Development of Multichannel Soft Tactile Sensors having Fingerprint Structure

H. Tsutsui, Y. Murashima, N. Honma and K. Kobayashi

***Abstract*— It is possible to accurately recognize the shape of an object or to grip it by setting soft tactile sensors on a robot's hands. We studied a multichannel soft tactile sensor as an artificial hand and evaluated the pressure's response performance from several directions and the slipping and sliding responses. The tactile sensor consisted of multiple pneumatic sensors and a soft cap with a fingerprint structure that was made of silicone gum and was separated from multiple spaces. Evaluation tests showed that the multiple soft tactile sensors estimate both an object's contact force and its contact location. Our tactile sensor also measured the object's roughness by the slide on surface texture.**

I. INTRODUCTION

Recently, many kinds of robot hands have been developed for medical, healthcare, and welfare application [1, 2]. These robot hands must hold or grasp objects without damaging or dropping them. To realize such behaviors, tactile sensors are required to obtain the tactile information between the objects and the robot fingers. Human fingers, on which robot hands are modeled, have soft skin and many sensors under it obtain the following data to detect textures: contact points, contact pressure, and slipping motions. For these reasons, many tactile sensors have been developed, and distribution patterned tactile sensors are clearly effective for robot fingers. To realize distributed tactile sensors, many kinds have been developed, including a pressure sensitive electrical conducting rubber type [3], a light wave guide type [4], and a pressure sensitive ink type [5]. However, these tactile sensors lack the flexibility of human fingers and it is not easy to detect slipping or the surface texture of objects.

Flexible tactile sensors have also been developed using flexible resin and strain gauges [6] and hyper elastic polymer filled with silicone rubber [7]. Other tactile sensors were developed using PVDF film [8] or piezoelectric elements [9] mounted under the fingerprints to detect slipping. But since the fingerprints were only built in one direction, slipping was mainly detected in just one direction.

Based on the above literatures, we have developed a soft tactile sensor that resembles a human hand. Our soft tactile sensor, which has four pneumatic sensors (transduced pressure to voltage) and a soft plastic cap made of silicone resin. Our sensor also has an additional fingerprints printed on the soft plastic cap's surface. This paper reports the angular characteristics and the detectability of object textures.

H. Tsutsui, Y. Murashima, N. Homma and H. Kobayashi are with Department of Robotics, Osaka Institute of Technology, 5-16-1 Omiya, Asahiku, Osaka, 535-8585, Japan (e-mail: Tsutsui@bme.oit.ac.jp)

II. TACTILE SENSOR DESIGN

2.1 Basic design of tactile sensors

A human finger consists of three phalanges, distal, intermediate, and proximal, and three joints, the distal interphalangeal (DIP), the proximal interphalangeal (PIP), and the metacarpophalangeal (MP). We developed three types of tactile sensors. Fig. 1 shows their structures. This soft tactile sensor, which consist of four or six pneumatic sensors (transduced applied pressure to voltage) and a soft plastic cap made of silicone resin, not only detects the math pressure (add four sensors data together) but also the applied pressure's direction. In this paper, the tactile sensor consisted of four pneumatic sensors is described.

2.2 Tactile sensor

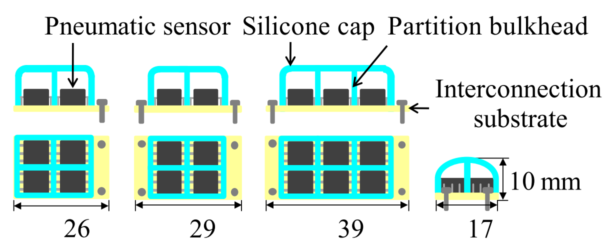


Fig. 1 Structure of the tactile sensors

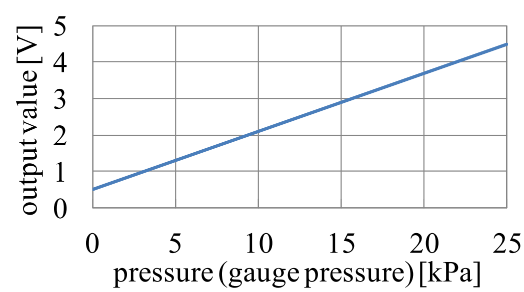


Fig. 2 Relationship between the output value and pressure

We developed a multichannel soft tactile sensor for a robot hand and examined the pressure's response performance from several directions. The soft tactile sensor consisted of four pneumatic sensors mounted on a circuit board and a soft plastic cap made of silicone resin that was separated by four spaces for four pneumatic sensors.

978-1-4244-7929-0/14/$26.00 ©2014 IEEE

The 7mm×7mm pneumatic sensor is an air pressure type with an amplifier and a thermal compensator (Panasonic ADP5120). Fig. 2 shows the relationship between the applied pressure and the output voltage.

Figure 3 shows a tactile sensor with structures that resemble fingerprints. The structure of the human fingerprint is about 0.5 mm pitch at its width and 0.1mm at its depth [10]. The tactile sensor's structure was 0.6 mm wide and 0.5 mm deep. An aluminum die was made using a machining center.

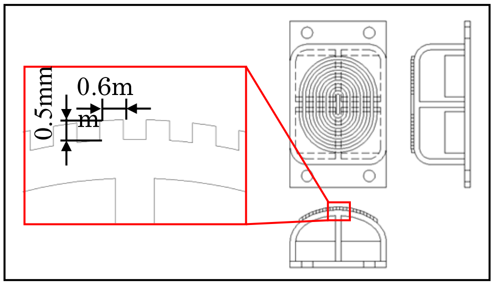
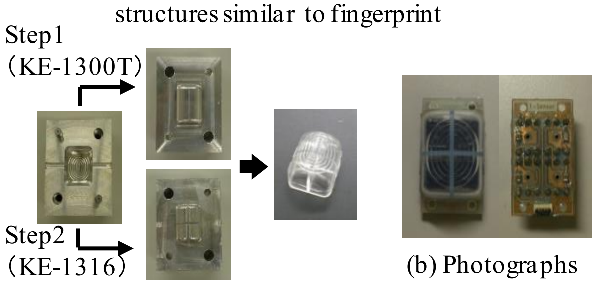


Fig. 3 Tactile sensor having structures similar to fingerprint



(a) Procedure to make the silicon cap

(b) Photographs of tactile sensors

Fig. 4 Tactile sensors

Figure 4 shows our tactile sensors. The soft tactile sensor consisted of four pneumatic sensors that were mounted on a circuit board and a soft plastic cap made of silicone resin that was separated by four spaces for the four pneumatic sensors.

The pneumatic sensor was an air pressure type (Panasonic ADP5120). The 1mm thick cap was made of silicone resin (Shinetsu silicone KE-1300T), and its hardness was 40 (Type A durometer). The partition was silicone resin (Shinetsu silicone KE-1316) and its hardness was 23 (Type A durometer). We designed the partition's hardness lower than that of the cap so to avoid disturbing the pressure measurements from the outside. With this soft tactile sensor, the robot hand can gently touch objects. We set the soft tactile sensor on the distal phalange, and the other dummy soft tactile sensors were set on the middle and proximal phalanges.

III. EXPERIMENTAL EVALUATION (1)

3.1 Experimental procedure

Figure 5 shows the experimental apparatus to obtain the directional characteristics. A 10 × 10 mm Al board was mounted on a load cell and pressed at 2N to the soft tactile sensor. Each sensor was respond linearly form 0.05N to 7N. Using the XYZ stage, we obtained angular distribution characteristics from -15°to 15°were obtained. Figure 6 shows the direction where the pressure was applied. The square broken line shows the initial point.

Figure 7 shows the experimental procedure to obtain the angular distribution characteristics using the same load cell. The contact point was changed from -15°to 15°in 5°steps.

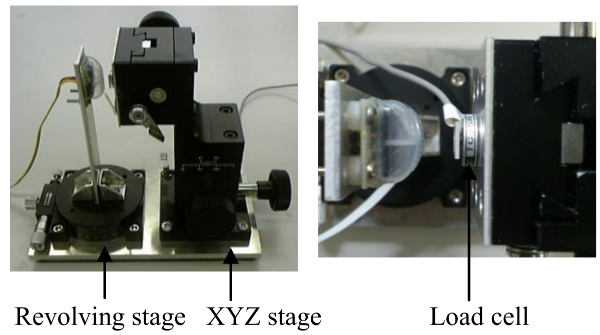


Fig. 5 Experimental apparatus to obtain directional characteristics

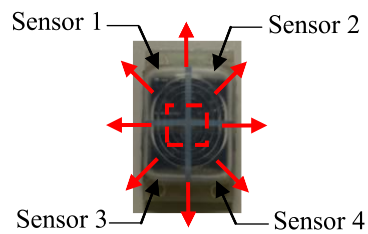


Fig. 6 Layout of pneumatic sensors and direction of experiments

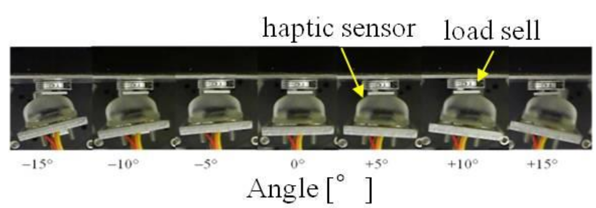
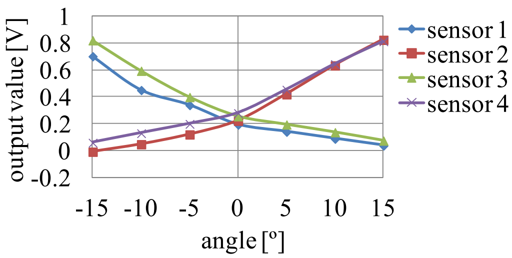


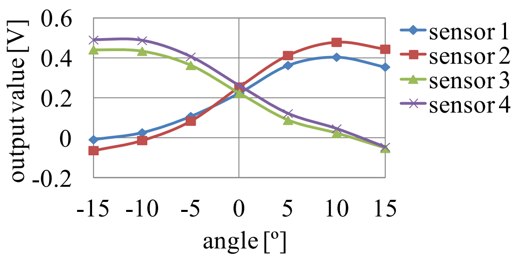
Fig.7 Experimental procedure of angular distribution

3.2 Experimental results (angular distribution)

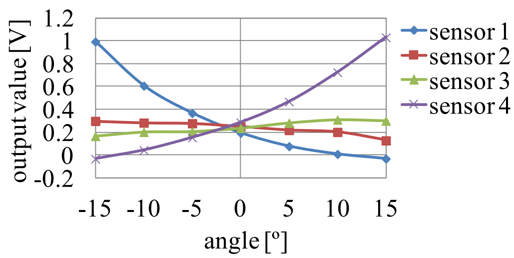
Figure 8 shows the results. Fig.8 (a) shows the result when pressure was applied at the wide direction, and Sensors 1 and 3 generated identical output and increased the reliance on the applied angle. Sensors 2 and 4 generated the same output and decreased the reliance on the applied angle. (b) shows the result when the pressure was applied in the long direction, and Sensors 1 and 3 generated identical output and increased the reliance on the applied angle, and Sensors 2 and 4 generated identical output and decreased the reliance on the applied angle. (c) shows the result when the pressure was applied at the left diagonal direction. Sensors 1 and 4 generated the opposite output relying on the applied angle, and Sensors 2 and 3 generated constant outputs. (d) shows the result when the pressure was applied in the right diagonal direction, and Sensors 2, and 3 generated the opposite output relying on the applied angle. Sensor 1 and 4 generated constant outputs.



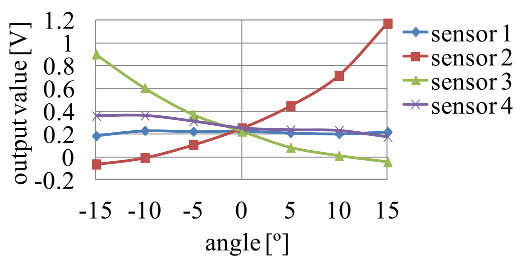
(a) Output data for wide direction



(b) Output data for long direction



(c) Output data for left diagonal



(d) Output data for right diagonal

Fig. 8 Output characteristics of each sensor

IV. EXPERIMENTAL EVALUATION (2)

4.1 Experimental procedure

Figure 9 shows the experimental apparatus and the object (acrylic plate) for the slipping evaluations. A tactile sensor was pressed against the acrylic plate at a constant pressure (1N) that moved the acrylic plate at a constant speed. A linear actuator (DRS28SB1G-03NKA Oriental motor) was used to move the object and to trace the tactile sensor. The tracing speeds were 5, 10, and 20 mm/sec, and transient response data were obtained using LabVIEW software. The transient condition was a stop motion for 1sec, a trace motion for 1sec, and a stop motion 1sec.

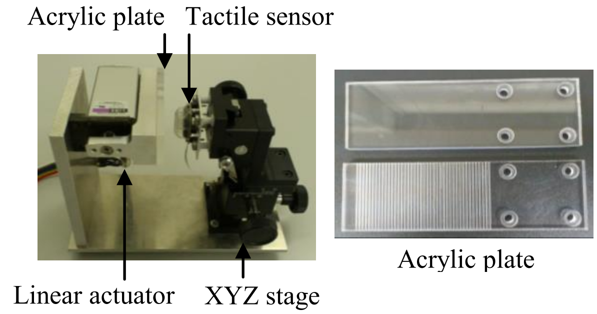


Fig. 9 Experimental apparatus for slipping

4.2 Experimental results (slipping)

Figure 10 shows the experimental results obtained from the tactile sensor. (a) shows the data for a tracing (forward direction) speed of 10 mm/sec, and the responses of Sensor1 and 3 show the received compressive stress. The responses of Sensor 2 and 4 show the received tensile stress. (b) shows the data for a tracing (forward direction) speed of 20 mm/sec, and the response was faster than (a). (c) shows the data for five tracing (reverse direction) speeds of 20 mm/sec to obtain reverse data. The data show that we detected both the slipping time and the direction

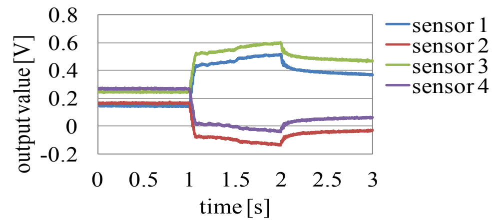
4.3 Experimental results: (sliding)

Next we examined the detectability of the object's surface roughness. Figure 9 shows the experimental apparatus and the object (acrylic plate for the sliding experiment). Its surface had cyclic roughness (0.8 mm wave length). In this experiment, a tactile sensor was pressed against the acrylic plate at a constant pressure (1N) that moved the acrylic plate at a constant speed. A linear actuator (DRS28SB1G-03NKA Oriental motors) was used to move the object and to trace the tactile sensor. The tracing speeds were 5, 10, and 20 mm/sec, and transient response data were obtained using LabVIEW software and by Fast Fourier Transformation (FFT). The transient condition was a stop motion for 1sec, a trace motion for 1sec, and a stop motion 1sec.

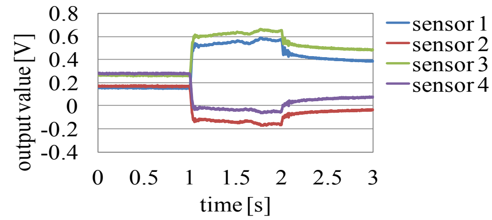
Figure 11 shows the power spectrum. (a) shows it for the plane acrylic plate that had a peak at about 5 Hz. (b) and (c) show the power spectrum for an acrylic plate that had a cyclic roughness of an 0.8 mm wavelength and main peaks at 12.5 Hz for (b) and 25 Hz for (c). When $\lambda$is the wave length of the acryl plate (mm) and v is the tracing speed (mm/s), these data satisfied equation $f = v/\lambda$ or λ=f/v. The power spectrum shows the roughness of the surface of objects or their textures. In other words, the roughness of the surface of objects will be obtained by using the data of power spectrum and the tracing speed.

V. CONCLUSION

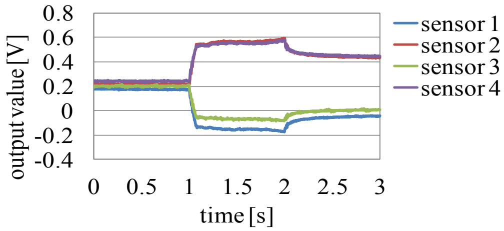
We developed a soft multichannel tactile sensor that resembled a human finger. This soft tactile sensor, which consisted of four pneumatic sensors (transduced pressure to voltage) and a soft plastic cap made of silicone resin, not only detected the math pressure but also the pressure distribution.



(a) Output data (v=10mm/s)

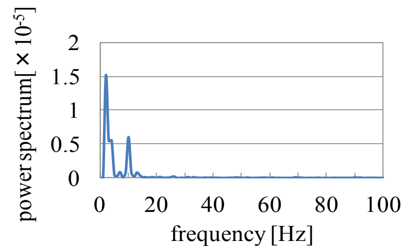


(b) Output data (v=20mm/s)

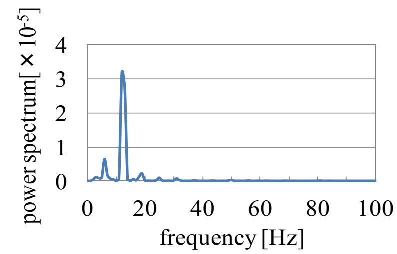


(c) Output data (v=10mm/s)

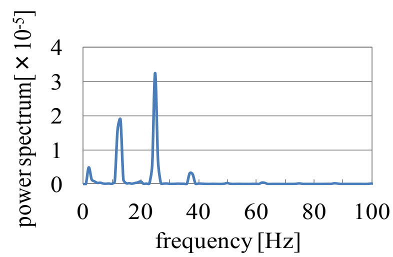
Fig. 10 Experimental results of each pneumatic sensor



(a) Power spectrum (v=10mm/s)



(b) Power spectrum (v=15mm/s)



(c) Power spectrum (v=20mm/s)

Fig. 11 Spectrum analysis of experimental results

By measuring the angular distribution, these results show that our tactile sensor obtained both the contact pressure and the rough contact position. The data showed we can detect the slipping time and the slipping direction. The power spectrum shows the roughness of the surface of objects or their textures.

ACKNOWLEDGMENTS

This work was supported in part by a Grant-in-Aid for Scientific Research C from JSPS (#25350689).

REFERENCES

[1] Shirafuji S, and Hosoda K: Detection and prevention of slip using sensors with different properties embedded in elastic artificial skin on the basis of previous experience. IEEE Advanced Robotics. pp.459–464, 2011.

[2] Hirata T, Nakamura T, Kato R, Morishita S, and Yokoi H: Development of mobile controller for EMG prosthetic hand with tactile feedback. IEEE Advanced Intelligent Mechatronics. pp.110–115, 2011.

[3] Aqilah A, Jaffar A, Bahari S, Low CY, and Koch T: Resistivity characteristics of single miniature tactile sensing element based on pressure sensitive conductive rubber sheet. IEEE Signal Processing and its Applications. 8th, pp. 223–227, 2012.

[4] Hanafiah Y, Sukarnur CA, and Masahiro O: Development of Optical Three-Axis Tactile Sensor and its Application to Robotic Hand for Dexterous Manipulation Tasks. IEEE Mathematical / Analytical Modelling and Computer Simulation. pp. 624–629, 2010.

[5] Byungjune C, Hyouk RC, and Sungchul K: Development of Tactile Sensor for Detecting Contact Force and Slip. IEEE Intelligent Robots and Systems. pp. 2638–2643, 2005.

[6] Y.Tenzer, L. P. Jentoft, R. D. Howe: Inexpensive and Easily Customized Barometers Chips. IEEE [Accepted], 2012

[7] Meng Yee Chuah: Composite Force Sensor using Discrete Pressure Mapping, Citable URI:http://hdl.handle.net/1721.1/78211

[8] Yamada Y, Morita H, and Umetani Y: Vibrotactile sensor generating impulsive signals for distinguishing only slipping states. IEEE Intelligent Robots and Systems. vol.2, pp. 844–850, 1999.

[9] Oddo CM, Beccai L, Muscolo GG, and Carrozza MC: A biomimetic MEMS-based tactile sensor array with fingerprints integrated in a robotic fingertip for artificial roughness encoding. IEEE Robotics and Biomimetics. pp. 894–900, 2009.

[10] Noda K, Matsumoto K, and Shimoyama I: Skin-type sensor using standing piezoresistive cantilever for micro structure detection. IEEE SENSORS 2010 conference. Pp. 2089-2092, 2010.