Design of the Tactile Sensor Element Using Microbending Optical Fiber Sensors

Jin-Seok Heo
Dept. of Mechanical Engineering
Korea Advanced Institute of Science and Technology,
Daejon, Korea 305-701
dandyheo3070@kaist.ac.kr

Cheol-Hee Han
Dept. of Mechanical Engineering
Korea Advanced Institute of Science and Technology,
Daejon, Korea 305-701
rapha012@kaist.ac.kr

Jung-Ju Lee
Dept. of Mechanical Engineering
Korea Advanced Institute of Science and Technology,
Daejon, Korea 305-701
leejungju@mail.kaist.ac.kr

Abstract

This paper describes the taxel for the flexible tactile sensor using the microbending optical fiber sensor. This sensor utilizes the microbending of the optical fiber which drives the light loss from the optical fiber. And the structure of this taxel with the optical fiber embedded in the silicone rubber is very simple: once the external force is loaded on the contact mesa of this taxel, the optical fiber experiences the microbending which makes the light loss, and then, the intensity of the transmitted light is decreased. Therefore, detecting this intensity change of the transmitted light, the external uniaxial force can be calculated. Compared with the other optical fiber sensor system, this sensor system can be easily evaluated using simple optical measuring system. Moreover, as the sense of touch of this taxel is similar to that of the human skin, it can be applied the intelligent robot system to the artificial skin.

1. Introduction

Sensory information of human skin for feeling some materials and determining many of their physical properties is provided by sensors in the skin. This tactile information is a kind of sense of touch that is one of the five senses including the sense of sight, hearing, smell and taste. Nowadays, many researchers try to apply the five senses to the intelligent robot system. Especially, many kinds of the tactile sensor combined small force sensors are introduced for intelligent robots, teleoperational manipulators and haptic interfaces. These tactile sensors which are able to detect the contact force, the vibration, the texture and the temperature can be recognized as the next generation information collection system.

Some tactile sensors using the MEMS(Micro Electric-Mechanical System) technology have been introduced[1-4]. Although these sensors have a good spatial resolution, they remain some problems to apply the practical system: they are not enough flexible to attach the curved surface and the more elements of sensor connect, the more wires they need. Therefore, in this paper, we will show the flexible uniaxial force sensor can be used the flexible optical fiber tactile sensor that can be easily applied to the curved surface minimizing the wiring.

2. The Structure of the Taxel

2.1 The Basic Principle of the Taxel

In general case, there is little light loss when the optical fiber is bended with a large radius of curvature. However, as shown in Fig.1, the conspicuous light loss is happened at the microbending of the optical fiber with the small radius of curvature. Although this microbending light loss is not effective to the optical communication, this can be utilized as the optical fiber sensor.

To be concrete, using this microbending loss, the environment change can be detected. This kind of sensor is called the microbending optical fiber sensor which is a sort of the intensity based optical fiber sensor. As this intensity based optical fiber sensor uses the light intensity change at the light detector, the optical measurement system of this type of sensor is composed of a simple light source and a light detector which cost too little.

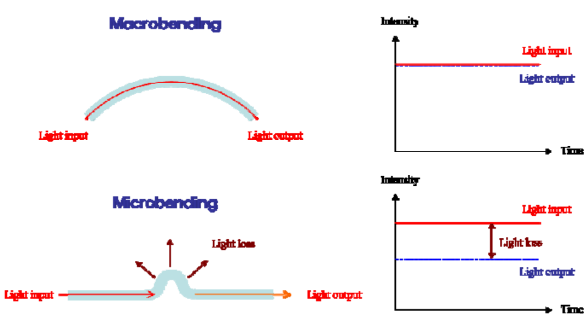

Fig.1 Microbending effect of the optical fiber.

2.2 The Structure of Taxel and the Tactile Sensor

In general case of small force sensor, the periodic zigzag transducer which can be easily microbended by the applied force is mostly used. But, this zigzag type transducer can be occupied large area considering the size of the optical fiber. Therefore, the minimizing the size of the transducer must be needed. In this study, we propose the cross fiber structure which is embedded in the silicone rubber such as Fig. 2. Once the contact force is applied to the contact mesa, the upper optical fiber and the lower optical fiber are microbended simultaneously by the change of the inner stress of the silicone rubber. Using this phenomena, we can extend the tactile sensor with the fabric structure of the optical fibers embedded in the silicone rubber like Fig. 3.

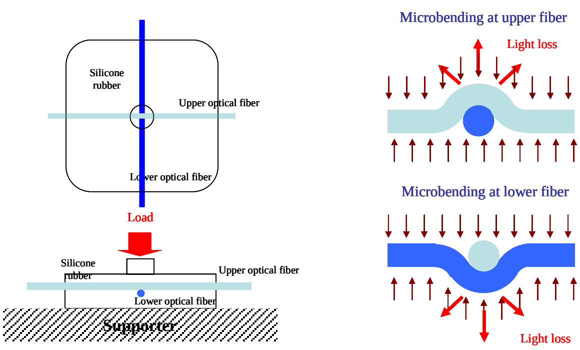

Fig. 2 Structure of the taxel using the microbending effect of the optical fibers.

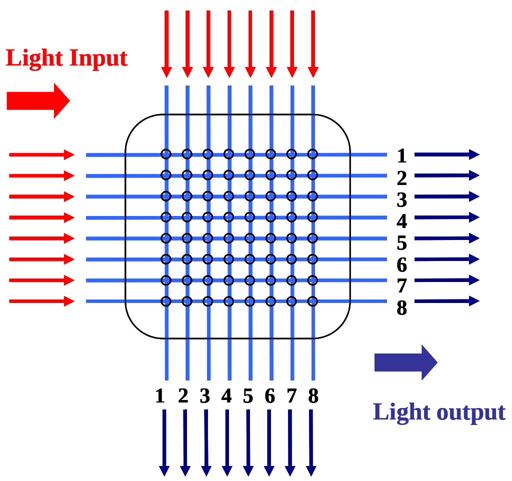

Fig. 3 Structure of the tactile sensor using the microbending effect of the optical fibers.

If the some area is contacted by some material, the contacted mesas make the microbending of the optical fibers in the silicone rubber which decreases the output of the light intensity of optical fiber. The numbers of the optical fiber contains the position of the contact area, and the light intensity informs the change of the contact force. Therefore, using this structure, the distributed contact force can be measured.

3. Fabrication of the Taxel

First of all, the dimension of this flexible force sensor must be decided. As this sensor will be applied to the tactile sensor system, the thinner we fabricate this sensor, the better we can apply it for the artificial skin. In this study, we decide the depth of this sensor to be 2mm by trial and error. 2mm depth can fix the optical fiber without the exposure of the optical fiber from the silicone rubber. The fabricate process is very simple as shown in Fig. 4. At first, a molding frame which can make the shape of the taxel must be prepared. And the optical fiber is aligned under the contact mesa position. Next, liquid silicone rubber is poured to the molding frame to the depth of the taxel. After cured the silicone rubber, the flexible taxel can be made removing the molding frame.

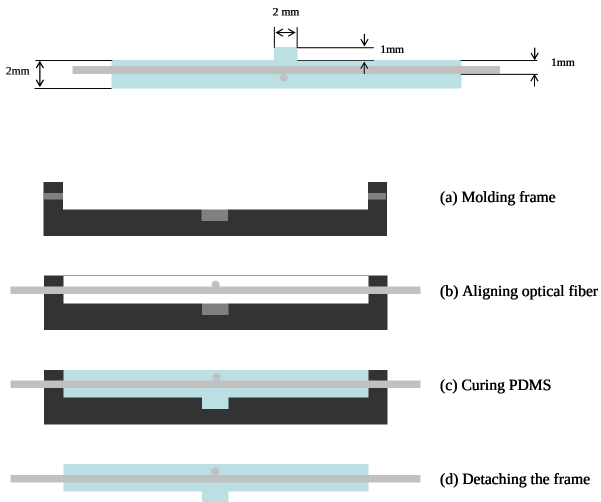

Fig. 3 Dimension of the taxel and its fabrication.

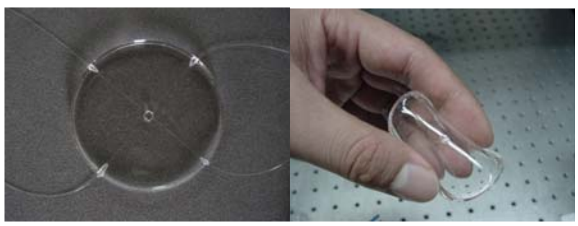

Fig. 4 Fabricated prototype taxel.

The fabricated prototype taxel is shown in Fig. 4. The prototype taxel is so flexible for the silicone rubber transducer that it can apply for the artificial skin for the intelligent robot system.

4. Evaluation of the taxel

The fabricated prototype taxel is calibrated by the verified experimental equipments composed of a uniaxial loadcell and a fatigue test system for small load as show in Fig. 5.

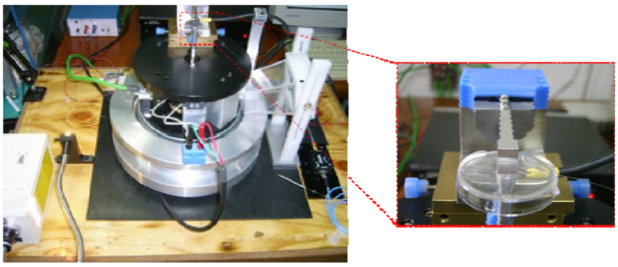

Fig. 5 Experimental setup for the evaluation of the taxel.

as shown in Fig. 6. A power LED(Light emitted diode) is used as the light source of this sensor, and a CCD(charge coupled device) plays a role of the light detector of this sensor system. Using the CCD as the light intensity detector, the intensity changes of each optical fiber can be measured when we apply this taxel for the tactile sensor. This means that a CCD makes it possible to minimize the optical measurement system. And we use the gray scale value from the output signal of CCD to evaluate the light intensity of the optical fiber.

The output signal of this prototype taxel is shown in Fig. 7. The light intensity of this taxel is decreased for its microbending loss as the contact load is increased. The sensitivity of this sensor is -20 gray scale value / N and the resolution of this prototype sensor is 0.05N. The calibration process is very simple. By multiplying the sensitivity to the light intensity change, we can calculate the applied contact force as shown in Fig. 8.

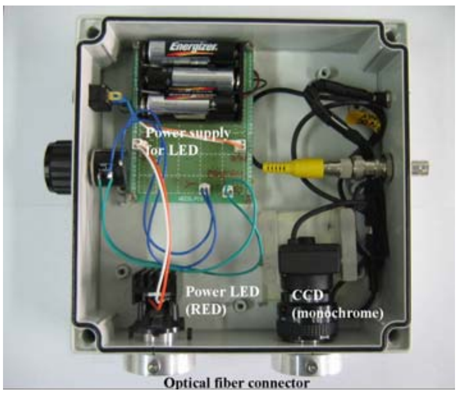

Fig. 6 Optical system of this tactile sensor system.

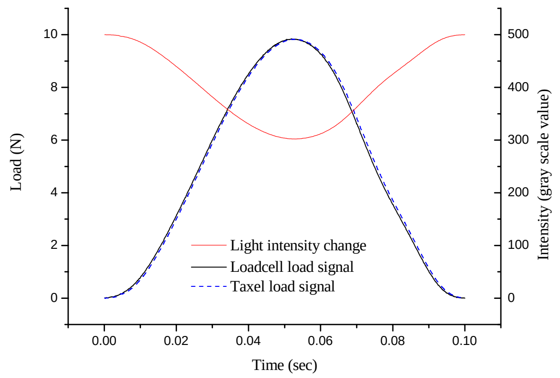

Fig. 8 Calibration of this prototype taxel.

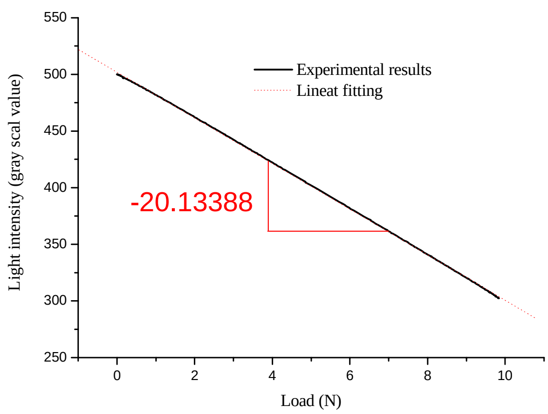

Fig. 7 Experimental verification of the prototype taxel.

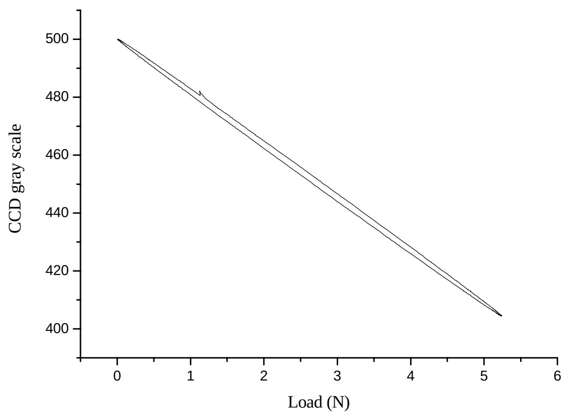

Fig. 9 Hysteresis of the prototype taxel.

As mentioned above, the optical system is very simple

And the hysteresis error of this sensor is about 6.3%

such as Fig. 9. This hysteresis error results in the characteristic of the silicone rubber which is the material of its transducer. And the error of repeatability is about 2%.

Next, we verified the maximum capacity of this prototype sensor. As shown in Fig. 10, the linearity between the light intensity change and the applied load is broken after 17N is applied. This non-linearity can be estimated as the abrupt stress change of the silicone rubber by the insertion of the contact mesa in Fig. 11. Therefore, the maximum capacity of this sensor is 17N which the linear response of the light intensity guarantees.

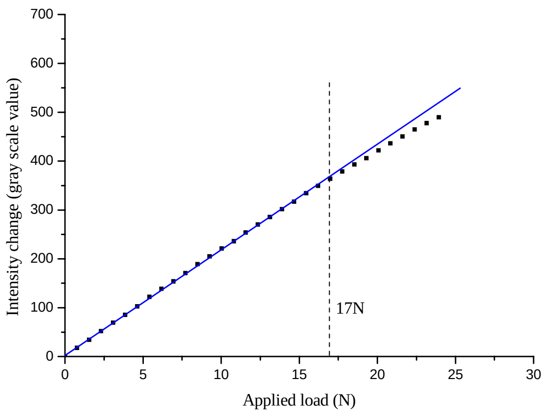

Fig. 10 Non-linear change of the light intensity by the applied contact load.

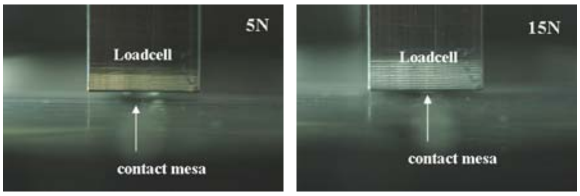

Fig. 11 Insertion of the contact mesa after 15N

5. Conclusion

In this paper, the force sensor using microbending light loss for the tactile sensor is newly designed and experimentally verified. The structure of this sensor with the crossed optical fiber embedded in the silicone rubber and the optical system which is composed of a simple power LED and CCD chip are very simple. The linear light intensity change by the applied load is verified by the experimental results. And this prototype sensor has a good performance: the resolution of this sensor is 0.05N for its maximum capacitance 17N. However, a little hysteresis error exists for the material of its transducer, silicone rubber. This prototype sensor is sufficient for its application of the artificial skin which includes the tactile sensor.

Acknowledgement

This research (paper) was performed for the Intelligent Robotics Development Program, one of the 21st Century Frontier R&D Programs funded by the Ministry of Commerce, Industry and Energy of Korea.

Reference

[1] T. Mei, W. J. Li, Y. Ge, Y. Chen, L. Ni and M. H. Chan, “An integrated MEMS three dimensional tactile sensor with large force range”, Sensors and Actuators (A), Vol. 80, pp155-162, 2000

[2] M. J. Yoon, K. H. Yu, G. Y. Jeong, S. C. Lee and T. G. Kwon, “Development of a Distributed Flexible Tactile Sensor System”, J. of KSPE, Vol. 19, No. 1, pp. 212~218, 2002

[3] N. Futai, N, Futai, K. Matsumoto and I. Shimoyama, “A flexible micromachined planar spiral inductor for use as an artificial tactile mechanoreceptor”, Sensors and Actuators (A), vol. 111, pp293~303, 2004

[4] U. Paschen, M. Leineweber, J. Amelung, M. Schmidt and G. Zimmer, “A novel tactile sensor system for heavy-load applications based on an integrated capacitive pressure sensor”, Sensors and Actuators (A), vol. 68, pp294~298, 1998