Determination of Object Stiffness Control Parameters in Robot Manipulation Using a Prototype Optical Three-Axis Tactile Sensor

Hanafiah Yussof, Masahiro Ohka
Graduate School of Information Science
Nagoya University
Furo-cho Chikusa-ku, Nagoya, Aichi, Japan
hanafiah@nuem.nagoya-u.ac.jp / ohka@is.nagoya-u.ac.jp

Abdul Rahman Omar, Muhammad Azmi Ayub
Faculty of Mechanical Engineering
University Teknologi MARA
Shah Alam, Selangor, Malaysia
aro@salam.uitm.edu.my /
muhammadayub@salam.uitm.edu.my

***Abstract*—This paper presents experimental results to define suitable parameters in object stiffness control using a prototype optical three-axis tactile sensor mounted on robotic fingers. We have developed a novel optical three-axis tactile sensor system based on an optical waveguide transduction method applying image processing technique. We conducted a series of calibration experiments with soft and hard objects to define suitable parameters in object stiffness control. We analyzed normal and shearing forces data detected in the experiments and compiled suitable parameters in an algorithm inside the robot control system. Verification experiment using robotic fingers to manipulate soft object was conducted whose result revealed that the finger's system managed to recognize the stiffness and safely manipulate the object.**

I. INTRODUCTION

The ability to sense hardness and/or softness will be particularly important in future applications of developmental robots that apply tactile sensing. To successfully manipulate objects in the real world, robot systems require some form of tactile feedback to distinguish the object's stiffness. Unfortunately, so far, no specific parameters in developmental robots can measure the hardness sensation. In robot manipulation, researchers are addressing this problem through a novel sensor design considering intelligent object exploration algorithms. However, it seems not enough since so far manipulation tasks are mostly demonstrated using solid and hard objects, and questions of low force interaction and stiffness distinction for the safe manipulation of soft and fragile objects have still not been fully researched.

In this research, we aimed to clarify control parameters involved in stiffness control of robot manipulation based on tactile sensing. We developed a prototype optical three-axis tactile sensor capable of acquiring normal and shearing forces to mount on the fingertips of robotic fingers. We used this system to perform calibration experiments and analysis.

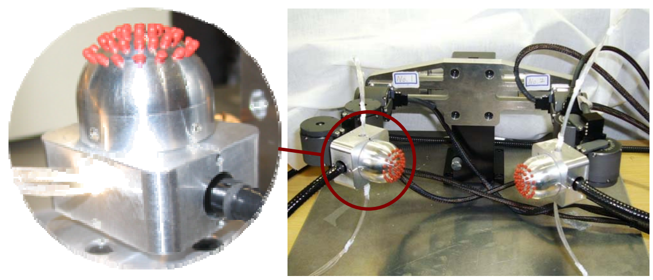

Figure 1. Optical three-axis tactile sensor mounted on robotic fingers.

II. OPTICAL THREE-AXIS TACTILE SENSOR

A tactile sensor is a device that can measure a given property of an object or contact event through physical contact between the sensor and the object. Tactile sensors have been developed using measurements of strain produced in sensing materials that are detected using physical quantities such as electric resistance and capacity, magnetic intensity, voltage and light intensity [1]. Research on tactile sensor is basically motivated by the tactile sensing system of the human skin. In humans, the skin's structure provides a mechanism to simultaneously sense static and dynamic pressure with extremely high accuracy. Meanwhile in robotics, several tactile sensing principles are commonly used, such as capacitive, piezoelectrical, inductive, piezoresistive, and optoelectrical sensors [2][3].

In this research, to establish object manipulation ability in a real humanoid robot, we developed an optical three-axis tactile sensor capable of acquiring normal and shearing forces. This tactile sensor uses an optical waveguide transduction method and applies image processing techniques [4]. This type of sensing principle is comparatively provides better sensing accuracy to detect contact phenomena from acquisition of three axial directions of forces. Fig. 1 shows the optical three-axis tactile sensor mounted on robotic fingers.

1-4244-2581-5/08/$20.00 ©2008 IEEE

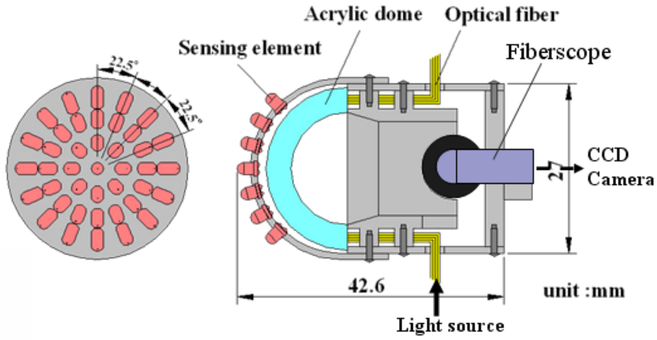

Figure 2. Structure of optical three-axis tactile sensor.

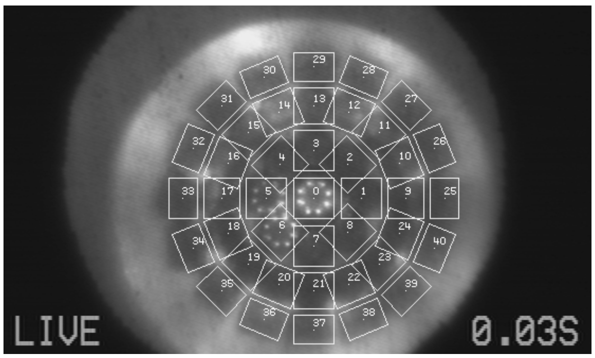

Figure 3. Image taken by CCD camera inside the optical three-axis tactile sensor, and configuration of 41 sub-regions of sensing elements.

The optical three-axis tactile sensor developed in this research is designed in a hemispherical dome shape that consists of an array of sensing elements. This shape is to mimics the structure of human fingertips for easy compliance with various shapes of objects. For miniaturization of the tactile sensor, measurement devices are placed outside the sensor. The hardware novelty consists of an acrylic hemispherical dome, an array of 41 pieces of sensing elements made from silicon rubber, a light source, an optical fiber-scope, and a CCD camera, as shown in Fig. 2. The optical fiber-scope is connected to the CCD camera to acquire image of sensing elements touching acrylic dome inside the tactile sensor. Meanwhile, the silicone rubber sensing element is comprised of one columnar feeler and eight conical feelers which remain in contact with the acrylic surface while the tip of the columnar feeler touches an object. The sensing elements are arranged on the hemispherical acrylic dome in a concentric configuration with 41 sub-regions as shown in Fig. 3. Such orientation is expected to provide good indication of contact pressure.

When an object contacts the columnar feelers, resulting in contact pressure, the feelers collapse. At the points where the conical feelers collapse, light is diffusely reflected out of the reverse surface of the acrylic surface because the rubber has a higher reflective index. Contact phenomena consisting of bright spots caused by the collapse of the feelers are observed as image data, which are retrieved by the optical fiber-scope connected to the CCD camera and transmitted to computer. Sensing program inside the computer is using Visual C++ and we utilized image analysis software Cosmos32 to analyze and measure the image data.

III. METHODOLOGY OF OBJECT STIFFNESS CONTROL

It is important to define object stiffness control to enhance performance of the tactile sensor system, and to improve its robustness during real-time object manipulation. In robotic finger's control system, normal and shearing forces, and slippage sensation detected by the tactile sensor are used to measure stiffness of the manipulated object. Consequently, suitable control parameters are required to specify so that robotic fingers can respond correctly to any objects with different stiffness conditions. However, serious conflicts are remained to specify such parameters, especially during contact point changes. To solve this problem, at first the finger must perform a soft touch on the object's surface and detect forces that occurred during the soft contact event. At this moment, the detected forces are definitely low and difficult to measure. However, this low force must be utilized to distinguish the object's stiffness so that the finger control system can conduct grasping motions without crushing the object or damaging the sensor elements. Therefore, the tactile sensor must be highly sensitive enough to detect a very low force. Furthermore, the sensor system must be able to detect not only normal force but also shearing force so that a slippage sensation that may occur during soft contact can be detected.

The optical three-axis tactile sensor used in this research is capable to satisfy the above requirements because the sensing principle, which utilized an optical waveguide transduction method, permits highly sensitive force detection from the acquisition of the three axial directions of forces; thus normal force and shearing force can be measured simultaneously with high accuracy [5]. In the current object manipulation scheme, motion planning is divided into two modes: grasping and moving. In the grasping mode, both fingers move slowly to grasp the object to define the optimum grasp pressure, while controlling the pushing velocity of both fingers to grip the object. When the optimum grasp pressure is defined, both fingers are automatically shifted to the moving mode and together manipulate the object.

IV. DETERMINATION OF IMPORTANT PARAMETERS

A. Calibration Experiment

We conducted a series of calibration experiments with soft and hard objects using the multi-fingered robotic system to determine the important parameters in object stiffness control. The hard object was an aluminum block, and the soft object was a paper box, as shown in Fig. 4. In this experiment, both fingers move along the x-axis to softly grip the object and define the optimum grasp pressure for the grasping mode. Then both fingers lift up the object along the z-axis in the moving mode.

In experiment with hard object, the reaction force applied toward the tactile sensor elements was large because the elasticity coefficient for the hard object is high. Therefore, the detected normal force becomes high. On the other hand, the object's weight caused great slippage.

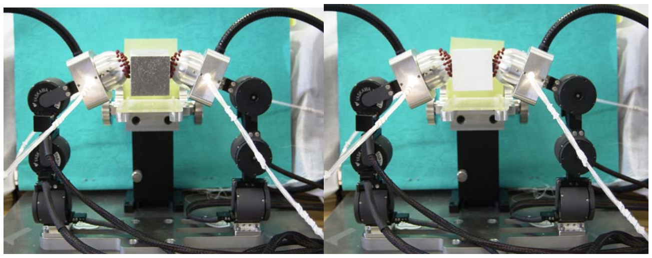

Figure 4. Calibration experiments with aluminium block and paper box.

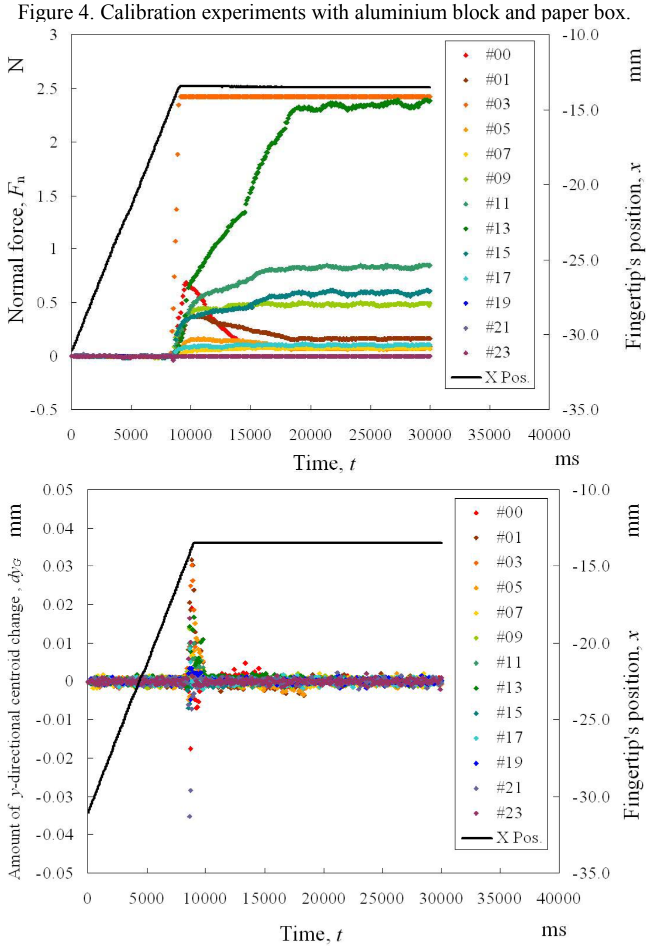

Figure 5. Relationship between normal (*top*) and shearing (*bottom*) forces with fingertip position at x-axis for experiment with aluminum block.

For soft object, small reaction force is applied to the sensing elements because the elasticity coefficient for soft objects is low. Accordingly, the detected normal force becomes low. Therefore, to correlate the stiffness distinction of both hard and soft objects, we utilized the increment of normal force ΔF, which was calculated within a specified progress time, as a stiffness distinction parameters.

To comply with the slippage that particularly occurred for hard object; we considered the amount of centroid change dr for x-directional (dx_G) and y-directional (dy_G) of the fingertip coordinate frame, by means of shearing force distribution. If slippage is over the dr value, the finger re-pushes toward the object to prevent it from slipping. However, if the detected ΔF was lower than a specified value (i.e., a soft object), the finger system uses the dr value

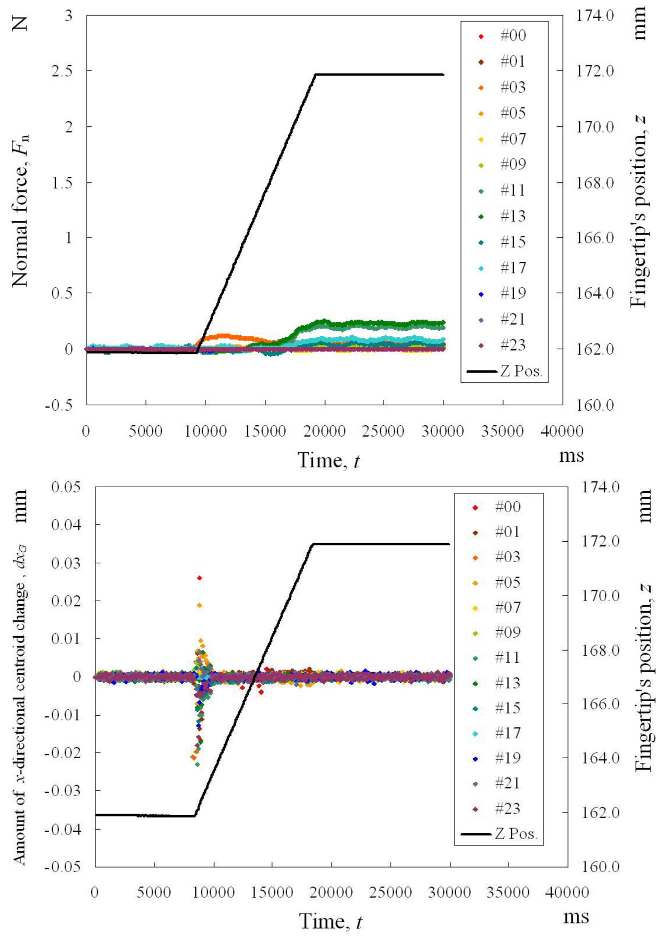

Figure 6. Relationship between normal (*top*) and shearing (*bottom*) forces with fingertip position at z-axis for experiment with paper box.

to control the finger's re-push velocity so that the grasping motion becomes gentler and finally stops when the centroid change is over a specified dr value. On the other hand, the fingertips movements are basically controlled by the thresholds of normal force F_1 and F_2. If the normal force is over the F_1 value, both fingers will not further re-push toward the object. F_2 is used for emergency stops in case of over push towards the object occurred.

B. *Experimental Result*

Based on the above control scheme, the results of calibration experiments were compiled in graphs and analyzed to define suitable parameters values. For example, Fig. 5 shows the relationship between normal and shearing forces with fingertips movements at x-axis during experiment with aluminum block for left finger. Meanwhile, for experiment with paper box, the relationship between normal and shearing forces with fingertips movements at z-axis for right finger are shown in Fig. 6.

To define increment of normal force ΔF, we measured amount of maximum normal force increments in specific progress time as shown in Fig. 7. For reference, we also conducted experiment using styrofoam as shown in this figure. These increments of normal force values are used to

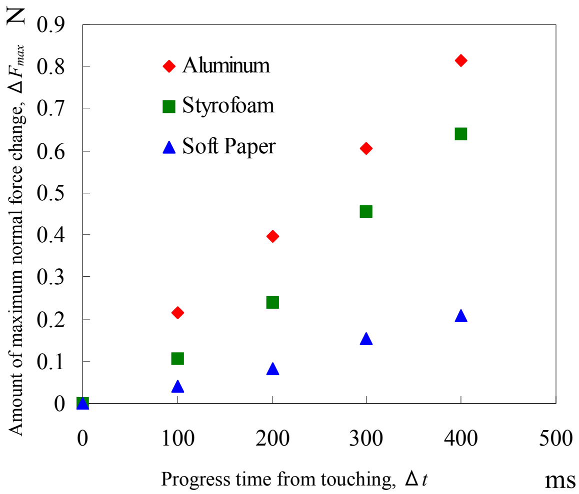

Figure 7. Amount of maximum normal force increments in specific progress time.

Figure 8. Verification experiment of robotic fingers manipulate paper box.

specify object's stiffness distinction to control fingertips movements during object manipulation tasks. After analyzing the calibration experiment results, we determined the parameter values as shown in Table 1. These control parameters enable the finger system to realize object's stiffness, even when the detected forces are very low, and then adjust grasp pressure to manipulate the object. These parameters are applied in the finger's control algorithm [6].

V. Verification Experiment

We conduct verification experiments based on the results of calibration experiment as shown in Table 1. In the control algorithm, at first the control system sees the threshold of centroid change *dr* before performing stiffness distinction using the increment of normal force *ΔF*. Then the fingers reinforce the grasping pressure to re-push the object according to the velocity ratio. Regarding the threshold of normal force, if the object was detected as soft object, the finger will no longer re-push the object when the normal force detected exceeds F_1. Meanwhile, F_2 is used for emergency case so that the finger will not over-push the object, especially when handling hard object. Fig. 8 show photographs of robotic fingers manipulate paper box. In this experiment, both fingers move along *x*-axis direction to grasp the paper box. The robot recognized stiffness of the object, and then both fingers lift up the paper box along *y*-axis. Then the fingers perform twisting motion. The fingers managed to manipulate the paper box without crushing it.

TABLE I. Parameters of Stiffness Control

Category		Parameter
Sampling interval	Sensor	100 ms
	Finger	25 ms
Threshold of normal force	F_1	0.5 N
	F_2	1.8 N
Threshold of shearing force	*dr*	0.004 mm
Velocity of re-push	v_p	2 mm/s
Velocity ratio	(Soft, Middle,Hard)	(0.25,1.00,1.25)
Increment of normal force	ΔF	soft< 0.08 N <hard
Progress time	Δt	0.1 s

VI. Conclusions

We have presented experimental results to define suitable parameters in object stiffness control using a prototype optical three-axis tactile sensor mounted on robotic fingers. We analyzed normal and shearing forces data detected in the experiments. To correlate the normal force characteristics of soft and hard objects, we measured the increment of maximum normal force in specific progress time to classify the stiffness of objects. Meanwhile, the shearing force is utilized to define re-pushes velocity of the robot fingers when grasping the object. Verification experiment using robotic fingers to manipulate soft object was conducted whose result revealed that the finger's system managed to recognize the stiffness and safely manipulate the object.

Acknowledgment

This research is partially supported by a fiscal 2006 Grant-in-Aid for Scientific Research in Exploratory Research from the Japan Ministry of Education, Culture, Sports, Science and Technology (Grant no. 18656079), and Grant-in-Research by Japan Society for the Promotion of Science (JSPS) for fiscal year 2008-2010.

References

[1] H. R. Nicholls, Tactile sensing using an optical transduction method, Traditional and Non-Traditional Robot Sensors (Edited by T. C. Henderson), Springer-Verlag, 1990, pp. 83-99.

[2] P. A. Schmidt, E. Mael and R. P. Wurtz, "A sensor for dynamic tactile information with applications in human-robot interaction and object exploration," Journal Robotics & Autonomous Systems, vol. 54, issue 12, Dec. 2006, pp. 1005-1014.

[3] M. H. Lee and H. R. Nicholls, "Tactile sensing for mechatronics – a state of the art survey," Journal Mechatronics, vol. 9, 1999, pp. 1-31.

[4] M. Ohka, Y. Mitsuya, Y. Matsunaga and S. Takeuchi, "Sensing characteristics of an optical three-axis tactile sensor under combined loading," Robotica, vol. 22, 2004, pp. 213-221.

[5] H. Yussof, M. Ohka, J. Takata, Y.Nasu and M. Yamano, "Low force control scheme for object hardness distinction in robot manipulation based on tactile sensing," In proc. of ICRA2008, 2008, pp. 3443-3448.

[6] H. Yussof, M. Ohka, H. Suzuki and N. Morisawa, "Tactile Sensing-Based Algorithm for Real-Time Grasp Synthesis in Object Manipulation Tasks of Humanoid Robot Fingers," In proc. of RO-MAN2008, 2008.