Proceedings of the 2004 IEEE
International Conference on Robotics & Automation
New Orleans, LA • April 2004

Evaluation of Human Sense of Security for Coexisting Robots using Virtual Reality

1st report: Evaluation of Pick and Place Motion of Humanoid Robots

Seri Nonaka*, Kenji Inoue*, Tatsuo Arai* and Yasushi Mae*
*Department of Systems Innovation
Graduate School of Engineering Science
Osaka University
Osaka Japan
E-mail:nonaka@arai-lab.sys.es.osaka-u.ac.jp, {inoue, arai, mae}@sys.es.osaka-u.ac.jp

***Abstract*—When robots coexisting with humans are designed, it is important to evaluate the influence of the shape and size of the robots and their motions on human sense of security. For this purpose, an evaluation system of human sense of security for coexisting robots using virtual reality is discussed. Virtual robots are visually presented to a human subject through a head mounted display; the subject and the robots coexist in the virtual world. Some kinds of physiological indices of the subject are measured, he answers the questionnaire about his impression of the robots, and his sense of security is evaluated. Because of using virtual reality technique, the shape and size of the robots and their motions can be easily changed and tested. In the present report, pick and place motion of humanoid robots is evaluated. As a result of analyzing the questionnaire, it is found that turning the body coordinating with the arm gives good impression on humans.**

I. Introduction

In the near future, it is expected that robots will be introduced into our living space and help us in our daily life. For this purpose, it is necessary to design the shape and size of the robots and their motions, considering the interaction between the robots and humans: "physical safety" and "mental safety". Physical safety means that robots do not injure humans. Mental safety will be said that humans do not feel fear of or surprised at robots. In addition, it is important that humans do not feel unpleasant to or disgusted at robots.

There are several ways to realize physical safety: robots avoid humans by measuring the distance between them with some kinds of sensors, or robots are covered with some kind of soft material so as not to injure humans. It is possible to evaluate physical safety quantitatively, and the evaluation could be used in designing robots and planning their motions. There are many researches on safe path planning and collision detection [1], [2]. On the other hand, mental safety is not yet fully discussed. This is because which parameters of robots (shape, size, motion, etc.) may affect human mentality is not clarified, the method of measuring the emotion which humans feel about robots is not established, and how to evaluate human sense of security for robots quantitatively is not defined. For these problems, it is necessary to investigate and compare human emotions for various kinds of robots and many patterns of their motion. That is, however, quite difficult by using real robots, because making and controlling real robots requires much cost and time.

In this study, an evaluation system of human sense of security for coexisting robots using virtual reality is discussed. Virtual robots are visually presented to a human subject through a head mounted display; the subject and the robots coexist in the virtual world. Some kinds of physiological indices of the subject are measured, he answers the questionnaire about his impression of the robots, and his sense of security is evaluated. Because of using virtual reality technique, the shape and size of the robots and their motions can be easily changed and tested. In this paper, the concept and characteristics of this system are described. Humanoid robots will be one of the candidates for coexisting robots. Hence pick and place motion of humanoid robots is evaluated. A robot picks up an object and places it on the table in front of human subjects in various ways. The subjects evaluate these motions using four emotions: surprise, fear, disgust and unpleasantness.

II. Related Works

There are some researches on the evaluation of human emotions against coexisting robots or the interaction between robots and humans [3]–[9]. Miyaji et al. evaluated the shape of humanoid robots [3]. Different shapes of head, body, arm and locomotion mechanism are modeled separately, and humanoid robots of various shapes are built up by combining them. The illustrations of these robots are presented to human subjects, and they answer the questionnaires. Takamatsu et al. evaluated the motions of a robot arm [4]. They discussed the mental stress to humans given by the back-and-forth and right-and-left motions of the robot arm, using electroencephalogram, electrocardiogram and blood pressure measurement. Mizoguchi et al. adopted a long-reach robot arm as a coexisting robot and investigated the interspaces and approach trajectories which make humans feel secure [5]. Mitsui et al. investigated psychophysiological effects on humans by interaction with mental commit robot [6].

These researches did not evaluate the shape and size of robots and their motions comprehensively or different types of robots were not compared. Appearance and motion cannot be decoupled; different motions of the same robots may give different impressions on humans, and different types of robots doing the same tasks may give different influences on human emotions. Accordingly, it is necessary to evaluate them comprehensively. Comparing different types of robots is also important. For example, humanoid robots seem to be more suitable as coexisting robots than other types of robots; it has not yet been ascertained. It is, however, quite difficult to evaluate many types of robots and their various motions using real robots, because making and controlling real robots requires much cost and time.

For these reasons, we propose to evaluate human sense of security for coexisting robots using virtual reality. Virtual robots are visually presented to a human subject through a head mounted display; the subject and the robots coexist in the virtual world. Because of using virtual reality technique, the shape and size of the robots and their motions can be easily changed and tested. Virtual robots do not physically conflict with human subjects; the subjects can experiment in safe.

III. Architecture of Evaluation System

Odashima et al. developed a system for a human subject and a virtual robot of coexisting in the virtual world using CAVE system [10]; CAVE is one of immersive displays [11]. The robot is a humanoid robot. Its motion is generated by capturing and simulating the motion of a human operator in another room and is presented to the subject in the CAVE system. Generating humanoid robot motion from human motion is easy. But this method is only applicable to humanoid robots, and the motion is limited to what humans can do. Furthermore, it is impossible to adjust the motion trajectory precisely.

In this study, we develop a system shown in **Fig. 1**. A human subject is presented a virtual robot using a head mounted display: VFX3D (Interactive Imaging Systems, Inc.). The animations of the virtual robot are made using a 3D modeling software: 3D Studio MAX (Autodesk, Inc.). Hence the entire trajectories of the robot can be programmed and easily modified.

Human sense of security is supposed to be evaluated using physiological indices and questionnaire. The current system measures the heart rate of the subject as a physiological index with a heart rate monitoring device: S810i (Polar Electro.).

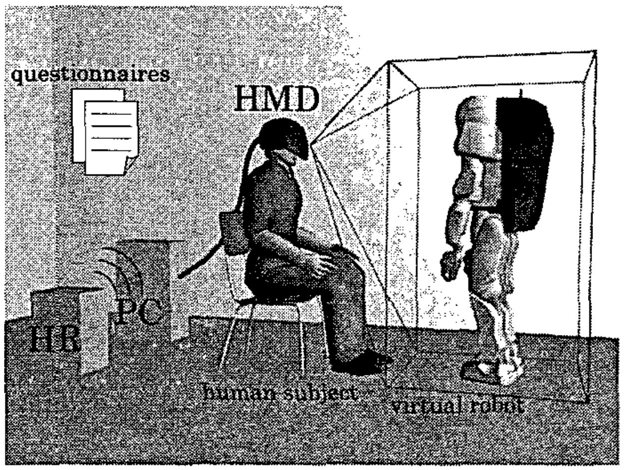


Fig. 1. Evaluation system of human sense of security for coexisting robots using virtual reality

IV. Evaluation of Pick and Place Motion of Humanoid Robots

Whether humans can predict the motion of objects (including machines) seems important in order for the humans not to feel fear of or surprised at the objects. Ikeura et al. studied a method for robot manipulators of preannouncement which gives less fear to humans; they attached LEDs for preannouncement to a manipulator [12]. Matsumaru et al. proposed a method for mobile robots of preannouncement using a display which resembles human eyes [13]. In these methods, humans must memorize the meanings of the preannouncement signs of the robots beforehand in order to predict their motions. By the way, humans can predict other person's motion quite naturally. In the same way, humanoid robots will be able to let humans predict their motions naturally, if they behave like humans. Furthermore, human-like behaviors of humanoid robots will make humans feel comfortable. This will be one of the merits of humanoid robots which have human-like shape and can behave like humans. In other words, this is an effective usage of the redundant degrees of freedom which are not used for performing objective tasks.

As the first experiment using the proposed system, this paper discusses pick and place motion of humanoid robots: a robot picks up an object and places it on the table in front of human subjects. This motion will happen quite often in the interactions between robots and humans in daily life.

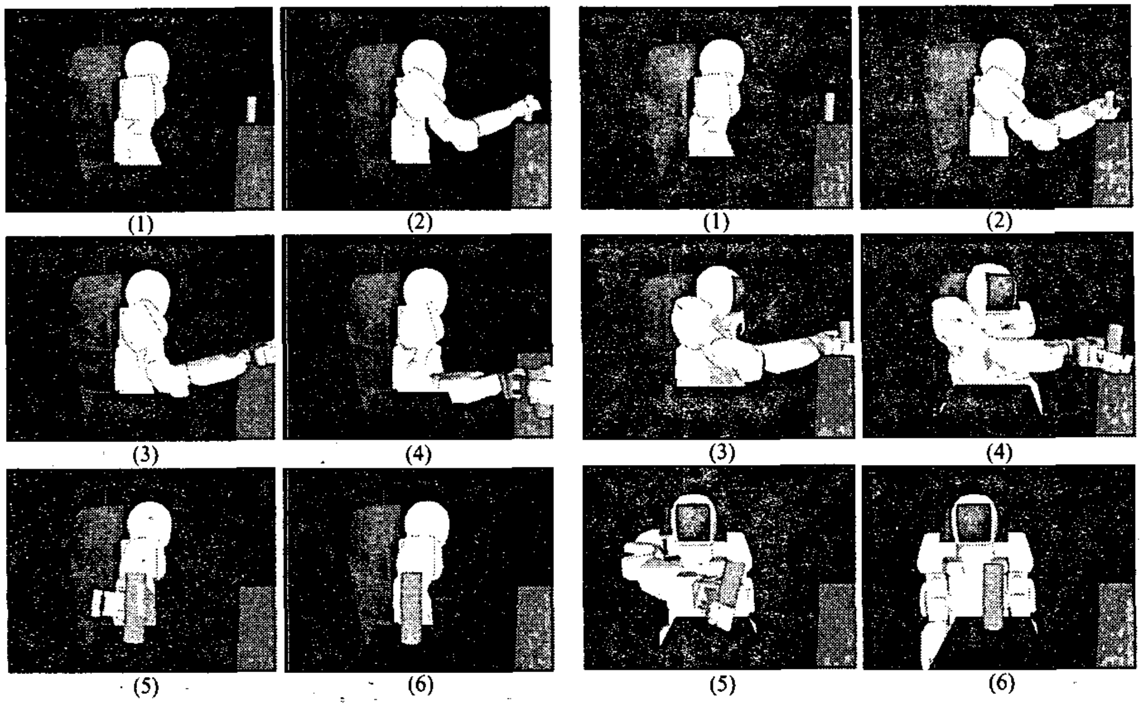
A. Experimental Method

The used model of humanoid robot is "HRP1", which was developed in "HRP: Humanoid Robotics Project" [14]. It is about 1.6[m] height. **Fig. 2** shows examples of its animations presented to human subjects through the head mounted display. These motions consist of three steps (the number in parenthesis corresponds to the number in Fig. 2):

- Step 1: In the beginning, the robot stands facing right (1). It reaches out its right hand for the object on the right table and picks it up (2).
- Step 2: The robot moves the object to the table in front of the subject (3, 4) and places it on the table (5).
- Step 3: The robot drops its right arm (6).

First, three combinations of moving parts in Step 2 are considered for comparing human-like motion and robot-like motion.

- A1: Moving only the arm.
- A2: Moving the arm and turning the head to the subject.



(a) Moving only arm (b) Moving arm and turning body to subject

Fig. 2. Examples of pick and place motion of humanoid robot presented to human subjects

A3: Moving the arm and turning the body to the subject.

Moving only the arm is enough for accomplishing this pick and place motion; it can be said robot-like motion. On the other hand, turning the head/body coordinating with the arm seems human-like motion. Fig. 2(a) and (b) illustrate the motions of A1 and A3, respectively.

Second, three levels of speed—total time T of the whole motion (Steps 1 through 3)—are applied.

B1: T=0.5[s] (fast).
B2: T=1.5[s] (normal).
B3: T=5.0[s] (slow).

0.5[s] is applied to only A1 (arm only). Let T_i be the time of Step i, $T_1 = T_2 = T_3 = T/3$. The time of moving the arm and that of turning the head/body in Step 2 are equal.

Finally, the start time of moving the arm and that of turning the head/body are also changed.

C1: The head/body starts later than the arm.
C2: The head/body and the arm start simultaneously.
C3: The head/body starts earlier than the arm.

In the cases of C1 and C3, the interval between arm starting and head/body starting is $0.14T$.

Combining the above-mentioned moving parts combination (A1, A2, A3), speed (B1, B2, B3) and start timing (C1, C2, C3), we prepare 15 motion patterns of the robot. In order to cancel out the order factor, these are presented to human subjects in randomized order. 23 men and women in the age between 21 and 26 experimented.

B. Evaluation of Human Emotion

In this experiment, questionnaire is used to evaluate the emotion of human subjects. The questionnaire is in 6 levels: from 1 ("never") to 6 ("very much"). In order to reduce easy answers of the subjects, median level is not included.

The following emotional words in Japanese are used:

- "odoroki" which means "surprise"
- "osore" which means "fear"
- "ken-o" which means "disgust"
- "fuyukai" which means "unpleasantness".

Ekman advocated that human basic emotions are "anger", "fear", "disgust/contempt", "happiness", "sadness", "surprise" and "interest". He determined them from facial expression, neurological basis and evolutionary consecutiveness [15]. We choose "fear", "surprise" and "disgust" as the words that seem to be influenced by robots, and add "unpleasantness" to them. "Fear" and "surprise" seem to have relation to sense of security, and "disgust" and "unpleasantness" seem to have relation to comfort.

In order to let the subject concentrate on the experiment, the difference between the current animation and the animation last presented is asked.

Heart rate is planned to be used as a physiological index. The device, S810i, measures the heart rate with the belt attached to the chest of the subject and sends the data to the computer by radio transmission. This reduces the restraint on the subject.

TABLE I
CORRELATION ANALYSIS AMONG SPEED AND FOUR EMOTIONS IN MOVING PARTS COMBINATION A1 (ARM ONLY)

	speed	surprise	fear	disgust	unpleasantness
speed	1.0000	.5413	.4221	.2595	.2064
		<.0001	.0005	.0368	.0964
surprise		1.0000	.7846	.4278	.3441
			<.0001	.0004	.0050
fear			1.0000	.4740	.3658
				<.0001	.0027
disgust				1.0000	.7759
					<.0001
unpleasantness					1.0000

TABLE II
CORRELATION ANALYSIS AMONG SPEED AND FOUR EMOTIONS IN MOVING PARTS COMBINATION A2 (ARM AND HEAD)

	speed	surprise	fear	disgust	unpleasantness
speed	1.0000	.2734	.1595	.0701	.0573
		.0019	.0732	.4333	.5203
surprise		1.0000	.8001	.2928	.3062
			<.0001	.0008	.0005
fear			1.0000	.2700	.2983
				.0021	.0007
disgust				1.0000	.7583
					<.0001
unpleasantness					1.0000

TABLE III
CORRELATION ANALYSIS AMONG SPEED AND FOUR EMOTIONS IN MOVING PARTS COMBINATION A3 (ARM AND BODY)

	speed	surprise	fear	disgust	unpleasantness
speed	1.0000	.4133	.3417	.1816	.1385
		<.0001	<.0001	.0379	.1132
surprise		1.0000	.7296	.0461	.0377
			<.0001	.6009	.6691
fear			1.0000	.1195	.1049
				.1741	.2332
disgust				1.0000	.7306
					<.0001
unpleasantness					1.0000

C. Result

Tables I, II and **III** show the results of correlation analysis among "speed", "surprise", "fear", "disgust" and "unpleasantness". The upper value in these tables is correlation coefficient, and the lower value is significance probability. From these tables, "speed" is positively correlated with "surprise" and "fear". There is a strongly positive correlation between "surprise" and "fear"; there is also a strongly positive correlation between "disgust" and "unpleasantness". These results coincide with common understanding. When the robot moves only the arm (A1) or moves the arm and head (A2), "surprise" and "disgust", "surprise" and "unpleasantness", "fear" and "disgust", and "fear" and "unpleasantness" have positive correlations. It means that the human subjects feel disgusted/unpleasant because they feel fear/surprised. But these pairs of emotions have no correlations when the robot moves the arm and body (A3). It means that surprise/fear do not always cause disgust/unpleasantness to the subjects.

TABLE IV

RANKING OF ALL MOTION PATTERNS WITH RESPECT TO "SURPRISE"

ranking	moving parts	speed	start timing*	point average	point variance
1	body	slow	C1	1.5	0.6
2	head	slow	C1	1.6	0.8
2	body	slow	C2	1.6	0.5
4	body	slow	C3	1.8	1.1
4	head	slow	C3	1.8	0.9
6	head	slow	C2	1.9	1.1
6	arm only	slow		1.9	1.0
8	head	normal	C1	2.2	1.2
9	head	normal	C2	2.3	1.7
10	arm only	normal		2.4	1.0
11	body	normal	C2	2.5	1.6
12	body	normal	C3	2.7	2.6
12	head	normal	C3	2.7	1.7
14	body	normal	C1	2.9	2.1
15	arm only	fast		3.4	1.5

* C1: arm starting → head/body starting
C2: arm starting = head/body starting
C3: head/body starting → arm starting

TABLE V

RANKING OF ALL MOTION PATTERNS WITH RESPECT TO "FEAR"

ranking	moving parts	speed	start timing*	point average	point variance
1	body	slow	C2	1.5	0.4
1	body	slow	C1	1.5	0.6
1	arm only	slow		1.5	0.7
4	body	slow	C3	1.6	0.8
4	head	slow	C1	1.6	0.7
6	head	slow	C3	1.7	0.9
7	head	slow	C2	1.8	1.0
9	body	normal	C2	2.0	1.0
9	head	normal	C2	2.0	1.2
9	head	normal	C1	2.0	1.4
11	arm only	normal		2.1	1.0
12	head	normal	C3	2.3	1.5
13	body	normal	C3	2.4	2.0
13	body	normal	C1	2.4	1.6
15	arm only	fast		2.7	1.8

* C1: arm starting → head/body starting
C2: arm starting = head/body starting.
C3: head/body starting → arm starting

TABLE VI

RANKING OF ALL MOTION PATTERNS WITH RESPECT TO "DISGUST"

ranking	moving parts	speed	start timing*	point average	point variance
1	body	slow	C2	2.6	1.3
2	body	slow	C3	2.8	1.2
3	body	slow	C1	3.0	1.7
3	body	normal	C2	3.0	0.9
5	head	slow	C2	3.1	0.9
6	head	normal	C2	3.2	0.8
7	body	normal	C3	3.3	1.1
7	body	normal	C1	3.3	1.0
9	arm only	slow		3.4	1.1
9	head	slow	C3	3.4	1.4
11	head	normal	C1	3.5	0.8
12	head	slow	C1	3.6	1.1
13	arm only	normal		3.7	0.9
14	head	normal	C3	3.8	1.1
15	arm only	fast		4.1	0.9

* C1: arm starting → head/body starting
C2: arm starting = head/body starting
C3: head/body starting → arm starting

TABLE VII

RANKING OF ALL MOTION PATTERNS WITH RESPECT TO "UNPLEASANTNESS"

ranking	moving parts	speed	start timing*	point average	point variance
1	body	slow	C2	3.0	1.2
2	body	slow	C1	3.1	1.4
3	body	slow	C3	3.2	1.4
3	body	normal	C2	3.2	1.3
5	head	normal	C2	3.3	0.8
5	head	slow	C3	3.3	1.2
5	head	slow	C2	3.3	1.1
8	body	normal	C3	3.4	1.0
9	head	normal	C1	3.5	0.8
9	body	normal	C1	3.5	0.8
11	head	slow	C1	3.7	1.4
12	arm only	slow		3.8	1.1
12	head	normal	C3	3.8	0.9
14	arm only	normal		3.9	1.2
15	arm only	fast		4.3	1.4

* C1: arm starting → head/body starting
C2: arm starting = head/body starting
C3: head/body starting → arm starting

For the question "What is the difference between the current animation and the animation last presented?", many subjects cannot notice the difference of start timing. Especially, when the robot turns its body (A3), they can less distinguish the difference. Many subjects misunderstand that the speed becomes slow when the head/body starts earlier than the arm (C3).

Tables IV, V, VI and **VII** summarize the ranking of all motion patterns with respect to "surprise", "fear", "disgust" and "unpleasantness", respectively. Each point ranges from 1 to 6; the smaller point means the better impression. With respect to "surprise" and "fear", it is clear that slower motion gives better impression on the human subjects. Speed is more dominant than moving parts combination or start timing. With respect to "disgust" and "unpleasantness", turning the body coordinating with the arm (A3) is better than moving only the arm (A1) or turning the head (A2).

Now we focus on the ranking of the motion patterns of the same moving parts combination and speed; only start timing is different (**Table VIII**). In all cases, start timing C2 (the head/body and the arm start simultaneously) is the best with respect to "disgust" and "unpleasantness". Because speed is dominant with respect to "surprise" and "fear", we could not draw a reasonable conclusion about start timing. Moving the head/body earlier than the arm (C3) does not play a role of preannouncement. This may be because the simultaneous motion of the head/body and the arm looks smoother than the others. Start timing C1 looks strange because the head/body is still moving after the arm stops and the task is achieved.

From these analyses, it is found that turning the body coordinating with the arm simultaneously and slowly gives good impression on humans with respect to four emotions.

TABLE VIII

RANKING OF MOTION PATTERNS OF THE SAME MOVING PARTS COMBINATION AND SPEED

moving parts	speed	start timing*	ranking "surprise"	"fear"	"disgust"	"unpleasantness"
body	slow	C1	1	2	3	2
		C2	2	1	1	1
		C3	3	3	2	3
head	slow	C1	1	1	3	3
		C2	3	3	1	1
		C3	2	2	2	2
body	normal	C1	3	3	3	3
		C2	1	1	1	1
		C3	2	2	2	2
head	normal	C1	1	2	2	2
		C2	2	1	1	1
		C3	3	3	3	3

* C1: arm starting → head/body starting
C2: arm starting = head/body starting
C3: head/body starting → arm starting

V. CONCLUSION

An evaluation system of human sense of security for coexisting robots using virtual reality is proposed. Evaluating human sense of security for coexisting robots will be necessary for designing the shape and size of the robots and their motions. This paper describes the concept and characteristic of the system, and pick and place motion of humanoid robots is evaluated. As a result of analyzing the questionnaire, it is found that turning the body coordinating with the arm gives good impression on humans. It will be an effect of the humanlike motion of humanoid robots.

In this experiment, we measured the heart rate of human subjects, but we could not draw a decisive conclusion about the relationship between heart rate and human sense of security. In the future work, we reconsider other physiological indices and methods of analyzing them.

This study aims at evaluating human sense of security for coexisting robots using virtual reality. Hence it is significant that human emotions for virtual robots indicate a similar tendency to those for real robots. We experimented with human emotions for pick and place motion of a real humanoid robot and found that slower motion and body turning give better impression on humans [16]; it seems the same as the result of this study. In the future work, we will investigate the relationship between human emotions for virtual robots and those for real robots in more detail.

We will experiment with many types of robots and their motions and compare them. That will give a hint to design coexisting robots.

ACKNOWLEDGMENT

This research was supported by The Ministry of Education, Culture, Sports, Science and Technology. Grant-in-Aid for Creative Scientific Research (No. 13GS0018).

REFERENCES

[1] M. Adams and J. Ibañez-Guzmán, *Safe Path Planning & Control Constraints for Autonomous Goal Seeking*, Proc. IROS2002, p2377-2382, 2002.

[2] D. M. Ebert and D. D. Henrich, *Safe Human-Robot-Cooperation: Image-based collision detection for Industrial Robots*, Proc.IROS2002, p1826-1831, 2002.

[3] S. Suzuki, Y. Miyaji and K. Tomiyama, *A Study on Emotional Influence of Shapes of Care-Worker Support Robot*, JSME ROBOMEC 2003 Conference, 1P1-2F-C7, 2003 (*in Japanese*).

[4] N. Takamatsu, K. Kida, M. Iwakawa and T. Iida, *MEasurement of Mental Load Received by a Robot Motion*, JSME ROBOMEC 97 Conference, Vol.B, p.969-970, 1997 (*in Japanese*).

[5] H. Mizoguchi, O. Nasukawa, T. Mori and T. Sato, *Generating Sence of Security by Behaviour of Human Symbiosis Robot*, JSME ROBOMEC 97 Conference, Vol.A, p561-562, 1997 (*in Japanese*).

[6] T. Mitsui, T. Shibata, K. Wada, A. Touda and K. Tanie, *Psychophysiological Effects by Interaction with Mental Commit Robot*, Proc. IROS2001, p1189-1194, 2001.

[7] P. Rani, N. Sarkar and C. A. Smith, *Affect-Sensitive Human-Robot Cooperation -Theory and Experiments*, Proceedings of the 2003 IEEE International Conference on Robotics & Automation, p2382-2387, 2003.

[8] S. Kajikawa, T. Okino, K. Ohba and H. Inooka, *Motion Planning for Hand-Over between Human and Robot*, Proc. IROS1995, Vol.1, pp.193-199, 1995.

[9] T. Nakata, T. Sato, H. Mizoguchi and T. Mori, *Synthesis of Robot-to Human Expressive Behavior for Human-Robot Symbiosis*, Proc. IROS1996, p1608-1613, 1996.

[10] T. Odashima, M. Onishi, F. Asano and Z. Luo, *A PC-based 3D Dynamic Simulation Environment for Developing Human Interactive Robot Systems*, SI2002, p59-60, 2002 (*in Japanese*).

[11] "The CAVE at NCSA", http://cave.ncsa.uiuc.edu/

[12] R. Ikeura, Y. Kawakita, M. Ito and K. Mizutani, *Prior notice method of robotic arm motion for suppressing a threat to human*, Proceedings of the 2000 IEEE International Workshop on Robot and Human Interactive Communication, p276-280, 2000.

[13] T. Matsumaru, K. Iwase, T. Kusada, K. Akiyama, H. Gomi and T. Ito *Preliminary-Announcement Function of Mobile Robot's Following Motion by using Omni-directional Display*, Proc. ICAR2003, p650-657, 2003.

[14] "Special issue HRP: Humanoid Robotics Project," *J. of the Robotics Society of Japan*, vol. 19, no. 1, pp. 1-36, 2001 (*in Japanese*).

[15] Ekman, Paul, *Emotion in the Human Face*, Cambridge University Press, Cambridge [Cambridgeshire], 1982.

[16] K. Sakata, T. Takubo, K. Inoue, Y. Mae, S. Nonaka, and T. Arai, *Human Support System Using Humanoid Robots for Safe, Secure and Reliable Society -Psychological Evaluation of Pick and Place Motion-*, SI2003, p73-74, 2003 (*in Japanese*).