Development of Tactile Sensing System of Microbending Fiber Optic Sensor

Jin-Seok Heo*, Cheol-Hee Han, Ju-Young Kim and Jung-Ju Lee**

**Samsung electronics* Semiconductor business, Hwasung, *Korea*
(Email: jin.seok.heo@samsung.com)
***Dept. of Mechanical Engineering Korea Advanced Institute of Science and Technology ,Daejon, Korea 305-701*
(Tel:82-42-869-3033; Fax:82-42-869-3095; Email: leejungju@kaist.ac.kr)

Abstract: This paper describes the tactile sensing system using microbending fiber optic(MBFO) sensor. The microbending of the optical fiber drives the light transmission loss from the optical fiber. Using the light loss, this sensor can also detect the external force. To develop this system, at first, the tactile sensor element(taxel) is designed. The structure of this type tactile sensor with the crossed optical fibers embedded in the silicone rubber is very simple. When the external force is loaded on the contact mesa of this sensor, the crossed fibers causes microbending. The optical measuring system for this sensor consists of a small light emitted diode(LED) and a charge coupled device(CCD) which used as a single light source and a light detector for the bundle of optical fibers respectively. And based on the taxel, the tactile sensors is designed and fabricated as a fabric structure and the performance of the sensor is evaluated.

Keywords: tactile sensor, optical fiber, microbending, optical measuring system

I. INTORDUCTION

Recently many researchers have studied to apply the five senses of human such as the sense of sight, hearing, smell, taste, and touch to the intelligent robot system. Among them, the tactile sensor for sense of touch is one of the essential means for interfacing between human and robots [1]. Several tactile sensors are introduced for intelligent robots and haptic interfaces to detect the contact force, the texture and the temperature, etc. 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 to the practical system such as low flexibility to apply the attach on the curved surface and complicated wires array.

To solve these problems, in this paper, the fiber optic sensors are used for the tactile sensors. The optical fibers have attractive characteristics such as flexibility and relative immunity to many environmental disturbances, especially electromagnetic and electrostatic fields existing commonly near industrial machinery. And the fiber optic sensors are not affected by even humid environment. In this paper, we designed the tactile sensor using MBFO sensors with the structure of crossed fibers in the silicone rubber. This type of tactile sensor has simple wiring by using optical fiber bundle. And the optical measuring system for this sensor has compact design with a single light source and a detector. which are not expensive.

II. TACTILE SENSOR ElEMENT

1. The basic principle of the fiber optic sensor

Generally, when the optical fiber is bended and the radius of curvature is large, there is little light loss in the optical fiber due to the flexibility of optical fiber. However, as shown in Fig.1, when the radius of curvature of the optical fiber is several millimeters, the conspicuous light loss is occurred in the optical fiber. Because, if there is microbending (bends on the order of millimeters) on the optical fiber, the transmitted light into the optical fiber is emitted through the cladding of the optical fiber [6]. In general case, this microbending effect of optical fiber is a problem for the optical communication because the microbending on the optical fiber causes light transmission loss. However, for the fiber optic sensor, this can be useful for sensing changes of external environment. If the amount of the microbending light loss is calculated, the external contact force can be simply measured. This kind of sensor is called the microbending fiber optic sensor which is a sort of the intensity based fiber optic sensor. As this intensity based fiber optic sensor uses the light i-

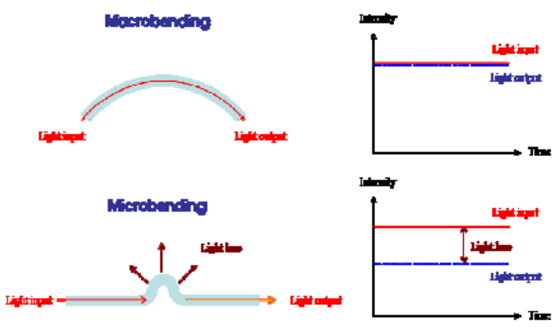

Fig.1. Microbending effect of the optical fiber.

ntensity 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 is small and not expensive.

2. The structure of taxel and its fabrication

At first, with this basic principle of fiber optic sensor, we designed the tactile sensor element. Instead of using other plates to cause microbending on the optical fiber, in this study, we propose the cross fiber structure which is embedded in the silicone rubber as shown in Fig 2.

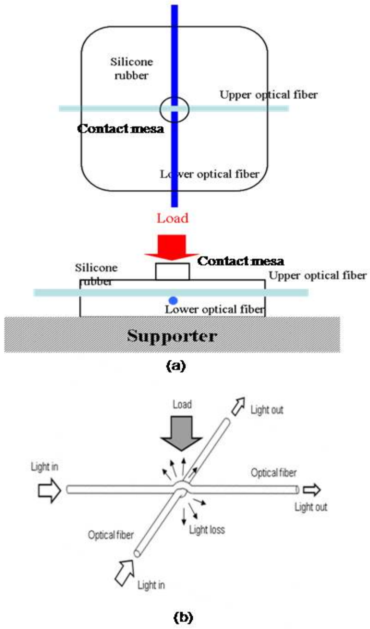

Fig. 2. (a) Structure of the taxel, (b) the microbending effect of the optical fibers in the silicon rubber.

And the contact mesa is designed with same silicon rubber like Fig. 2 to concentrate the external contact force on the cross section of the optical fibers. When the contact force is applied to the contact mesa, the upper optical fiber and the lower optical fiber are simultaneously microbended by the change of the inner stress of the silicone rubber.

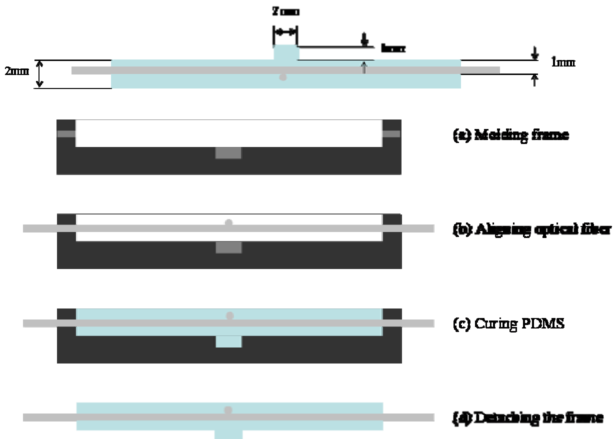

Fig. 3. Dimension of the taxel and its fabrication.

The fabrication process of this taxel is very simple as shown in Fig. 3. Before starting the fabrication of the tactile sensor element, the dimension of this flexible force sensor must be decided above all. Especially, the thickness of the sensor is important to apply this sensor to the artificial skin. The thinner sensor we fabricate, the better we can apply it to the artificial skin. In this study, we decide the thickness of this sensor to be 2mm by trial and error. 2mm thickness can fix the optical fiber without the exposure of the optical fiber from the silicone rubber.

The fabrication starts with building a molding frame which can make the shape of the taxel. And the optical fiber is aligned on the contact mesa position. Next, liquid silicone rubber is poured to the molding frame. After cured the silicone rubber, the flexible taxel can be separated from the molding frame. The fabricated prototype taxel is shown in Fig. 4. As shown in Fig. 4, the prototype taxel is so flexible due to the silicone rubber transducer. Consequently, it can be easily applied for any shape like curved surface.

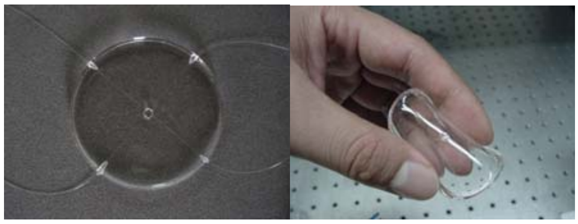

Fig. 4. Fabricated prototype taxel.

3. Optical measuring system

For the tactile sensor using MBFO sensors, the optical measuring system is very simple due to using light instead of electric signal. As shown in Fig. 5, 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 at once by CCD. 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.

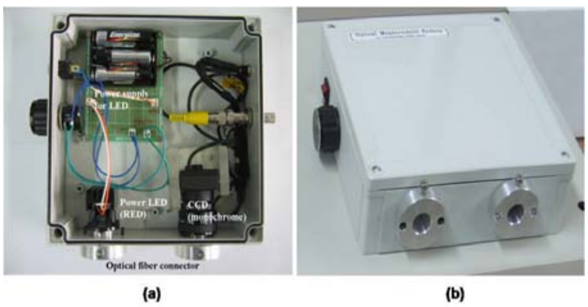

Fig. 5. Optical measuring system of this tactile sensor system; (a) The interior, (b) The exterior

4. Evaluation of the taxel

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 soon as the uniaxial load is given on the taxel by fatigue test system, the load-cell detects the amount of given load. And the optical measuring system also detects the output light signal of the taxel. Through comparing the light intensity change of the optical fiber with load-cell load signal, the load information which is applied on the taxel can be obtained.

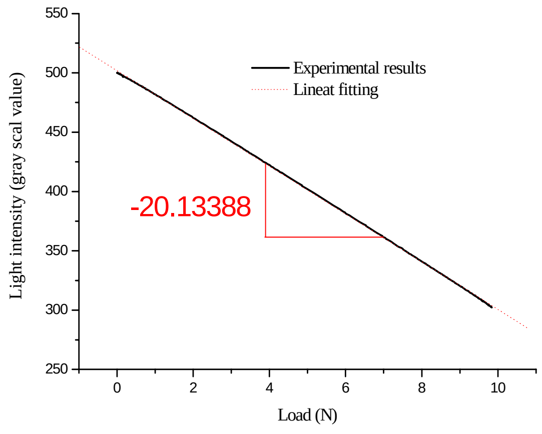

Fig. 6. Experimental verification of the prototype taxel.

The properties of the prototype taxel are obtained by the evaluation. The output signal of this prototype taxel is shown in Fig. 6. 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 inverse of sensitivity to the light intensity change, we can calculate the applied contact force. However, about 6.3% hysteresis error of this sensor is found. 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%.

The silicon rubber has also an effect on the capacity of the sensor. By the same experimental equipments, we verified the maximum capacity of the 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 an abrupt stress change of the silicone rubber by the insertion of the contact mesa. Therefore, the maximum capacity of the sensor is 15N, up to which a linear light intensity response is guaranteed.

III. DISTRIBUTED TACTILE SENSOR

1. Distributed tactile sensor and its fabrication

Based on this taxel, we designed the tactile sensor with the fabric structure of the optical fibers embedded in the silicone rubber as shown in Fig. 7. Each number of the optical fiber contains the position information of

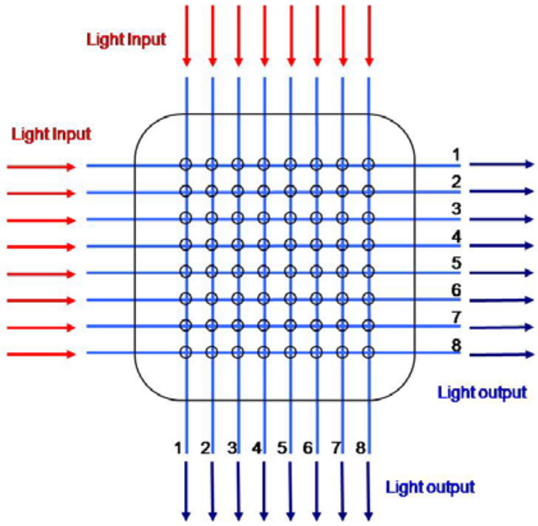

Fig. 7. Schematics of the tactile sensor using microbending fiber optic sensors with the fabric structure

the contact area like a matrix, and the change of the light intensity informs the change of contact force. If the distributed force is applied on some area of the tactile sensor, the microbending is occurred on the optical fibers of that area. Hence, using this structure, the point contact load and distributed contact load can be measured.

And the prototype tactile sensor using the MBOF sensors for distributed force is fabricated with the same fabrication process of the taxel. The increasing optical fibers are handled by optical fiber bundles as shown Fig.8. Fig. 9 shows the fabricated tactile sensor which has 5mm spatial resolution and its flexibility.

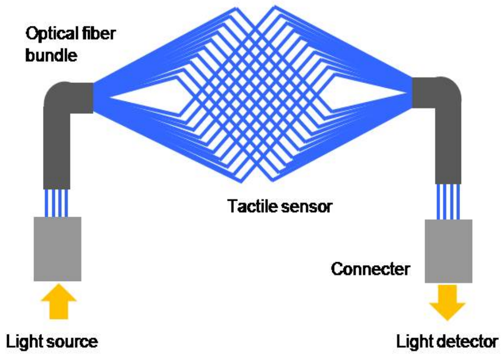

Fig. 8. Schematic for the tactile sensing system

Fig. 9. Fabricated prototype tactile sensors and its flexibility

2. Evaluation of the distributed tactile sensor

Fabricated distributed tactile sensor is experimentally evaluated by applying point load and distributed load to the sensor respectively. At first, when about 2N is applied to cross point of 6th fiber in X axis and 3rd fiber in Y axis, the output is verified. As shown in Fig. 10. (a), the output is measured as about 1.8N. And when about 5N of distributed force is applied to 9 taxels of the sensor, the output is verified. As shown in Fig. 10. (b), the output is about 0.5~0.6N for each taxel. The error of point and distributed contact load are about 0.1% and 5.0% respectively. The errors of each taxel for the distributed contact load are due to the differences of height of each taxel which contact to loading material.

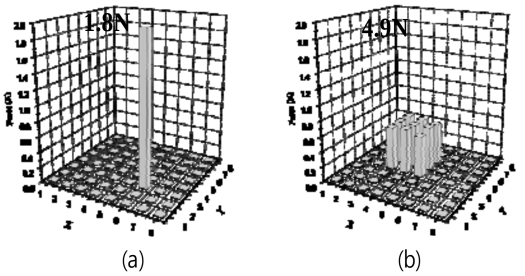

Fig. 10. Experimental results of the tactile sensor; (a)point load detection, and (b)distributed load detection.

IV. CONCLUSION

In this paper, the tactile sensing system using microbending fiber optic sensor is introduced. To develop this tactile sensing system, at first the taxel using microbending light loss is designed and experimentally verified. The structure of this sensor with the crossed optical fibers embedded in the flexible silicone rubber is very simple. The linear light intensity change by the applied load is verified by the experimental results. And the fabricated prototype taxel has a good performance. The sensitivity of this sensor is -20 gray scale value/N, the resolution of this sensor is 0.05N, and its maximum capacity is 15N. However, a little hysteresis error exists due to the material of its transducer, silicone rubber. And then we designed the tactile sensor with the fabric structure of the optical fibers based on the taxel. The distributed tactile sensor shows relatively good performance. The error of point and distributed contact load are about 0.1% and 5.0% respectively. We also introduced the optical measuring system using a power LED and a CCD which are used as a light source and a light detector respectively. As a CCD can process hundreds of optical fibers' light output, this type of tactile sensor can be easily expanded and applied to humanlike skin of intelligent robot to detect the sense of touch.

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] 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] Berthold, J.W., "Historical review of microbend fiber-optic sensors", *Journal of lightwave technology : a joint IEEE/OSA publication,* v.13, pp.1193-1199, 1995