The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

Command Recognition Based on Haptic Information for a Robot Arm

Ryosuke Hanyu, Toshiaki Tsuji, Shigeru Abe, *Member, IEEE*

Abstract— **Recent development of motion control technology brings robots to our daily life. In the daily life, physical distance between humans and robots get very closer. This closed distance leads new issues in human robot interaction, such as safety issue and communication issue. The authors developed haptic sensing system called haptic armor. The sensory system can detect any contact on the robot surface and also it can distinguish the haptic command using contact information. The haptic command is the command which is delivered by physical contact to the robot. The present paper proposes the haptic commands for human robot interfaces. Furthermore, the design algorism of the haptic command is established in the paper.**

I. INTRODUCTION

Recent development of motion control technology brings robots to our daily life. In the daily life, physical distance between humans and robots get closer. This closed distance leads new issues in human robot interaction, such as safety issue and communication issue. Researchers have studied human robot communication in the daily life environment [1], [2].

In the study of human robot communication, how users tell their will is an important issue. Usually, users communicate with robots through voices (sounds) [3], [4], body gestures (vision) [5], [6], or use a controller (switch) to send commands directly. However, communication by voice commands has difficulty in the noisy environment. Using cameras may have blind spot around the user. Using controller is a good solution for those problems, but users may feel uncomfortable to use controller, because commands and tasks for the robot will be complicated. Especially children and old people are not skilled to use complicated controller, some other solution is required.

Noda, Miyashita, Ishiguro and Hagita proposed a system with haptic sensors and attempted to collect information of haptic communication [7], [8]. The system recognizes how an operator contacts its surface.

Tsuji and Ito proposed a command recognition method for haptic interface on human support robot [9] – [12]. Multidimensional information can be transmitted to the interface by a single motion.

Sakamoto, Honda, Inami, and Igarashi proposed a stroke based interface, which can control robots by using stroke gestures on a computer screen [13]. The interface is very effective to control moving robots, when the mobile computer is available.

Although, mouse gesture [14] and some interfaces on video games or music players have already accomplished intuitive interfaces, no study has shown the command recognition based on haptic information for a robot arm.

The present authors propose haptic command for robot arm, which provides easy and efficient communication, because haptic command can deliver multi-signals (speed, power, direction, etc) at the same time. Since robot arm is one of the most active parts of the robot, controlling their arm is important. Even though, the haptic command recognition for a mobile robot has been developed [11], [12], the haptic command on a robot arm has difficulty. For example, many patterns of commands are required to move the robot arm in 3D field and the command designing algorism is not established. Present paper proposes haptic commands for human robot interaction and verifies its design method.

II. REQUIRED COMMANDS FOR A ROBOT

A. Required Command

Robot in the daily life will interact with many people such as child, adult, male and female. They may have variety of nationalities, diverse abilities and many backgrounds like culture and language. Since haptic command should be useful for all those people, the concept is similar to the one of UNIVERSAL DESIGN.

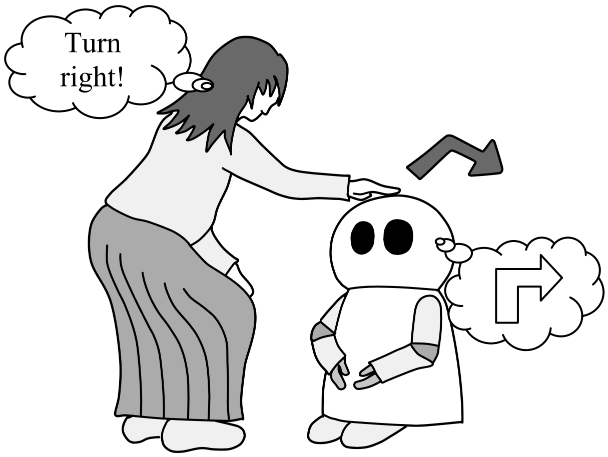


Fig. 1. Haptic command for a robot.

Manuscript received March 10, 2010. This work was supported in part by Microsoft Institute for Japanese Academic Research Collaboration (IJARC).

R. Hanyu, T. Tsuji and S. Abe are with Graduate School of Science and Engineering, Saitama University, 255 Shimo-ohkubo, Sakura-ku, Saitama 338-8570, Japan.

978-1-4244-6676-4/10/$25.00 ©2010 IEEE

B. Haptic Command

Haptic commands are recognized based on direction and magnitude of the force and trajectory of the contact point. The list below is an example of allotments.

a) Direction of the force — The direction of the arm movement.

b) Magnitude of the force — The speed of the arm movement.

c) Trajectory of the contact point — The task for the robot.

Trajectory also has information of speed, but the authors did not allot a task to it. Also, time derivative of the force are used to detect impact force on the robot surface.

III. HAPTIC SENSING MECHANISM

Although, whole body force sensation is not necessary for the aim of haptic command recognition, it is necessary for the safety issue. Thus, the authors developed a whole body force sensation called haptic armor. A haptic armor is a sensing mechanism without any touch sensors on its surface [15]. The experimental model which used haptic armor for a manipulator is shown in Fig.2. This mechanism consists of a solid end-effector and three sensor devices. The external force on the robot is transmitted to the sensor device through the end-effector. Then, the contact point on the end-effector is calculated from the response of the sensors.

The design of end-effector must satisfy the following conditions:

a) End-effector is a convex hull.

b) End-effectors do not interfere with each other, when many end-effectors are used to cover whole body.

c) End-effector contacts the robot only through sensors.

d) End-effector can withstand contact expected under normal use.

While the end-effector is satisfying the conditions, the robot can calculate force and contact position. Contact features are calculated from the following calculation method.

A simple force and torque diagram of the haptic armor is illustrated in Fig. 3. In the diagram, $\boldsymbol{P}^o$, $\boldsymbol{F}^o$ and $\boldsymbol{M}^o$ denote the tri-axial position, the tri-axial force, and the tri-axial torque acting at the standard point. $\boldsymbol{P}^e$ and $\boldsymbol{F}^e$ denote the tri-axial position of the contact point and tri-axial external force. $\boldsymbol{P}_i^s$ denotes the positions of the sensors, and $\boldsymbol{F}_i^s$ denotes the tri-axial forces measured by the sensors. Subscript i denotes the sensor number.

A. Calculation of the Resultant force

The following equation expresses the equilibrium of the force on the end-effector:

$$\boldsymbol{F}^e + \sum_{i=1}^{n} \boldsymbol{F}_i^s = 0 \tag{1}$$

The subsequent equation expresses the equilibrium of the torque measured by the sensor and the resultant torque due to the external force:

$$\boldsymbol{F}^e \times (\boldsymbol{P}^e - \boldsymbol{P}^o) + \boldsymbol{M}^o = 0 \tag{2}$$

$$\boldsymbol{M}^o = \sum_{i=1}^{n} \boldsymbol{F}_i^s \times (\boldsymbol{P}_i^s - \boldsymbol{P}^o)$$

where n is the number of sensors.
Then, (2) can be rewritten as follows:

$$\begin{aligned} M_x^o &= F_z^e(P_y^e - P_y^o) - F_y^e(P_z^e - P_z^o) \\ M_y^o &= F_x^e(P_z^e - P_z^o) - F_z^e(P_x^e - P_x^o) \\ M_z^o &= F_y^e(P_x^e - P_x^o) - F_x^e(P_y^e - P_y^o) \end{aligned} \tag{3}$$

$$P_z^e - P_z^o = \frac{-M_x^o + F_z^e(P_y^e - P_y^o)}{F_y^e} = \frac{M_y^o + F_z^e(P_x^e - P_x^o)}{F_x^e}, \tag{4}$$

$$\begin{aligned} P_z^e &= \frac{-M_x^o - F_z^e P_y^o}{F_y^e} + P_z^o + \frac{F_z^e}{F_y^e} P_y^e \\ &= \frac{M_y^o - F_z^e P_x^o}{F_x^e} + P_z^o + \frac{F_z^e}{F_x^e} P_x^e, \end{aligned} \tag{5}$$

where subscripts x, y, and z represent the axes of the Cartesian coordinate system. In the above equations, $F_x{}^o$, $F_y{}^o$, $F_z{}^o$, $M_x{}^o$, and $M_y{}^o$ are calculated from the responses of the sensor device. In addition, $P_x{}^o$, $P_y{}^o$, and $P_z{}^o$ are derived by direct kinematics. Then, (5) yields a straight line that follows vector $\boldsymbol{F}^e$. If the shape of the end-effector is known, then the contact point can be estimated. If an outer shell composed of some curved and plane surfaces is used, then the shape of the outer shell is given

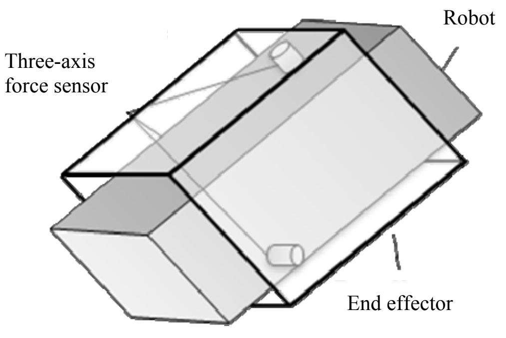


Fig. 2. Experimental model.

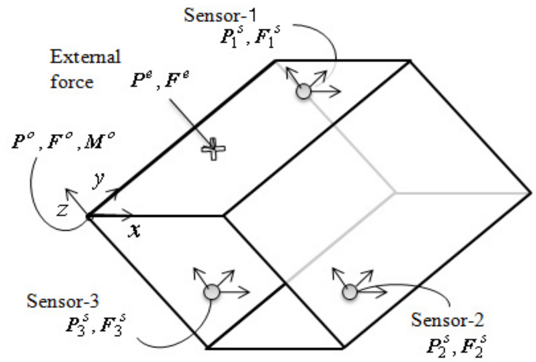


Fig. 3. Force and torque diagram.

by the following equation:

$$f_k(\boldsymbol{P}^e)=0 \qquad (k=1,2,\cdots,p), \tag{6}$$

where p denotes the number of surfaces.

When the outer shell is a convex hull, two points will appear in the result of the simultaneous equations given as (5) and (6). In order to decide one contact point, an assumption is made regarding which external force is acting in the direction of pushing the end-effector. Using this method, a contact point and the magnitude of the outer force can be detected as long as the end-effector is a convex hull.

B. Prototype Haptic Sensor and a Robot

The authors constructed a prototype of the haptic armor shown in Fig. 4. The prototype consists of three-axis force sensors and a very simple acrylic end-effector. The acrylic end-effector is 200mm long, 101mm wide and 107mm deep. Thickness of the end-effector is 3mm and weight of the end-effector is 313g.

IV. HAPTIC COMMAND

A. Experimental Situation

The authors set an experimental situation of two people sharing the robot, which is shown in Fig. 5. Each person has their work space called territory, and deliver things like a glass of water or tools using the robot. Under this situation, the robot and the person share their working space. Thus this situation assume daily environment that robots and humans work together in a same area.

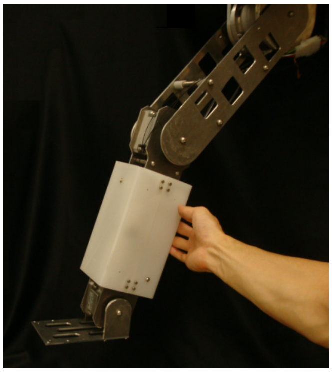


Fig. 4. Photo of the haptic armor.

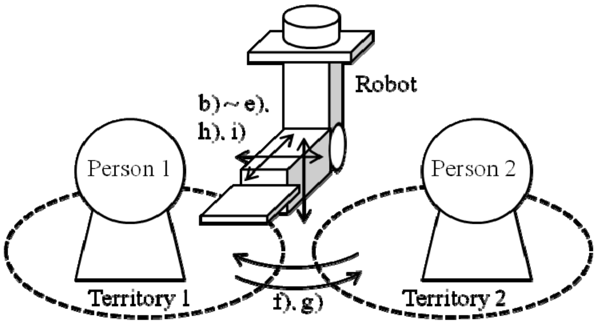


Fig. 5. Experimental situation

B. Haptic Command Design Algorism

Because the working area for the robot arm is three-dimensional, the commands for the robot arm should be designed differently from the commands used for mobile robots which we have developed before [12]. The command design algorism for a robot arm is shown below. The haptic command should include at least three types; emergency command, following force command, and gesture command. The list below is arranged in superiority order.

1) Emergency command — Emergency command has the first priority in the command design algorism, because safety is the most important factor for the robot. Emergency command should be simple, fast and easy command like slapping on the body of the robot.
2) Force following command — Force following command is a command that the robot follows an external force. It is necessary, because the users can move the robot directly with the command. This command is useful when the user want the robot to move to a certain position. When the system detects the following force command, the robot follows external force while the user is touching on the surface. Since this command will be used frequently and the command requires faster response, it has the second priority.
3) Gesture command — The gesture command is the command which uses trajectory of the external force. Many tasks can be allotted to the gesture command. There are two solutions to avoid the ambiguity between the following command and the gesture command. One is to separate the command area, and the other is to observe if the contact position is moving or not. When the aria is separated, the variation of the command is limited. On the other hand, observing its trajectory for command type detection needs a little time and it delays the response of the following action. Thus the suitable solution should be chosen depending on the purpose of the robot. In this paper, authors separate the command area to avoid the ambiguity between following command and gesture command. If the former method is chosen, the command area does not have to be limited to one specific area, but it should avoid the aria of force following command.

C. Type of Commands

The command is delivered to the robot directly by touching its surface. To control the robot satisfactorily, the authors prepared nine commands. The command is given by touching on the surface or by simple stroke gestures. Figure of commands are shown in Fig. 6. The black arrow is the direction or trajectory of the contact, and dotted circle means the definite area. Details of each command are as follows.

a) Emergency stop — The robot stops its movement safely.

b) Follow (left) ― The robot goes leftward while the person is touching on the surface. When the contact force is stronger, the speed become faster.
c) Follow (right) ― The robot goes rightward while the person is touching on the surface. When the contact force is stronger, the speed become faster.
d) Follow (up) ― The robot goes upward while the person is touching on the surface. When the contact force is stronger, the speed become faster.
e) Follow (down) ― The robot goes downward while the person is touching on the surface. When the contact force is stronger, the speed become faster.
f) Move left ― The robot move toward left direction, which is territory 1 to territory 2 in Figure. 6.
g) Move right ― The robot move toward right direction, which is territory 2 to territory 1 in Figure. 6.
h) Go forward ― The robot comes closer to the person.
i) Go backward ― The robot goes away from the parson.

Here, only four gesture commands are applied, because small number of command makes the system simpler and users can easily remember the commands. More commands can be added if it is necessary.

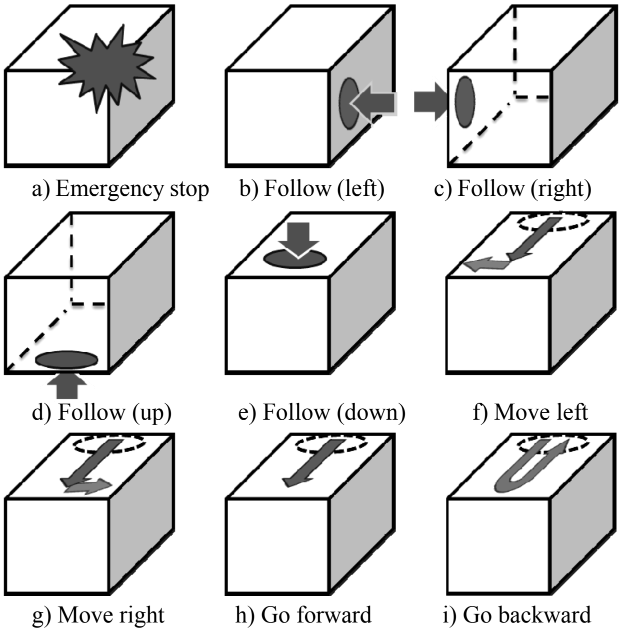
D. Recognizing Method

Command recognition is extended based on the stroke recognition method [12].

Also, we observe time derivative of the force. If the time derivative of the force becomes larger than a threshold value, that means something/someone hit to the robot or robot hit to something/someone. When the impact occurs, the robot stops its movement safely.

E. Calculation Algorism

The flowchart for command recognition is shown in Fig. 7. The algorithm starts with the detection of the physical touch movement, then classifies the contact and recognizes the command, and finally completes the task. The magnitude of the detected external force $|\boldsymbol{F}^e|$ and the threshold $F_{contact}$ derived to determine whether the external force is detected or not. The magnitude of time derivative of the force $|\dot{\boldsymbol{F}}^e|$ and threshold F_{th}, $\dot{F}_{th}$ derived to detect the impact on the end-effector. This comparison leads the task of emergency stop. When it is not the task of the "emergency stop" and the contact starts at the definite area, the task is "gesture command". If the contact starts at the outside of the definite area, the task is "move while touching". One of the advantages of command recognition using haptic interface is that multidimensional information can be transmitted by a single motion. For example, when issuing the command to move the robot arm to certain direction in certain speed, multi-parameters (direction and speed) are needed. These parameters can be transmitted by a single motion on of the haptic command. Since this study uses information based on the force direction, magnitude, and trajectory, the interface can also apply information of the external force vector. Thus, there is a possibility to further increase of the transmittable information volume.



a) Emergency stop b) Follow (left) c) Follow (right)

d) Follow (up) e) Follow (down) f) Move left

g) Move right h) Go forward i) Go backward

Fig. 6. Haptic commands

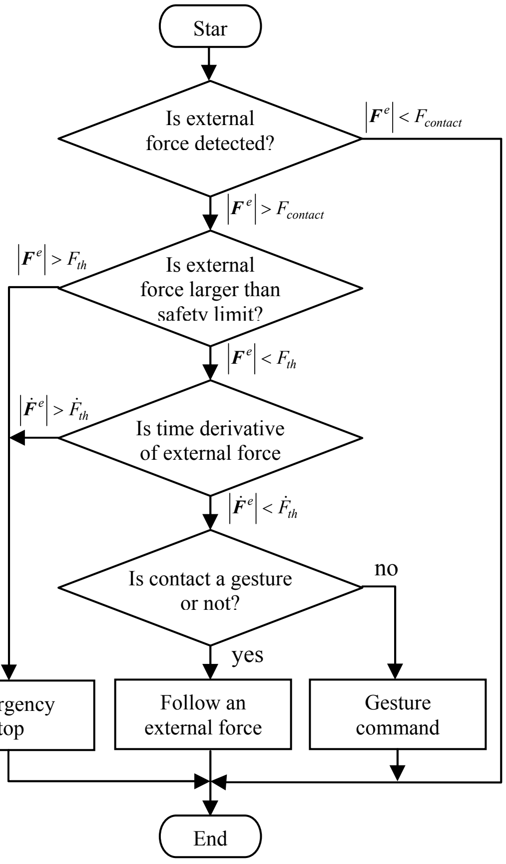


Fig. 7. Flow chart of the sensing system

EXPERIMENT

A. Haptic Sensing System Accuracy

The calculation accuracy of the haptic sensing system was examined. Nine points on the top and side of the surface were determined as sampling points and external force of 3N was added on point by point. The result of contact point detection is shown in Fig. 8 and the average error is shown in Table I. Those results show that the experimental machine is able to use for the contact point tracking.

Then, the experiment on detecting the magnitude of the external force is examined. In the experiment, external forces of 2.5N, 5.0N, 7.5N, and 10.0N are added on 9 points on the top of the surface. The result is shown in Fig. 9. Average error of the force detection was 0.3N, thus, the system is able to detect the contact force accurately.

B. Emergency Stop

An experiment of emergency stop was done. In the experiment, user slapped one of the robot surfaces. At the same time, the system detected external force and the time derivative of the external force. The result of detected force and force differential is shown in Fig. 10 and Fig. 11. Since the user just slapped on the robot, the maximum force $|\boldsymbol{F}^e|$ was smaller than its threshold F_{th}, and force differential $|\dot{\boldsymbol{F}}^e|$ become bigger than its threshold $\dot{F}_{th}$. As a result of the experiment, the impact command is detected and the robot can stop safely.

C. Command Detection

The haptic command detection was done and the detected commands are shown in Fig. 12. Those alphabet b) through i) correspond the input commands in Fig. 6. Although, the commands d) through i) are very clear, command b) and c) are not detected clearly. This is because the robot detected the point where the resultant force was acted on. In this case, the users touched the robot with their palm when they transmit the commands b) and c), and the point of resultant force moved while touching. When the authors asked users to touch with one finger, this problem was defused. After a few minutes of practice, command recognition rate had been increased to the available level in the daily life. Thus, the haptic commands were good solution to transmit users command to the robot.

TABLE I.
Average error of the experimental haptic sensing system

Direction	Average error
x	11[mm]
y	24[mm]
z	7[mm]

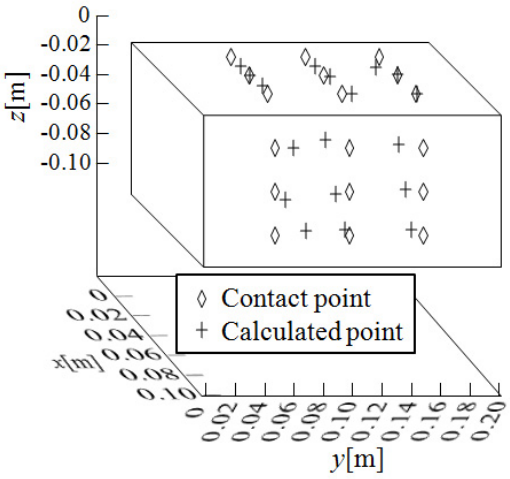


Fig. 8. Position detection results

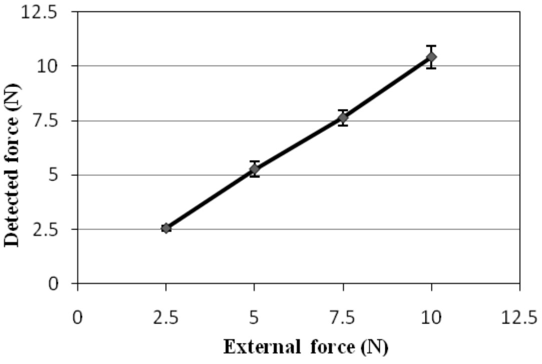


Fig. 9. Force detection results

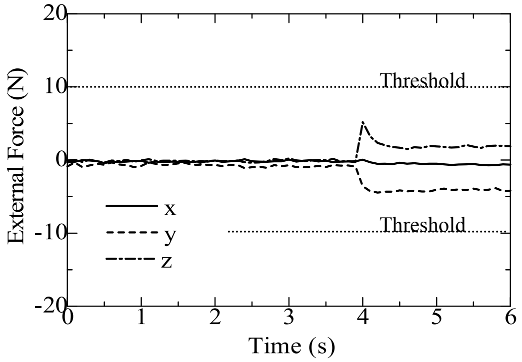


Fig 10. Detected force of the impact command

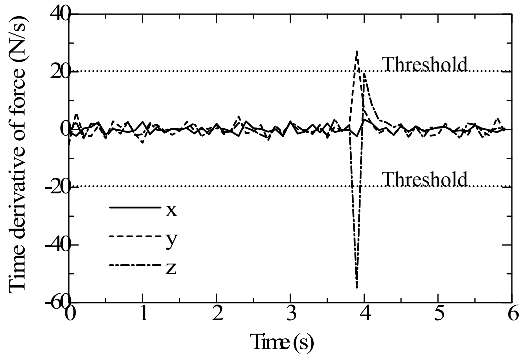


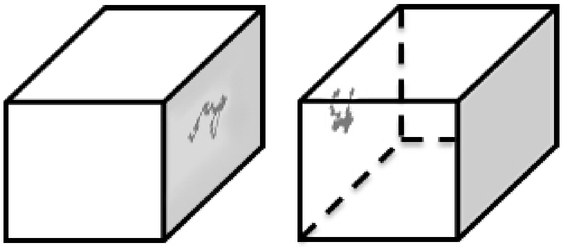
Fig 11. Time derivative of the external force of the impact command

VI. CONCLUSION

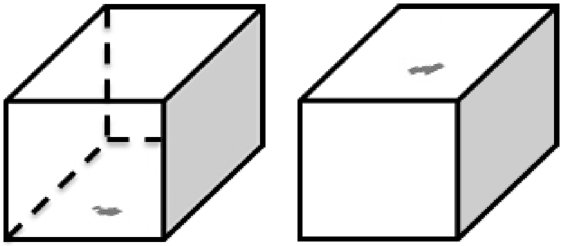
A robot control method using haptic commands is proposed in this paper. This method allows users to control a robot intuitively. In the experiment, users can satisfactory control the robot by touching its surface. However, it still needs a little practice to use haptic command. Only nine commands were applied in the experimental test, we can add more haptic commands.

This paper is written based on the combination of a manipulator and a shell-shaped force sensor, but the manipulator and the force sensor can be replaced to other types of robots and sensory systems.

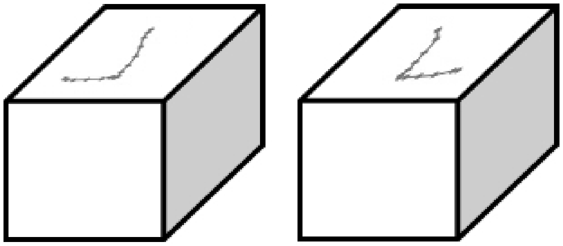
In the public use of the robot, more complicated tasks are expected such as combination of many simple tasks. Therefore, how to develop such combined task by haptic command are our future works.



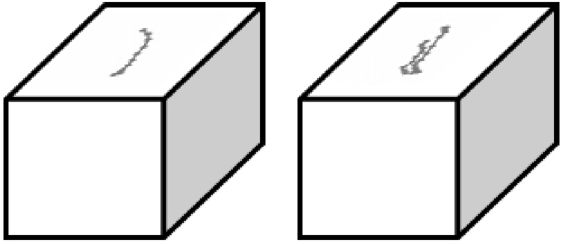
b) Follow (left) c) Follow



d) Follow (up) e) Follow



f) Move left g) Move right



h) Go forward i) Go backward

Fig. 12. Haptic command detection results

ACKNOWLEDGMENT

This study was supported in part by the Microsoft Institute for Japanese Academic Research Collaboration (IJARC).

REFERENCES

[1] A. Yamazaki, K. Yamazaki, Y. Kuno, M. Burdelski, M. Kawashima, and H. Kuzuoka: "Precision Timing in Human-Robot Interaction: Coordination of Head Movement and Utterance" *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems,* pp. 131–140, 2008.

[2] T. Ono, M. Imai, and H. Ishiguro: "A Model of Embodied Communications with Gestures between Humans and Robots." *Proceedings of Twenty-third Annual Meeting of the Cognitive Science Society (CogSci2001)*, pp. 732–737, 2001.

[3] H. Okuno: "Robot Audition: Present and Future" *J. Robot. Soc. Jpn.*, vol. 28, no. 1, pp. 2–5, 2010, (in Japanese).

[4] S. Muto, H. Tezuka, Y. Nakamura, and M. Motegi, "Study on Voice Command Control for Robotic Agents using Wearable/Mobile Personal Computers" *IEICE Technical Report of HCS 2001, vol. 100, no. 712,* pp.1–6, 2001, (in Japanese).

[5] M. Takeuchi, K. Yamamoto, and K. Kato: "Direct gesture recognition by using hand waving frequency analysis", *IEICE Technical Report of PRMU 2009, vol. 109, no. 64,* pp. 123–128, 2009, (in Japanese).

[6] A. Utsumi and J. Ohya, "Direct manipulation interface using multiple cameras for hand gesture recognition," *International Conference on Multimedia Computing and Systems,* pp.264–267, 1998.

[7] T. Miyashita, T. Tajika, H. Ishiguro, K. Kogure, and N. Hagita: "Haptic Communication between Humans and Robots," *Proc. of 12th Int. Symp. Robotics Research*, pp. 525–536, 2007.

[8] T. Noda, T. Miyashita, H. Ishiguro and N. Hagita: "Super-Flexible Skin Sensors Embedded on the Whole Body, Self-Organizing Based on Haptic Interactions." *Robotics: Science and Systems conference,* 2008.

[9] T. Tsuji, Y. Kaneko, and S. Abe: "Whole-Body Force Sensation by Robot with Outer Shell," *Proc. 10th IEEE Int. Workshop on Advanced Motion Control (AMC'08)*, pp. 365–370, 2008.

[10] T. Tsuji, Y. Kaneko, and S. Abe: "Whole-Body Force Sensation by Force Sensor with Shell-shaped End-effector," *IEEE Trans. Ind. Electron.,* vol. 56, no. 5, pp. 1375–1382, 2009.

[11] T. Tsuji and T. Ito: "Command Recognition by Haptic Interface on Human Support Robot," *Proc. of IEEE/RSJ 2009 International Conference on Intelligent Robots and Systems (IROS 2008)*, pp. 3178–3183, 2009.

[12] T. Ito, and T. Tsuji: "Command Recognition of Robot with Low Dimension Whole-Body Haptic Sensor," *IEEJ Trans. IA, vol.130, no.3,* pp. 293–299, 2010, (in Japanese).

[13] D. Sakamoto, K. Honda, M. Inami and T. Igarashi: "Sketch and Run: A Stroke-based Interface for Home Robots," *Proceedings of the 27th international Conference on Human Factors in Computing Systems (CHI 2009),* pp.197–200, 2009.

[14] M. S. Dulberg, R. St. Amant, and L. S. Zettlemoyer: "An Imprecise Mouse Gesture for the Fast Activation of Controls," *Proc. INTERACT'99*, pp. 375–382, 1999.

[15] R. Hanyu, T. Tsuji, and S. Abe: "A Simplified Whole-Body Haptic Sensing System with Multiple Supporting Points" *Proc. 12th IEEE Int. Workshop on Advanced Motion Control (AMC 2010),* pp.691–696, 2010.

[16] H. Iwata, and S. Sugano: "Whole-body Covering Tactile Interface for Human Robot Coordination," *Proc. of IEEE Int. Conf. on Robotics and Automation (ICRA'02),* vol.3, pp. 3818–3824, 2002.

[17] H. Iwata, and S. Sugano: "Human-Robot-Contact-State Identification Based on Tactile Recognition," *IEEE Transactions on Industrial Electronics*, vol.52, no.6, pp. 1468–1477, 2005.