35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Robot hand with soft tactile sensors and underactuated control

H. Tsutsui, Y. Murashima, N. Honma, K. Akazawa

Abstract— **We developed a robot hand with three fingers and controlled them using underactuated control to obtain a more flexible grip. With underactuated control, we can flexibly operate an artificial robot hand and reduce the number of actuators. The robot fingers had three joints to imitate human fingers. One finger was driven by one wire and one servo motor for bending and by three torsion springs for extension. We also developed a soft tactile sensor having three pneumatic sensors and mounted it on front of each robot fingers. We obtained the following information from our experimental examinations of the robot hand. It adaptively grasped an object by underactuated control. The soft tactile sensor deftly touched an object, and the data showed the contact position with. By analyzing the data from tactile sensors, we obtained the rough information of the object's shape.**

I. Introduction

Since human hands have great flexibility and superior tactile sensors, they can perform accurate and quick operations. By exploiting this advantage, many kinds of both robot and artificial hands have been developed that can done complicated motions [1-6]. In these papers underactuated control has been applied to adaptively grip an object with fewer actuators than joints [7-11]. In addition, many kinds of tactile or haptic sensors have been developed [12-16]. Haptic interfaces have also been researched to directly transmit the force or tactile sense to human hands or brains. But almost of all tactile sensors were not so soft as compared with human fingers.

Based on the above literatures, we developed an artificial hand that was simply operated by underactuated control and could adaptively grip an object. This robot hand had the following two characteristics. First, each of its fingers was managed using underactuated control. Only one servomotor and one wire were applied for bending a finger, and three torsion springs were fit to each joint and applied to extend the fingers. An appropriate value of each spring constant was selected to smoothly move the fingers. The second characteristic was that each finger has a soft tactile sensor that resembles a human hand. This soft tactile sensor, which consisted of three pneumatic sensors (transduce pressure to voltage) and a soft plastic cap made of silicone resin, detected not only the math pressure but also the pressure's direction. With these two characteristics, the robot hand adaptively grasped various shapes, and an adaptive handle for firm, soft, heavy, and light variations was enabled.

H. Tsutsui, Y. Murashima, N. Homma and K. Akazawa 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. Robot Hand Design

2.1 Basic Design of Robot Hand

The robot hand's structure consists of three fingers; a forefinger, a middle finger, and a thumb, (Fig. 1). We placed tactile sensors on each finger of the robot hand. A finger consists of three phalanges, distal, intermediate, and proximal, and three joints, distal interphalangeal (DIP) joint, proximal interphalangeal (PIP) joint, and metacarpophalangeal (MP) joint. Since the forefinger and the thumb face each other, the robot hand can smoothly grip an object. The robot finger's length is based on the human finger. We set the three phalanges at the following distances: distal phalange, 30 mm, intermediate phalange, 36 mm, and proximal phalange, 46 mm.

The robot hand has three phalanges and three joints for each finger. Each joint is bent by winding a wire located on the left and right sides of the finger and is extended by a torsion spring that is attached to each joint. Fig. 2 shows the schematics of the robot hand and the torsion springs.

Underactuating control enables bending and extension simply by winding or slackening a wire. To select the value of the spring constants, which are higher for the DIP joint and lower for the MP joint, the hand can bend and grip an object smoothly using only one servo motor for one finger. Fig. 3 shows the schematics of the wire drive method, and Fig. 4 shows the finger's movement by winding a wire.

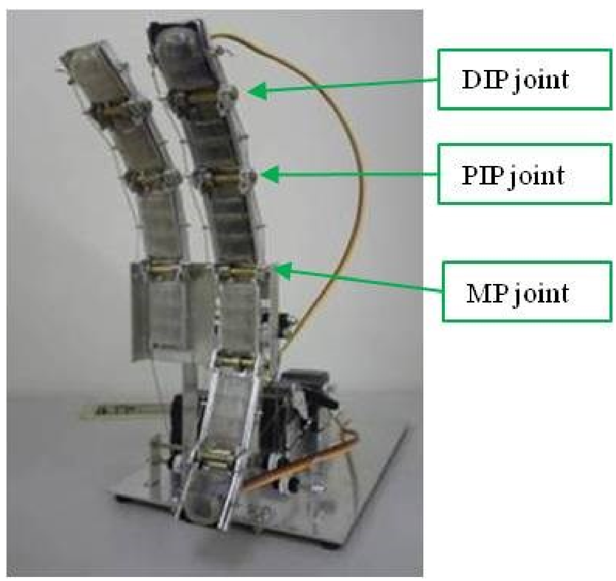

Fig.1 Photograph of robot hand

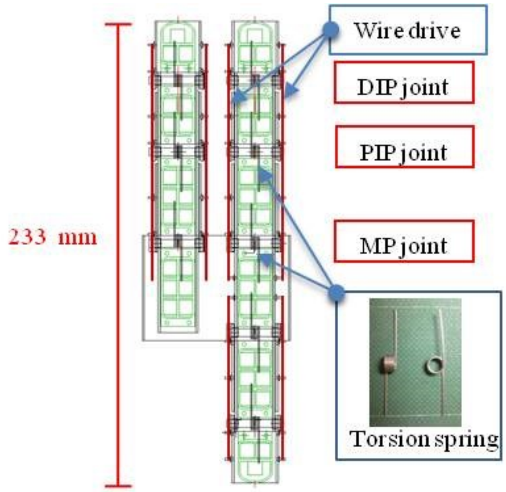

Fig.2 Schematics of robot hand

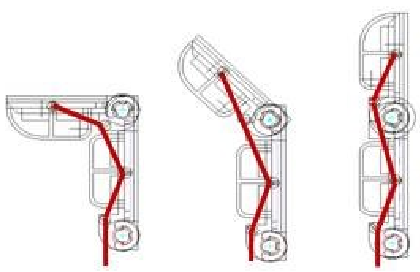
Fig.3 Schematics of wire drive

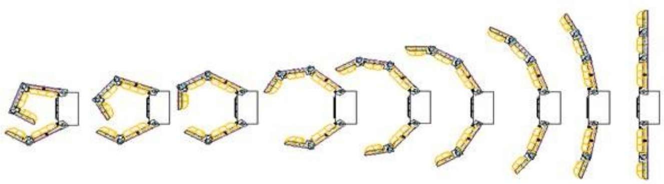
Fig.4 Schematics of bending movement of fingers

2.2 Tactile sensor

A robot can recognize an object's shape or grip adaptively if we put a soft tactile sensor on its fingers. We developed a multichannel soft tactile sensor for a robot hand and examined the response performance of the pressure from several directions. The soft tactile sensor consisted of three pneumatic sensors that were mounted on a circuit board and a soft plastic cap made of silicone resin that was separated from three spaces for three pneumatic sensors. The pneumatic sensor was an air pressure sensor (Panasonic ADP5120). The 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 of lower than that of the cap so that it did not disturb the pressure measurement from the outside. With this soft tactile sensor, the robot hand can softly contact the object. The soft tactile sensor was set on the distal phalange, and the other dummy soft tactile sensors were set on the middle and proximal phalanges.

Figure 5 shows a soft tactile sensor with three pneumatic sensors and silicone cap, and a circuit board that is used for a base plate of this soft tactile sensor. Fig. 6 shows the output results when pressure was applied at three points. The blue line shows the result when the pressure was applied on the fingertip side, the red line shows the result when the pressure was applied at the middle, and the green line shows the result when the pressure was applied on the bottom. We did the measurement as follows. We mounted a10 mm × 10 mm Al board on a road cell that was pressed at 2N to the soft tactile sensor that measured the output of pneumatic sensors 1, 2 and 3. When the pressure was applied on the upper side (blue line), it showed a big value from sensor 1. When the pressure was applied on the middle side (red line), it showed about the same value. When the pressure was applied on the bottom (green line), it showed a big value from sensors 2 and 3. The tactile sensor obtained not only the contact pressure but also the rough contact position.

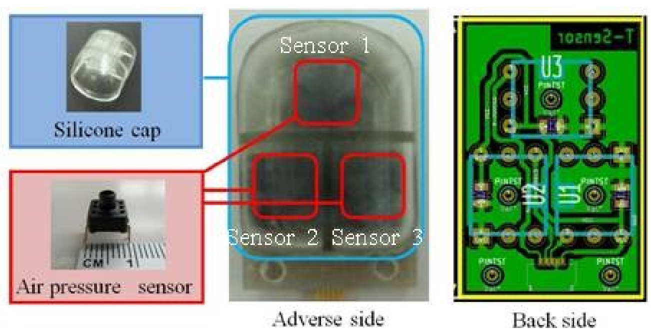

Fig5. Tactile sensor for fingertip

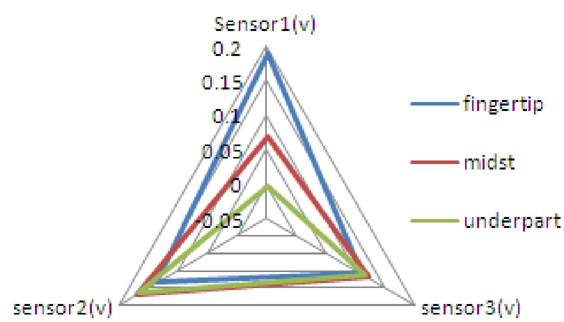

Fig.6 Detected pressure distribution

Figure 7 shows the experimental procedure to obtain the angular distribution characteristics using the same road cell. The contact point was changed from -15° to 15° in 5° step. Fig. 8 shows the results. The broken yellow lines of the left side show the contact areas of the road cell. (a) shows the result when the pressure was applied at the fingertip, and only sensor 1 generated approximately constant output without relying on the applied angle. (b) shows the result when the pressure was applied to the middle side. Sensors 2 and 3 generated output the relying on the applied angle, and sensor 1 generated approximately constant output and approximately constant output and without relying on the applied angle. (c) shows the result when the pressure was applied on the bottom. Sensors2, 3 generated output that relied on the applied angle, and sensor 1 did not generate any output. These results show that the tactile sensor not only obtained the contact pressure but also the rough contact position.

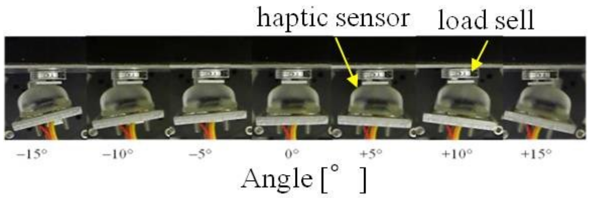

Fig.7 Experimental procedure of angular distribution

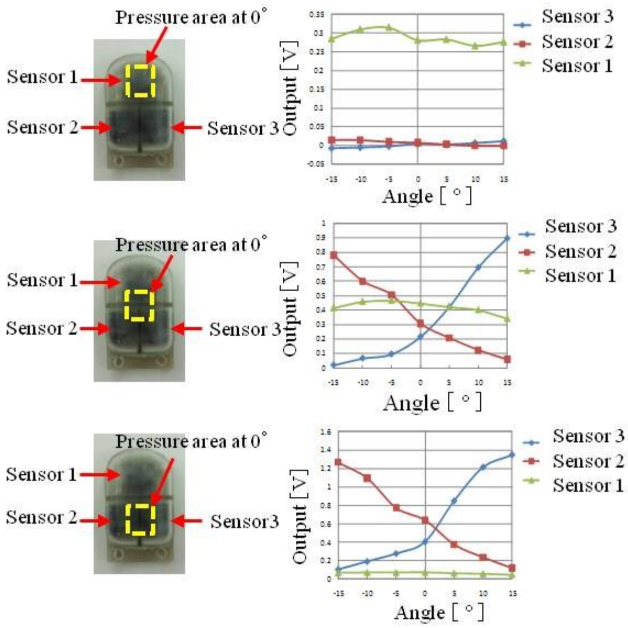

Fig.8 Angular characteristics of tactile sensor

2.3 Control of robot hand Equations

The robot hand must be controlled strongly to grip a heavy object and deftly to grip a light and/or soft object using the data from the tactile sensors. When the grasping level was set up, each finger of the robot hand was bent in the order of the MP joint, the PIP joint and the DIP joint until the output of the tactile sensor exceeded or equal the grasping level. Fig. 9 shows the program's flowchart that consisted of two parts; myogenic potential control and grasping control. The control of the robot hand consists of the electromyography (EMG) control and the grasping control. The signal of EMG is obtained from lower arm. The signal is processed using rectification and smoothing. After processed, if the data become Larger than threshold level, the control is reveled up to the grasping control stage. The program of this control was designed using LabVIEW soft program.

In this paper, we focus on grasping control. In Fig. 9, F shows the grasping level set up previously and F1 shows the measured value, which is combined values of sensors 1, 2, and 3. Comparing F1 and F, each finger gradually grips an object so that F1 = F. Because this finger is managed by underactuated control, the proximal phalange makes contact with an object earlier, and the PIP and the DIP joints bent in turn, to smoothly grasp the object. In this experiment, we examined the second part of the program. If F1 < F, servomotor is operate to grasp by one step and the contact pressure is measured. Then if F1>F, servomotor operates to open by one step and the contact pressure is measured. This control is continued until F1=F and proper grip will be established.

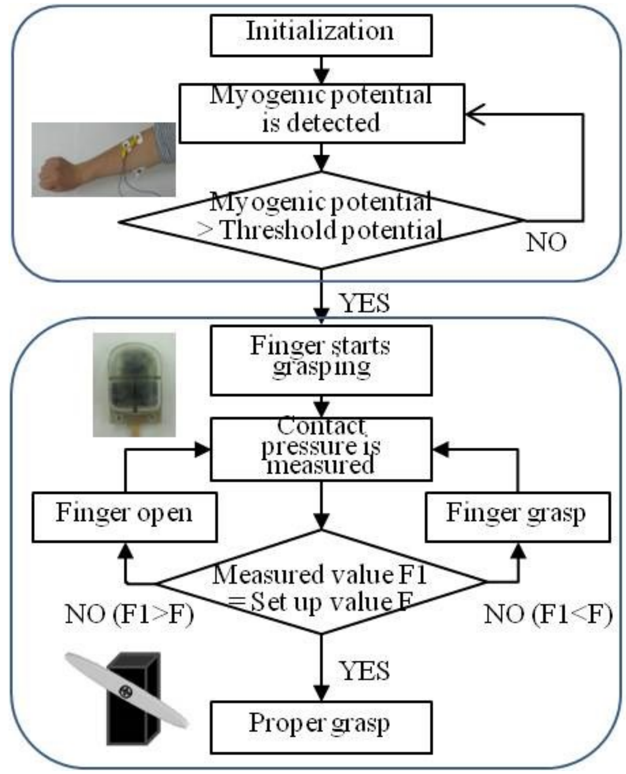

Fig. 9 Flowchart of finger control

III. GRASPING EXPERIMENT

The robot hand had three fingers, and each finger had one tactile sensor and dummy sensors. The experimental objects were a φ 60 mm cylinder waiting 52 g, a rectangular a 60 mm square weighting 113g, a φ 50 mm sphere weighting 140 g, and a truncated cone, φ 60 mm at top and φ 30 mm at the bottom, weighing 66 g. Fig. 10 to 13 shows the experimental results. Fig. 10 shows a cylinder being grasped and the output data. The data of each tactile sensor were similar, and the graph shows that each tactile sensor touched the object's bottom. Fig. 11 shows the output data for grasping a square object. The forefinger and middle finger data were similar, but the thumb data were different, indicating that the thumb touched the inside. Fig. 12 shows the output data for grasping a sphere; the center of the object was inside of each finger. Fig. 13 shows the output data for grasping a truncated cone, indicating that the object was a cone that was narrowing in on the middle finger side. The robot hand adaptively grasped different objects and estimated their shapes by analyzing the data obtained from tactile sensors.

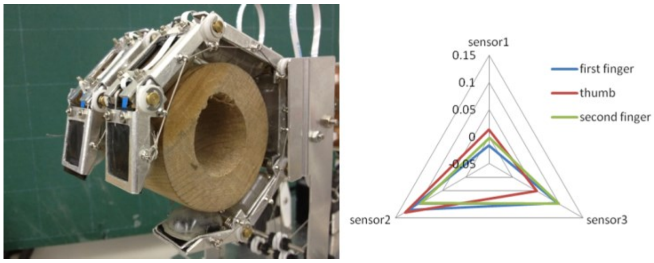

Fig.10 Grasping a cylindrical object

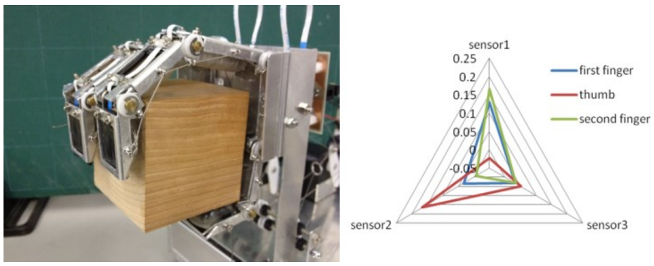

Fig.11 Grasping a square object

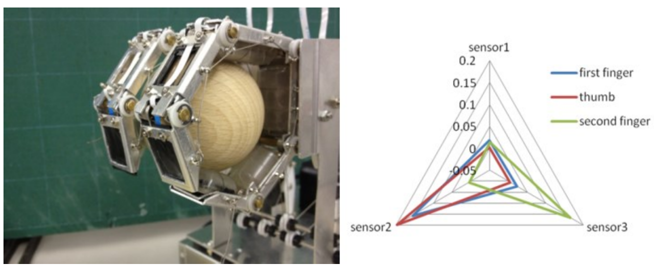

Fig.12 Grasping a spherical object

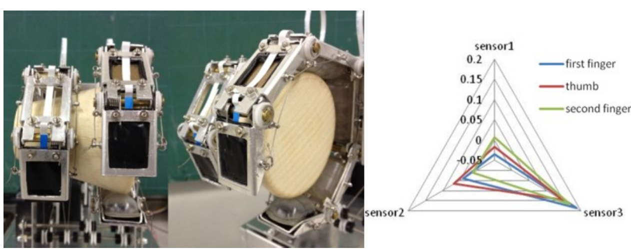

Fig.13 Grasping a circular truncated cone object

IV. CONCLUSION

We developed a robot hand. The robot hand had three robot fingers. Each robot finger had a soft tactile sensor that was constructed with three pneumatic sensors and a soft plastic cap made of silicone resin that was separated from multiple spaces. The robot hand had three fingers and was driven by underactuated control. We examined our robot hand and obtained following information.

This robot hand adaptively grasped an object using underactuated control and only required one servo motor for each finger.

The soft tactile sensor deftly touched an object, and the output data not only showed the contact pressure but also the contact position of an object and the robot fingers. Using the grasping level set up previously, the robot hand grasped an object with suitable strength.

By analyzing the data from the tactile sensors, we obtained rough information of object's shape.

REFERENCE

[1] H. Kawasaki, T. Komatsu, and K. Uchiyama, "Dexterous Anthropomorphic Robot Hand with Distributed Tactile Sensor: Gifu Hand Ⅱ," IEEE/ASME TRANS. ON MECHATRONICS, Vol.7, No.3, pp. 296-303, 2002

[2] H. Kawasaki, T. Komatsu, and K. Uchiyama, "Anthropomorphic Robot Hand: Gifu HandⅢ," ICCA2002, pp. 1288-1293, October 16-19, Korea

[3] C, DARIO P, ZACCONE F, STELLIN G, BECCAI L, CAPPIELLO G, CARROZZA M, and DARIO P. "Closed-loop Controller for a Bio-inspired Multi-finger Under Actuated," Proc. IEEE Int. Conf. Rob. Autom, Vol.5 pp. 2111-2116 (2006)

[4] H. Nakata, Masato Nagamatsu, and Shigeru Takeuchi, "Development and Structure Evaluation of Robotic Hand with Five Fingers," Memoirs of Hokkaido Institute of Technology, No. 36, pp.113-117 (2008)

[5] Atsushi Fukuda, Koh HOSODA, and Takeshi ANMA," Development of the Bionic Hand covered with soft skin with multiple tactile receptors," Proceedings of the 2008 JSME Conference on Robotics and Mechatronics, 2A1-E20 (2008)

[6] H. Nakata, N. Masao, and S. TAKEUCHI, "Development and Structure Evaluation of Robotic Hand with Five Fingers," Memoirs of the Hokkaido Institute of Technology, No.36 pp.113-117 (2008)

[7] K. KANEKO, K. HARADA, and F. KANEHIRO, "Development of Multi-fingered Hand for Life-size Humanoid Robots," Proceedings of the Robotics Society of Japan, Vol.26, No.1, pp. 98-109 (2008)

[8] T. B. Martin, R. O. Ambrose, and M. A. Diftler, "Tactile Grooves for Autonomous Grasping with the NASA/DARPA Robonaut," Proc. of the 2004 IEEE International Conference on Robotics &Automation, pp. 1713-1718, New Orleans, LA, April 2004

[9] N. Yamano, S. Takamuku, and K. Hosoda, "Development of Underactuated Humanoid Robot Hand or Adaptable Grasp," ROMBUN NO.1 A1-A11 (2008)

[10] Y. KAMIKAWA, M. Wisse, and T. MAENO: "Underactuated Robot Finger mechanism with leaf spring," Proceedings of the 2007JSME Conference on Robotics and Mechatronics, ROMBUN NO. 2A1-E0 (2007)

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

[12] S. Shirafuji, and K.Hosoda: "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

[13] A. Aqilah, A. Jaffar, S. Bahari, CY. Low, and T. Koch: "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

[14] Y. Hanafiah, CA. Sukarnur, O. Masahiro, "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

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

[16] CM. Oddo, L. Beccai, GG. Muscolo, and MCCarrozza: "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