The Seventeenth International Symposium on Artificial Life and Robotics 2012 (AROB 17th '12),
B-Con Plaza, Beppu, Oita, Japan, January 19-21, 2012

Development of tactile sensing system and evaluation for the application to the intelligent robot using the microbending fiber optic sensors

Ju-Won Jeong[1], Heo-Jin Seok[2] Jung-Ju Lee[3]

[1, 3] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea
(Tel: 82-42-350-3033, Fax: 82-42-350-3210)
[2]Samsung Electronics company, San #16, Banwol-dong, Hwasung-city, Gyeonggi-do, 445-701 Korea

[3]*leejungju@kaist.ac.kr*

Abstract: This paper describes the system design and the structural design to evaluate the tactile sensor using the microbending fiber optic (MBFO) sensors. The small light emitted diode (LED) and charge coupled device (CCD) are used as a single light source and a light detector for the bundle of optical fibers respectively. And the structure of this type tactile sensor which is composed of crossed fibers in the silicone rubber is very simple. And the tactile sensor element using MBFO sensor is fabricated and the performance of this sensor is evaluated.

Keywords: 3-6 key words or phrases in alphabetical order, separated by commas.

1 INTRODUCTION

The tactile sensor is one of the essential means for interfacing between human and robots [1]. Some tactile sensors using the MEMS(Micro Electro Mechanical System) technology have been introduced [2-5]. Even though these sensors have several merits such as their small size, good spatial resolution, and so on, they still have some problems to apply the practical system: they don't have enough flexibility to attach on the curved surface and the more elements of sensor are connected, the more wires they need. To mimic human skin, a new design for a tactile sensor array that uses optical fiber both as sensing elements and as signal-transmission media is tried. Heo, Cheong and Lee [6] introduced an optical fiber tactile sensor using fiber Bragg grating sensors embedded in silicone rubber, which to a degree mimics the feeling of human skin. This type of tactile sensor has simple wiring for application of the wavelength division multiplexing method with a broadband light source and some fiber Bragg gratings, which have different Bragg wavelength in a given optical fiber. Nevertheless, the optical system, especially the broadband light source, is too expensive to be applied to a practical system. Therefore, in this paper, we designed the flexible tactile sensor using microbending optical fiber sensor with the structure of crossed fibers in the silicone rubber. And, we designed the tactile sensor system using a single light source and a detector for the bundle of optical fibers which are not expensive.

2 STRUCTURE AND SYSTEM OF THE TACTILE SENSOR

2.1 Structure of the tactile sensor

Using the taxel of this study, we designed the tactile sensor with the fabric structure of the optical fibers embedded in the silicone rubber like Fig. 1.

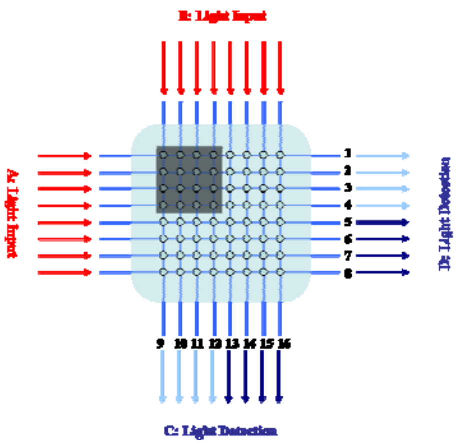


Fig. 1. Schematics of the tactile sensor using microbending optical fiber sensors with the fabric structure

If the some area is contacted by a wide material, the contact mesas make the microbending on 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 information of the contact area, and the light intensity informs the change of the contact force. Hence, using this structure, the point contact load and distributed contact load can be measured.

The input light is incident to the optical fibers, which are located on sides A and B in Fig. 1. The output light is transmitted through optical fibers of sides C and D. If some area is pressed, as in Fig. 1, the intensities of the output light from the optical fibers, which are related to the pressed area, are decreased by the microbending loss. Based on the intensity changes and positions of the optical fibers, the quantity and the position of the applied force can be calculated at each taxel. And Fig. 2 shows the fabricated prototype tactile sensor using the microbending fiber optic sensors and its flexibility.

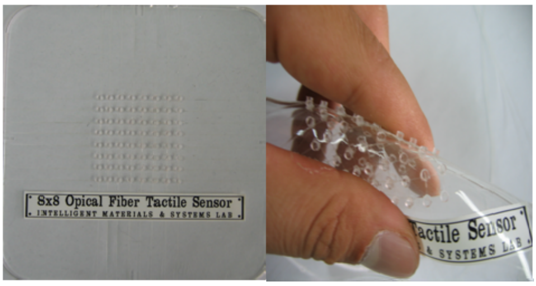


Fig. 2. Fabricated prototype tactile sensors and its flexibility.

2.2. Tactile sensor system

The Fig. 3 indicates the concept of the optical measurement system for the tactile sensor system using microbending optical fiber sensors. The wider distributed tactile sensor we fabricate, the more optical fibers are needed. To solve this problem, we use the optical fiber bundle as shown in Fig. 3. Many optical fibers can be united as one optical fiber bundle. Hence, using the optical fiber bundle, many fibers can be handled as one line.

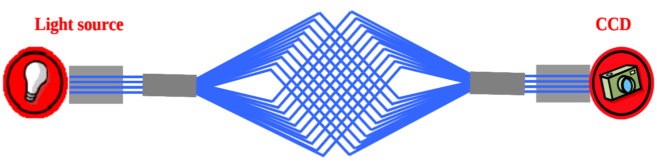


Fig. 3. Schematics for the tactile sensor system

As mentioned before, the optical measurement system of the intensity based optical fiber sensor is composed of a simple light source and a light detector. In this study, a small power LED(Light Emitted Diode) is used as the light source and a CCD(Charge Coupled Device) module is used for the light detector of this sensor system. The intensity changes of each optical fiber can be measured at once by the CCD module. This means that a CCD module makes the optical measurement system minimized. When the light intensity of the optical fiber is changed by contact force, the light intensity is evaluated from the output signal of the CCD. The gray scale value from the output signal of the CCD expresses the light intensity change of the optical fiber.

2.3. Light detection of multiple fibers using CCD

Using the prototype sensors, we can design artificial skin including the fabric-structured microbending optical fiber tactile sensors, as shown in Fig. 4. The fabric structure allows the implementation of simple and well arranged wiring. In addition, the fiber-cross area plays the role of a microbender, inducing light loss via perpendicular contact force.

Although this tactile type sensor needs many optical fibers compared with a FBG tactile sensor [6], they can be arranged as a bundle of optical fibers. In a general case, one light detector is used at one optical fiber when light intensity is measured. Thus, numerous detectors are required when the tactile sensor array is evaluated. However, by using a CCD as a light intensity detector, the intensity changes of all optical fibers can be measured at once. Thus, the CCD makes it possible to minimize the number of the optical measurement system and detect multiple light intensity changes from the optical fiber bundle.

In order to realize accurate and reliable measurement, a connector to a CCD must be designed to make intensities from all optical fibers similar at the same light input. An aligner, which is the main part of the connector, consists of four V-grooved plates to align the optical fibers on a plate a nd four dummy plates so that the space will not interfere with the neighboring lights, as illustrated in Fig. 4. The V-grooved plates and dummy plates are made of Si wafer and are fabricated by a wet etching process.

Using the plastic molding, the connector body can be made. Finally, the end of the connector needs to be polished to align all fibers on the bottom plate. Fig. 5 shows the fabricated fiber bundle connectors to align the optical fibers to the CCD.

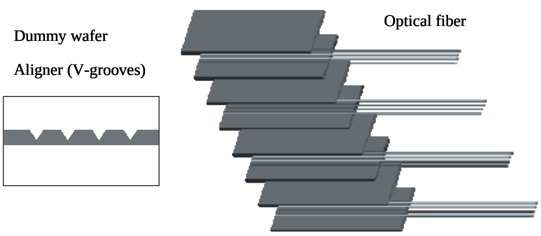
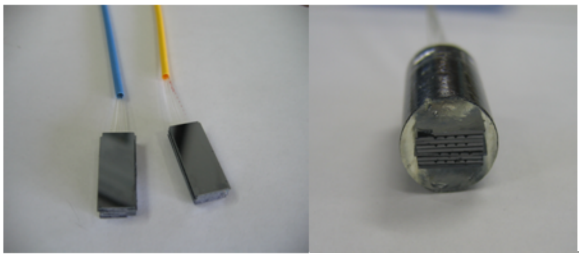


Fig. 4. Structure of the aligner



(a) (b)

Fig. 5. Fiber bundle connector: (a) fabricated aligner, and (b) connector

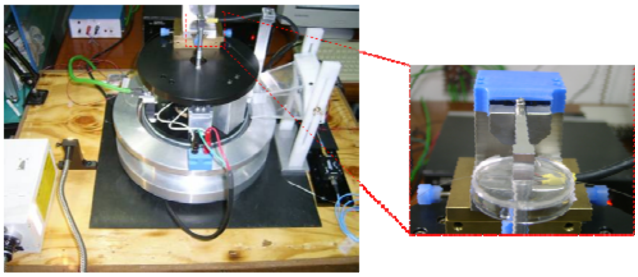


Fig. 6. Experimental setup for the evaluation of the taxel.

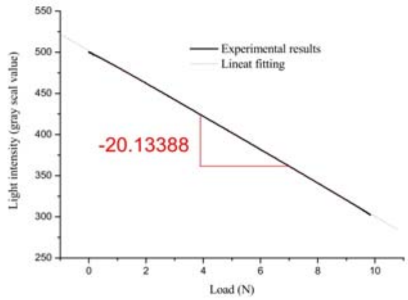


Fig. 7. Experimental verification of the prototype taxel.

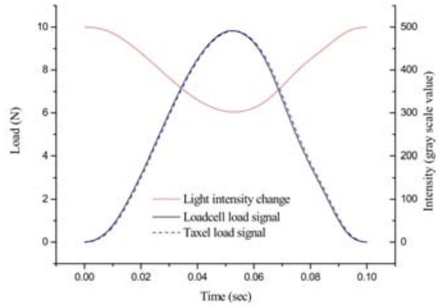


Fig. 8. Calibration of this prototype taxel.

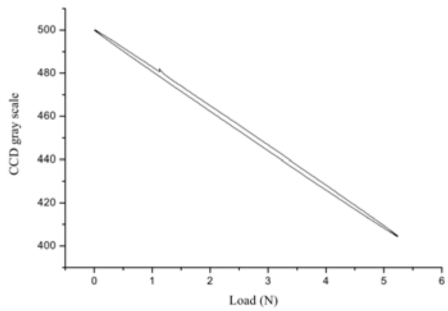


Fig. 9. Hysteresis of the prototype taxel.

3 EXPERIMENTAL RESULTS

3.1. Evaluation of the tactile sensor element

The fabricated prototype taxel is evaluated by the verified experimental equipments composed of a uniaxial load-cell and a fatigue test system for small load as shown in Fig. 6.

This main device applies perpendicular load to the taxel which is placed on the top of this device. So, when the perpendicular load is applied to the taxel, the light intensity of the optical fiber is changed because of the low of action and reaction between the taxel and the load-cell. Also the load-cell detects the load. Therefore, through comparing the light intensity change of the optical fiber with load-cell load signal, the load information which is applied on the taxel is obtained.

The output signal of this prototype taxel is shown in Fig. 7. The light intensity of this taxel is decreased for its microbending light 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. And the exact load amount which is applied on the taxel is obtained by calibrating the sensitivity of the taxel.

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. And the hysteresis error of this sensor is about 6.3% as shown in Fig. 9. This hysteresis error is caused by the characteristic of the silicone rubber which is the material of its transducer because the characteristic of silicone rubber is nonlinear. And the error of repeatability is about 2%.

Next, we verified the maximum capacity of this prototype taxel. The linearity between the light intensity change and the applied load is broken after 15N is applied. This phenomenon can be estimated as the abrupt stress change of the silicone rubber by the insertion of sensor is 15N which the linear response of the light intensity guarantees.

3.2. Evaluation of the connector for the tactile sensor

To check the performance of the connector, the intensities changes from 16 optical fibers included in a bundle were tested, the results of which are graphically displayed in Fig. 10.

A single light input is incident to a bundle of 16 optical fibers and the light intensities measured from the output signal of the CCD. All light intensities indicate an approximately 500 gray scale value, and the difference between the maximum intensity value and the minimum inten sity value is about a 10 gray scale value. This indicates that all fibers in a bundle are well arranged and aligned to measure the light intensities changes. Point load and distributed load tests are conducted to check the proper output load from the fabricated tactile sensors. When a point load of 1.8N was applied to the pixel (6, 3) in the 5mm spatial resolution tactile array sensor, approximately 1.8N is indicated from the change of light intensity. When 5N is applied to nine taxels, as illustrated in Figure 12, each taxel that is pressed by the weight displays about 0.5×0.6 N. The small deviation of mesa depth and the relatively long spatial resolution result in differences in the output load from the taxels. A 8×8 tactile array sensors are fabricated using a molding process, as mentioned with regard to taxel fabrication. From the evaluation process, we confirmed that fabricated artificial skin by using microbending optical fiber sensor system showed us good performance during the demonstration for verification as shown Fig. 11.

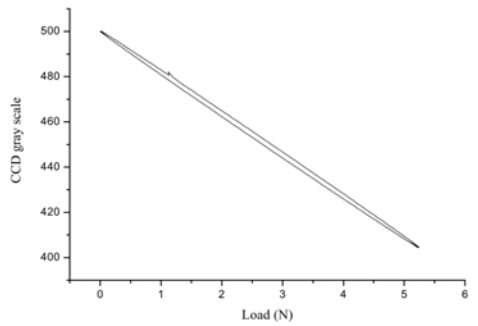
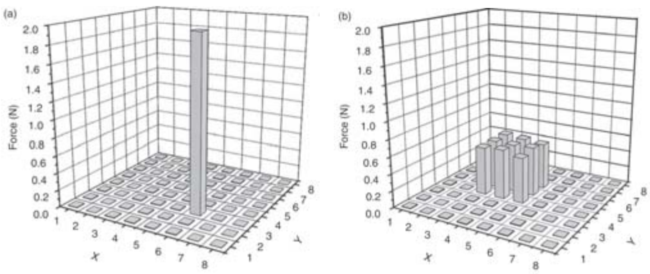


Fig. 10. Intensity change detection using CCD



(a) (b)

Fig. 11. Experimental results of the tactile sensor (spatial resolution = 5mm): (a) point load detection, and (b) distributed load detection

4 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 fibers embedded in the silicone rubber is 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 and its maximum capacitance is 15N. However, a little hysteresis error exists due to the material of its transducer, silicone rubber. And we designed the tactile sensor with the fabric structure of the optical fibers based on the taxel. When the tactile sensor is fabricated, even though many optical fiber sensors are needed, they can be handled as one line by using the optical fiber bundle. This prototype sensor is sufficient for its application of the artificial skin which includes the tactile sensor. And, we introduce the tactile sensor system using a power LED and a CCD module which are used as a light source and a light detector respect ively. Especially, as a CCD can process hundreds of optical fibers' light output, this type of tactile sensor can be easily expanded maintaining the same optical systems. And, we design the connectors to align the cross sectional area of the optical fiber. A connector which contains 16 optical fibers shows the good performance and it is sufficient to align the optical fibers.

REFERENCES

[1] Nicholls and Lee "Tactile sensing for mechatronics – a state of the art survey", Mechatronics, Volume 9, Issue 1, 1 February 1999, Pages 1-31

[2] 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

[3] 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

[4] 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

[5] 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

[6] Jin-seok Heo, Jong-ha Cheung, and Jung-Ju Lee, "Tactile Sensor Arrays Using Fiber Bragg Grating Sensors", Sensors and Actuators, Vol.126, No.2, pp.312-327, 14 February, 2006.