A STUDY ON THE DETECTION PERFORMANCE OF MULTI-AXIAL DETECTION OF PVDF FIBER EMBEDDED SMART POLYMER STRUCTURES

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Abstract

In this study, the PVDF fiber embedded PDMS structure was developed as the flexible tactile sensor for detecting the multi-axial loads. Several methods to arrange the PVDF fibers in the PDMS were considered. Electric signals from PVDF fibers were measured with respect to the arrangement methods under multi axial loads. To investigate the performance of various designs of the PVDF fiber embedded PDMS structure, finite element analyses were conducted. Experimental results were also observed in the finite element analyses.

1. Introduction

The area of tactile sensing technology is a study about expression and measurement methods like human feel, and various studies and developments have been carried out along with robot technology. The early phase of tactile sensing technology focused on the magnitude determination of simple touch and impact while the recent studies expands the range of research into the technology approaching the actual human skin's roles: e.g. contact objects' roughness level, shape, or temperature [1-3]. In addition, studies on developing flexible tactile sensors similar to the actual human skin are carried out [4-6].

A variety of research on flexible tactile sensors that can simultaneously detect multi axis loads (vertical load and horizontal load) acting on the sensor has been carried out in the field of tactile sensor with a structure in which a sensor fiber was arranged in polymer matrix materials [7-8]. These sensors have a form in which sensor fiber such as piezoelectric sensor or optical fiber sensor was inserted in flexible materials such as silicon, polyester and PDMS.

For a tactile sensor using a piezoelectric sensor, the materials surrounding the sensor fiber by external load is deformed, so that the sensor fiber is also deformed. Deformation of the sensor fiber leads the change of the dipole arrangement in the sensor materials, and we can detect the load by measuring the voltage changes due to the dipole changes. So far, various studies on the tactile sensor with sensor fiber and matrix have been carried out [9-10]. But there are insufficient technical data on the signal characteristics of the sensor according to the arrangement of the inserted piezoelectric fiber, and detection and analysis of a multi axis load.

Accordingly, this study attempts to analyze the signal characteristics of a sensor for a multi axis load using piezoelectric fiber and conduct an analysis of the characteristics of the signal measured according to the arrangement of sensor fibers.

2. Materials and structures of flexible tactile sensor

Polyvinylidene fluoride (PVDF) film (Product name, Manufacturer, Country) was used for fabricating the sensor fiber by cutting film into the narrow strip with 2mm width. . The tactile sensing structure for measuring a multi axis load was manufactured by arranging sensor fibers into Polydimethylsiloxane (PDMS) (Product name, Manufacturer, Country). PVDF has the biggest dielectric constant among polymer materials, excellent flexibility and impact resistance. PMDS has many advantages such as excellent processibility, durability and flexibility. So PVDF fibers embedded PDMS structures can be a good flexible tactile sensor.
The mechanical properties and characteristics of the PDMS and PVDF film used in this study are shown in Table 1.

	Piezoelectric constant (pC/N)			Tensile Modulus [GPa]	Tensile Strength [MPa]
PVDF	d_{31}	d_{32}	d_{33}		
	22	2	35	3.0~3.2	11.7~14.1
PDMS		-		0.36~0.87	2.24

Table 1. Mechanical properties of PDMS and PVDF Film.

3. Optimization of the sensor arrangement by finite element analyses

When the uniaxial load applies on the sensor, it can be easily discerned by experimentally analyzing the load - signal relationships. However, when the sensor is under multi-axis loads, then it is not easy to discern each loads with signal characteristics of one sensor. In this case, we have to compare the several sensor signal characteristics arranged at regular intervals to analyze the load - signal relationships, and therefore the shape of arrangement within the sensor becomes an important factor.
As such, in this study we compared the sensor's sensitivity with respect to the types of the arrangement under a multi-axis load, and optimized the sensor's arrangement in order to find the arrangement with an easy signal separation. For this process, commercial software (ABAQUS 6.10, Dassault Systemes Simulia Corp., USA) was used.
Figure 1 shows the finite element model of the tactile sensing structure and loading jig. The tactile sensing structure with the cross arrangement of sensor fibers was modeled as shown in Figure 1(a). To apply the multi-axis load, the tip of the loading jig was modeled and the contact interaction condition was assigned between the bottom surface of the tip and the upper surface of the tactile sensing structure in Figure 1(b). The vertical and horizontal forces were applied as the pressure on the top surface of the tip and frictional forces between the tip and the tactile sensing structures, respectively, for the multi-axis load.
Figure 2 shows the modeling of 5 different arrangement of sensor fibers considered in this study. A and C are the horizontally arranged horizontal structural shapes of the upper part sensor and the lower part sensor, B and D are the structural shapes of the upper part sensor and lower part sensor crossed in arrangement. Lastly, E shape shows the mixed arrangement structure when the upper part and the lower part are horizontally and vertically arranged. PVDF sensor was interpreted with the film type and the fiber type divided.

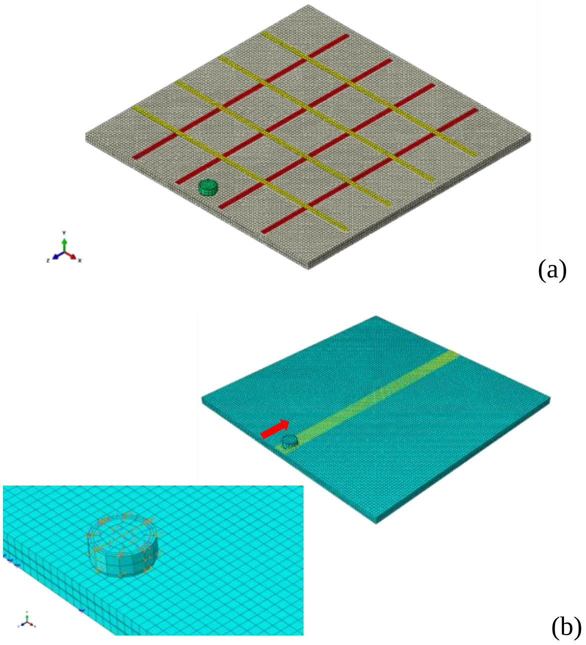


Figure 1. Finite element model of (a) smart skin (b) the smart skin for optimize the sensor arrangement.

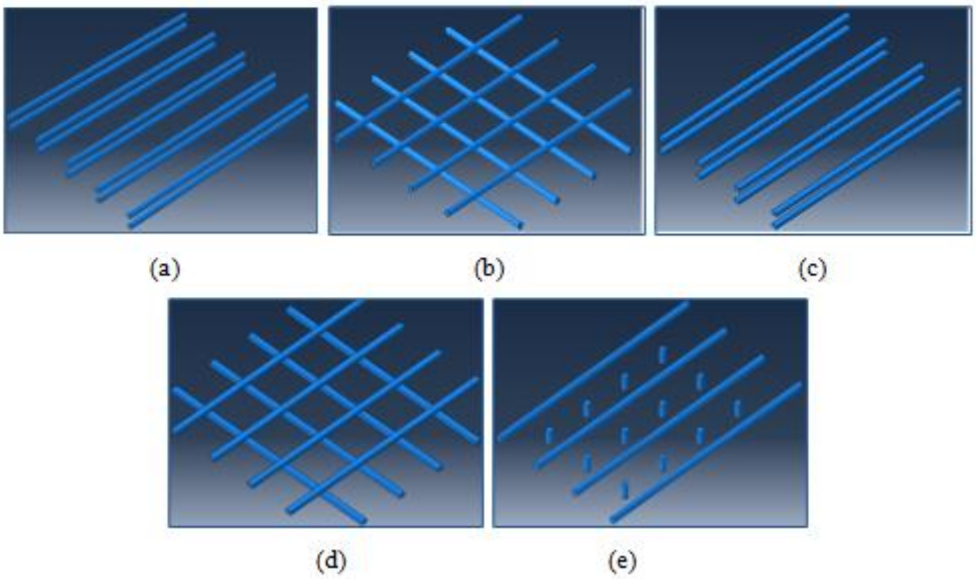


Figure 2. Considered arrangement of sensor fibers: (a) parallel arrangement with circular fibers, (b) cross –wise arrangement with circular fibers, (c) parallel arrangement with rectangular fibers, (d) cross –wise arrangement with rectangular fibers, (e) parallel and perpendicular arrangement with circular fibers.

Figure 3 is a representative graph to show the signal shape when the experiment process is simulated. The contact part passes above the each sensor as it moves in the horizontal direction, when momentarily at each sensor the maximum charge signal is brought about. The characteristics of sensor signals are shown differently in the upper and the lower arrangement. Based on such characteristics, we compared 5 different arrangements with the maximum output value, sensitivities to each load of the upper and lower arrangement. Table 2 shows comparison results with respect to the sensor arrangement.

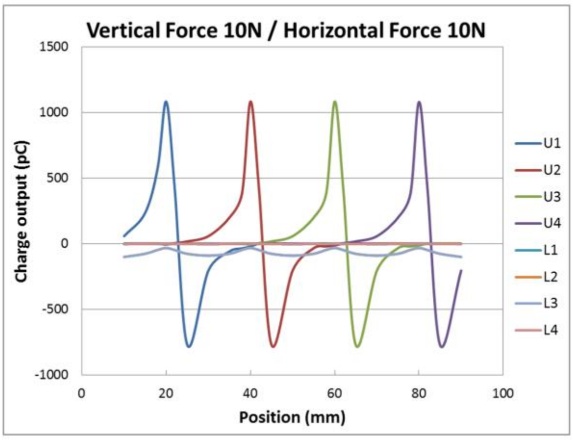


Figure 3. Sensor output of the cross-wise arrangement under 10N of the vertical load and 10N of the horizontal load.

	Max. output(pC)	Load type	Sensitivity(pC/N) Upper PVDF sensors	Sensitivity(pC/N) lower PVDF sensors
A	945	Vertical load	20	3
		Horizontal load	44	1
B	945	Vertical load	20	15
		Horizontal load	44	1
C	1083	Vertical load	37	7
		Horizontal load	90	2
D	1083	Vertical load	37	30
		Horizontal load	90	0.5
E	1320	Vertical load	71	38
		Horizontal load	58	1

Table 2. Maximum output, sensitivities of upper PVDF sensors, and lower PVDF sensors against the vertical load and the horizontal load with respect to the sensor arrangement.

The maximum output values are observed in the arrangements E and C. Also, we can see there is a clear difference between the upper and the lower arrangement in the sensitivity according to the vertical load and the horizontal load. In the upper arrangement, it is influenced by both the vertical load and the horizontal load; whereas in the lower arrangement, the sensitivity shows almost zero with the horizontal load. This result can help the determination of the vertical load with the signal of the lower arrangement, and then figure out the horizontal load with the signal of the upper arrangement, and ultimately separate the multi-axis load easily.

34. Verification of FEM results

In the above finite element analyses, E model shows the best performance and also allows the separation of the vertical and the horizontal loads. However, this can cause difficulty in the real manufacturing process, and therefore, we selected C arrangement, which showed relatively good performance, to conduct the experiment.
In the experiment, vertical and horizontal forces were applied as the gravity of the weight on the loading jig and the friction forces. The experiment variables were analyzed on the signal

characteristic of the PVDF sensor according to the magnitude of vertical and horizontal load.

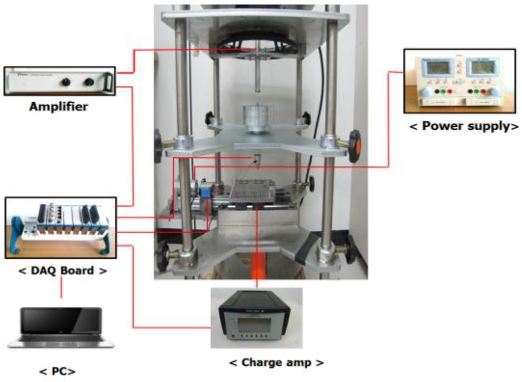


Figure 4. Photographs of testing equipment

Figure 5, which depicts the typical signals measured with the sensor fibers, has similar shape and characteristics with the FEM results in Figure 3. As the loading jig passes above the sensor, the signal was maximum, and the signal characteristics were shown differently in the upper and lower arrangement.

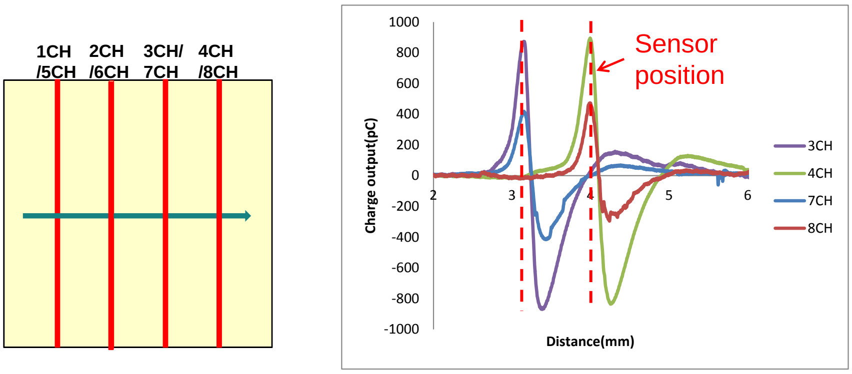
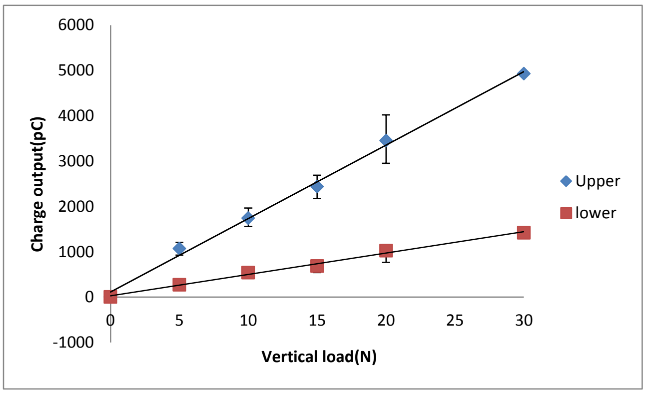
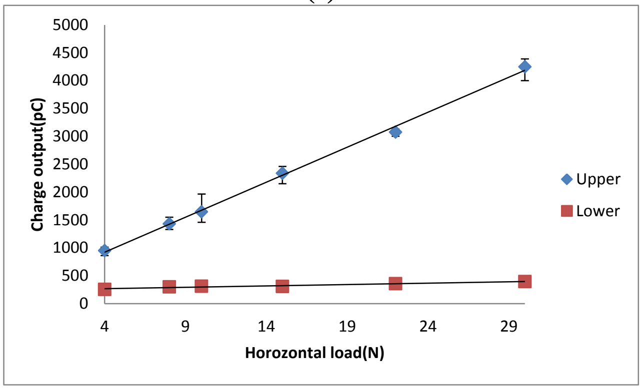


Figure 5. Configuration of multi-axial loading experiments

Figure 6 shows the maximum signal of the upper and lower arrangement with respect to the magnitude of the vertical and horizontal load. As shown in Figure 6(a), the output value of the upper and the lower arrangement linearly increased when the vertical load increased. However, as in Figure 6(b), when the horizontal load was increased, the output value of the upper arrangement linearly increased but the lower arrangement didn't have a significant change. This result is similar to the FEM result in Table 2, meaning that the FEM results corresponded with the experiment result.



(a)



(b)

Figure 6. (a) Vertical load (b) Horizontal load increases the magnitude of the signal to measured

Conclusion

This study used PVDF's piezoelectric characteristics in order to develop the tactile sensor that allows the load measurement in multi axis, and analyzed the generating signal characteristics with respect to the sensor arrangement by the finite element analysis. The result showed that the horizontal – vertical arrangement in the arrangement structure showed the best performance. However, due to the difficulty in the manufacturing process, the next good horizontal – horizontal arrangement was selected. The selected arrangement was made into the test specimen to conduct the experiment verification.

In the upper arrangement, both the vertical and horizontal loads influenced on the sensor signal, while in the lower arrangement, the horizontal load hardly influenced. This corresponds with the FEM result, through which we concluded that the vertical loads can be determined with the signal of the lower arrangement, and the horizontal load with the signal of the upper arrangement.

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References

[1] P. Dario and G. Buttazzo. An anthropomorphic robot finger for inverting artificial tactile perception. *The international journal of robotics research*, volume. 6(no. 3):25-48.1987 .

[2] M. H. Lee and H. R. Nicholls. Review article tactile sensing for mechatronics – a state of the art survey. *Mechatronics*, volume. 9(no. 1):1-31. 1999.

[3] H. Y. Hwang. Piezoelectric particle-reinforced polyurethane for tactile sensing robot skin. *Mechanics of composite materials,* volume. 47(no. 1):137-144. 2011.

[4] J. H. Kim, J. I. Lee, H. J. Lee, Y. K. Park, M. S. Kim and D. I. Kang. Development of tactile sensor and its application. *Journal of the Korean society of precision engineering,* volume. 21(no. 9):20-25. 2004.

[5] A. Kimoto, N. Sugitani and S. Fujisaki. A multifunctional tactile sensor based on PVDF film for identification of materials. *Browse journals & magazines,* volume. 10(no. 9):1508-1513. 2010.

[6] S. Omata , S. Murayama and C. E. Constantinou. Real time robotic tactile sensor system for the determination of the physical properties of biomaterials. *Sensors and Actuators A,* volume. 112(no. 2-3):278-285. 2004.

[7] R. R. Reston, Kolesar and S. Edward. Robotic tactile sensor array fabricated from a piezoelectric polyvinylidene fluoride. *Aerospace and electronics conference,* volume. 3:1139-1144. 1990

[8] B. J. Choi, S. C and H. R. Choi. Development of tactile sensor for detecting contact force and slip. *The Korean society of mechanical engineers*, volume. 30(no. 4):364-372. 2006

[9] Y. R. Wang, J. M. Zheng, G. Y. Ren, P. H. Zhang and C. Xu. A flexible piezoelectric force sensor based on PVDF fabrics. *Smart Materials and Structures*, Volume. 20(number. 4): 2011.

[10] S. K. Hwang, O. M. Kwon, H. Y. Hwang, A Signal Analysis of Sensor Structure for Measuring Multi-axis Forces Using Piezoelectric Fibers, *The Korean society of mechanical engineers*, 59-60. 2013.