sensitivity to normal force, adding normal force should be avoided. The sensor detects tensional force with the sensitivity of 2.1 %/N.

(2) Normal force detection: We are able to ignore the small amount of the tensional force when we detected normal force. The sensor detects the normal force with the sensitivity of 40.7 %/N.

6. CONCLUSION

We developed a tensional force sensor by applying artificial PFA hollow fibers. We made the artificial fibers by depositing the thin metal and the insulation layer on the PFA tube, and the fabric sensor was obtained by weaving the tube and the conventional cotton yarns together. The total size was 57 x 4.0 mm.

The following results were obtained.

(1) The sensor output linearly increased with the increase of the tension. The increasing rate of the sensor output against the applied tension was 2.1 %/N.

(2) The increasing rate of the sensor output against the applied normal load was 40.7 %/N. This result means that the sensitivity of the normal force was 20 times higher than that of the tensional force.

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