Embodied Cooperative Behaviors by an Autonomous Humanoid Robot

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***Abstract*— Previous research works in robotics and cognitive science have reported that humans utilize embodied cooperative behaviors in communication, such as nodding in response to another's it utterance and looking at a certain object in a certain direction as others look or point at. We have developed a humanoid robot that utilizes such an embodied cooperative behavior for natural communication in a route guidance situation. It obtains numerical data on a human's body movement via a motion capturing system and then autonomously selects appropriate cooperative embodiment units from 18 implemented units. Each unit realizes a certain cooperative embodiment behaviors such as eye-contact by using the motion capturing system as well. As a result of a subject experiment, we have verified the effectiveness of the embodied cooperative behaviors of the robot for reliable and sympathetic communication. Moreover, we analyzed how the auditory expression and the embodiment contributed to the effect.**

I. Introduction

Over the past several years, many humanoid robots have been developed. We believe that in the not-too-distant future humanoid robots will interact with humans in our daily lives. Their human-like bodies enable humans to intuitively understand their gestures and cause people to unconsciously behave as if they were communicating with humans. That is, a humanoid robot can provide an abundance of non-verbal information as well as vocal information, which enables us to smoothly communicate with it. This could allow robots to perform communicative tasks in human society such as route guidance.

Several researchers have investigated the non-verbal communication between humans and robots, such as facial expression, eye-gaze, and gestures. Moreover, mutually related body movements have been investigated. The joint-attention mechanism[2] is one of the typical mutually related body movements. Humans utilize their eye-gaze and pointing gestures to mutually synchronize their attention. Scassellati developed a robot as a testbed for a joint-attention mechanism[3]. In this work, the robot follows the others' gaze in order to share attention. Imai and his colleagues used a robot's arms as well as eyes to establish joint attention and verified its effectiveness[4].

Furthermore, Ono and his colleagues found the importance of entrainment among the mutually related body movements through human-robot communication. They verified the importance of eye contact, arm gestures, and appropriate positional relationships (orientation of body direction) in a route guide robot[5]. In this research, it was found that body movements are not only used for visually understanding what the speaker says but also for synchronizing communication. Such an unconscious synchronization of body movements is called "entrainment." That is, the speaker's body movements entrain hearers to establish a relationship between them. Kanda and his colleagues found that cooperative body movements, such as eye-contact and synchronized body movements, cause entrainment in human-robot interaction[6]. Watanabe and his colleagues found the importance of temporal cooperativeness. They have developed a robot named InterRobot that is capable of giving responses synchronized to the behaviors of an interacting human. This robot system prompted entrainment for natural communication[7]. By using the robot, they also investigated the delay effect of the cooperative behaviors[8]. We believe that cooperative body movement is essential for humanoid robots that entrain humans into natural communication with it.

In this paper, we report the development of an interactive humanoid robot that autonomously performs cooperative body movements in a route guidance situation. Although several previous works have reported that humans behave cooperatively toward robots for natural communication as they do toward humans, little research has been conducted to develop such an autonomous robot that is capable of both spatial and temporal cooperative body movements. Our robot utilizes a motion capturing system to numerically obtain human body movements. It selects appropriate cooperative embodiment units from 18 implemented units, while each of them realizes a certain cooperative body movement such as eye-contact. We conducted experiments with subjects to verify the effect of the developed autonomous mechanism of embodied behavior as well as the importance of cooperative body movements.

Fig. 1. embodied cooperative behaviors for human-human communication

II. Importance of Embodied Cooperative Behaviors

We define embodied cooperative behaviors as "Embodied behaviors (body movements and utterances) that correspond to others' behaviors temporally and spatially." Although previous research works have investigated temporal cooperative behavior from robots [7], [8], little research has conducted on spatial cooperative behavior from robots. The term "embodied" emphasizes spatial cooperative aspects among cooperative behavior.

Humans unconsciously utilize embodied cooperative behaviors in communication. Ono et al. conducted experiments on inter-human communication in a route-guidance situation to investigate embodied behaviors between two persons [5]. In the experiment, a subject (named Learner) asked another person (named Teacher) who was passing by the route to a destination. While Teacher taught the route to the Learner, cooperative arm movements were observed in eight cases among ten experiments. Cooperative arm movement is described as, "a Teacher moved his/her arm to show the directions, and a Learner moved his/her arm the same way." Figure 1 is an example of such a movement. In addition, all Teachers performed pointing and established eye-contact with each other, and all Learners gave backchannel feedback such as "uh" or "huh."

More concretely, embodied cooperative behaviors were observed as head movements, arm movements, and utterances: eye-contact and looking in a direction indicated by pointing were observed as head movements; imitation of arm movements and pointing in the same direction as the other were observed as arm movements; backchannel feedback was observed as utterances. Some of the subjects performed such embodied cooperative behaviors by switching the orientations of the movements (right and left) based on the other's movements.

These embodied cooperative behaviors corresponded both temporally and spatially with the other's behavior. In other words, they synchronized the communication by utilizing their body properties. Since we observed the embodied cooperative behaviors in all examples, we believe that humans unconsciously utilize such embodied behavior, which is the essential mechanism of naturalness and smoothness in inter-human communications.

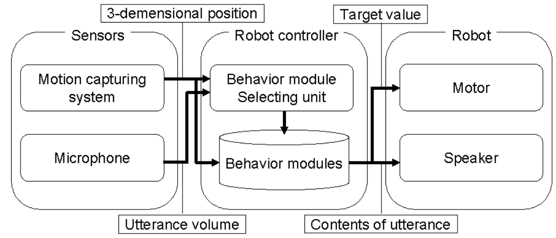


Fig. 2. Structure of system

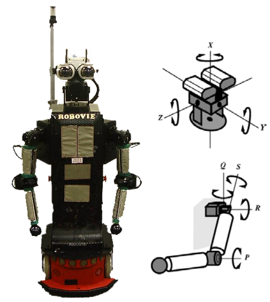


Fig. 3. Photo of humanoid robot "Robovie"(left) and the robot's head and arm motion mechanism(right).

III. Autonomous Robot for Embodied Cooperative Behaviors

We developed a robot controller for an autonomous humanoid robot that performs embodied cooperative behaviors in a route-guidance situation. It is proposed to realize human-robot communication that is as smooth and natural as that between humans. It autonomously selects appropriate embodied behaviors from the 18 candidate behaviors we implemented. It numerically obtains human embodied behavior from a motion capturing system.

A. System configuration

The system consists of a humanoid robot, sensors, and a robot controller (Figure 2).

B. Humanoid robot "Robovie"

We used a humanoid robot named "Robovie" that is characterized by its human-like body expression (Figure 3(left)). The human-like body consists of eyes, a head and arms, which generate the complex body movements required for communication. Robovie has two 4-DOF arms and a 3-DOF head (figure 3(right)). Thus, its body has an expressive ability that is sufficient for making gestures for route-guidance task, such as pointing a certain direction and establishing eye-contact. The height is 1.2 m, the radius is 0.5 m, and the weight is about 40 kg.

C. Sensors

We integrated a microphone and a motion capturing system into the system. The microphone is attached to the robot, which acquires the utterance volume of a human. The motion capturing system acquires 3-dimensional numerical data on the human body movements. It consists of 12 sets of infrared cameras with an infrared irradiation

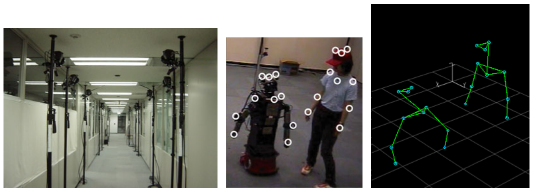


Fig. 4. Photo of motion capturing system (left), attached markers (center), and obtained 3-D numerical position data of body movement (right).

function and markers that reflect infrared rays. The motion capturing system calculates the 3-dimensional position of each marker based on the 2-dimensional positions on all of the cameras' pictures. The system's time resolution is 60 Hz and spatial resolution is about 1 mm in the experimental environment. The attaching position of each marker is shown in Figure 4.

D. Robot controller

The robot controller acquires the human's behavior from the sensors and executes the embodied cooperative behaviors corresponding to the human's behavior. The robot controller consists of behavior modules and a behavior module selector. We used a PentiumIII PC (600 MHz) for the robot controller. The details of the robot controller are described below.

1) Behavior modules: The embodied cooperative behaviors observed in Section II as head movements, arm movements, and utterances are implemented as behavior modules (Table I). Henceforth, each behavior module is described with its name identifier, such as Rsr, shown inside the brackets.

TABLE I

IMPLEMENTED BEHAVIOR MODULES

right arm	left arm
same motion as human's right hand (Rsr)	same motion as human's left hand (Lsl)
same motion as human's left hand (Rsl)	same motion as human's right hand (Lsr)
points the direction indicated with right hand (Rpr)	points the direction indicated with right hand (Lpr)
points the direction indicated with left hand (Rpl)	points the direction indicated with left hand (Lpl)
Do-nothing (Rno)	Do-nothing (Lno)
head	**utterance**
eye contact (Hec)	says "eh?" (Seh)
looks in the direction indicated with right hand (Hrp)	says "un." (Sun)
looks in the direction indicated with left hand (Hlp)	says "unun." (Suu)
nod (Hnd)	says "sorede." (Ssd)

Each behavior module related to the head and arms calculates the robot's destination angle of each joint of the head and arms based on numerically obtained data of human body movements. For instance, the calculations in Hec (eye-contact) and Rsr (synchronized arm movement) are as follows:

- Hec
  This calculates a robot's head direction vector and the human's head direction vector and then calculates the desirable angle of the robot's head so that these two vectors exactly indicate the opposite direction on a certain line.
- Rsr
  This calculates the angle of a human's shoulder and elbow and then reconfigures these angles into the angle of the robot's right arm so that the robot seems to show the same motion as the human does. (The same angles do not seem to show the same motion. Thus, we need to adjust the angles between the robot and humans).

2) Behavior module selector: The behavior module selector selects appropriate behavior modules from all implemented behavior modules according to the state of a human's embodied behavior.

[State of human embodied behavior]

The states of a human is embodied behavior consist of both the present embodied behavior state and the past embodied behavior state. The present embodied behavior state discriminates the following six states based on the input from sensors.

$Point$: Is he/she pointing with the right (left) hand?

$Direction$: Which side (right or left) of robot is he/she pointing toward?

$Move$: Is the right (left) hand moving? (Is the right (left) hand moving more than threashold speed?)

$Active$: Is he/she using the right (left) hand(pointing or indicating the direction gesture or so) for route guidance?

Hit : Is he/she staying in the region where the robot's right (left) hand might hit him/her?

$Speech$: Is he/she speaking?

The past embodied behavior state discriminates the following five states based on the past selection of behavior modules.

- Has the behavior module related to its head continued for the past few continuous seconds?
- Has Hrp or Hlp continued for some continuous seconds?
- Has Rpr, Rpl, Lpr or Lpl continued for the past few continuous seconds?
- What has been the amount of hand movements during the past few continuous seconds.
- What did it last say?

[Behavior selection rules]

Behavior selection rules are prepared for autonomously switching the appropriate embodied behavior modules. The implemented rules are mainly retrieved from the knowledge in a previous experiment with WOZ settings[11], where a human operator switches the behavior modules. As a result of the previous experiment, we found that the human operator mainly follows the following rules.

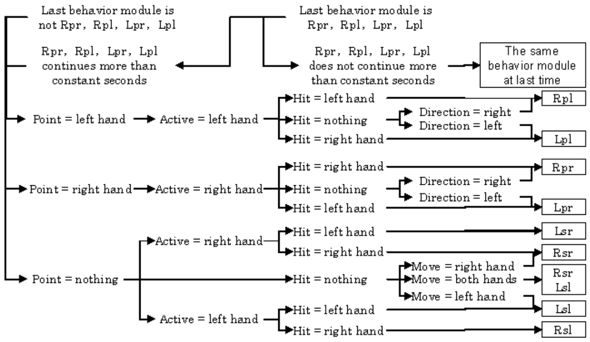


Fig. 5. Arm behavior module selection rule

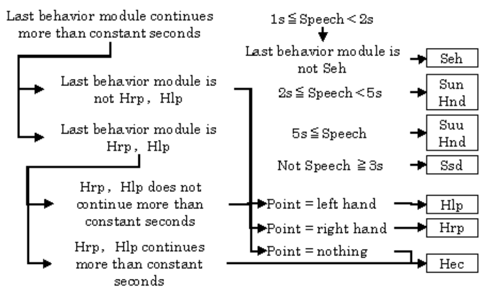


Fig. 6. Head and Voice behavior module selection rule

- Eye contact and the same arm movement are usually selected.
- When a subject points in a certain direction, it points in the same direction and looks toward the pointed direction.
- Backchannel feedback is given in response to the explanation of a subject (after a certain blank after humans' utterances).

Following these rules, we have implemented the behavior selection rules. The rules refer to the state of the present embodied behavior and the past embodied behavior. Figures 5 and 6 describe all implemented rules related to the arms and those related to the head and utterances, respectively. For example, in Figure 5 the last behavior module is not Rpr, Rpl, Lpr, and Lpr, a human is pointing with the right hand (Point = right hand), the human is using the right hand for route guidance (Active = right hand), the human is not staying in the region where either of the robot's hands might hit him or her (Hit = nothing), the human is pointing to the left side (Direction = left), and then Lpr is selected.

E. Delay of reaction

We believe the delay of the reaction in an embodied cooperative behavior is very important. If a robot performs such an embodied cooperative behavior instantly when a human does something (for example, when the human points, the robot's head immediately turns in the same direction), it is evidently unnatural. Thus, we measured the delay of reaction among humans and implemented the delay into the developed system.

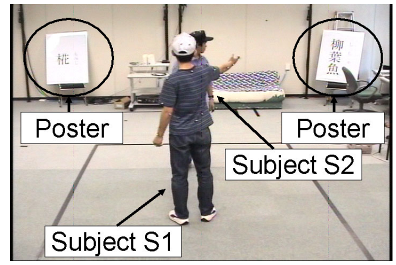


Fig. 7. Measurement of delay time

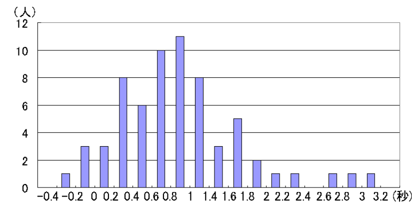


Fig. 8. Distribution of delay time

[Measurement procedure]

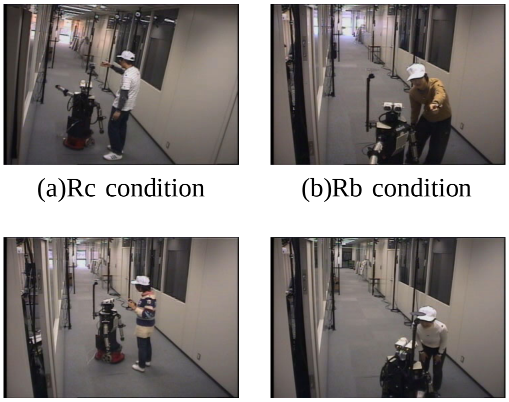
We placed four posters, P1, P2, P3, and P4, in each corner of a room ($8\ m \times 15\ m$). The posters described difficult Kanji characters (since Kanji or Chinese characters describe the meaning, even Japanese adults usually do not know the readings of difficult Kanji). Two subjects S1 and S2 were face-to-face in the center of the room. S1 pointed at a poster, and said the reading of the Kanji to teach the reading to S2. S1 repeated this for each poster from P1 to P4. The task (teach the reading of the Kanji) is a pseudo task so that the subjects would not be nervous about their the body movements. The true purpose was to measure the delay of the movements from the start of S1's to that of S2's, which were measured by using a motion capturing system. The setup of the experiment is shown in figure 7.

[Calculation method]

By using the numerically obtained body movement data, we determined the start time of S1's movement (t1) to be the earlier time of two movements: the time when S1 started to move his/her arm (the start of pointing) and the time when S1 started to move his/her head (the start of eye-gaze). Similarly, the start time of S2 (t2) was defined as the time when S2 started to move his/her head (the start of the looking motion). Thus, the delay time of the reaction is t2-t1.

[Results]

We employed 25-pairs of university students (23 men, 27 women) for the measurement. The delay of the reaction of inter-human communication (Figure 8) was retrieved as the average of these 25 samples. As a result, the delay time is 0.89 seconds (standard deviation 0.63). We utilized this parameter in the developed system so that the behavior module of the robot's head and arms reacted with 0.89 seconds delay.



(a)Rc condition (b)Rb condition

(c)Rv condition (d)Rs condition

Fig. 9. Scenes of experiment under Robot conditions

IV. EXPERIMENT

We conducted experiments to verify the significance of embodied cooperative behavior for human-robot communication. The hypothesis for the experiment was "if a robot performs embodied cooperative behaviors corresponding to the interacting human, the human will smoothly communicate with the robot to guide a route."

A. Experimental method

A human teacher (denoted as $Teacher$) taught a route to a destination to a robot or a human learner (denoted as $Learner$). The following is the detailed procedure of the experiment.

[Subjects]

We employed 81 university students as subjects of the experiment (36 men, 45 women). They had not visited this environment, so they did not know the route that they would teach or be taught.

[Experimental conditions]

We investigated the effect of the $Learner$'s embodied behaviors on the $Teacher$. We set five $Learner$ conditions as follows:

- Human condition (H condition)
  $Teacher$ teaches a human the route.
- Robot cooperative condition (Rc condition)
  $Teacher$ teaches the robot that performs embodied cooperative behaviors.
- Robot body move condition (Rb condition)
  $Teacher$ teaches the robot that performs embodied cooperative behaviors without utterances(Only body movements).
- Robot voice condition (Rv condition)
  $Teacher$ teaches the robot that performs embodied cooperative behaviors without body movements(Only utterances).
- Robot static condition (Rs condition)
  $Teacher$ teaches the robot that remains stationary.

We defined Robot condition (R condition) as the set of Rc, Rb, Rv, and Rs conditions.

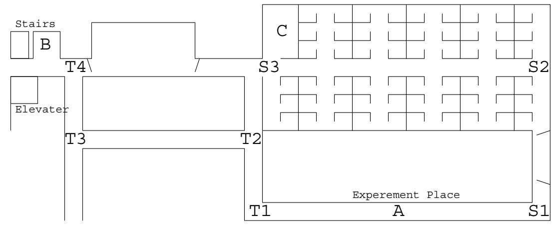


Fig. 10. Experimental environment

[Experimental environment]

Figure 10 shows the experimental environment. $Teacher$ told the route to the $Learner$ at A, and the destination that the $Teacher$ taught is one of two lobbies (B or C).

[Experimental procedure]

Table II shows an example of the experimental procedure. Since a human taught a route to another human, we needed to operate two subjects simultaneously. One of the subjects was named Subject A and the other subject was named Subject B.

TABLE II
EXPERIMENTAL PROCEDURE

order	condition	Subject A	Subject B	robot
1	H condition	$Teacher$	$Learner$	
2	R condition	$Teacher$		$Learner$
3	H condition	$Learner$	$Teacher$	
4	R condition		$Teacher$	$Learner$

Each subject participated in both H condition and R condition experiments. As R condition, one among Rc condition, Rb condition, Rv condition, and Rs condition was chosen randomly. In H condition, each subject behaved as both $Teacher$ and $Learner$. In addition, an experimenter guided the $Teacher$ along the route that he or she would teach to the $Learner$ before the experiment. The order of the two experiments (R and H conditions) was counterbalanced. (For half of them, we conducted the experiments in the H-R order, while the R-H order was used for the rest.)

[Evaluation method]

We administered a questionnaire to obtain subjective evaluations. In the questionnaire, we considered the influence of embodied cooperative behvaviors that affect communications. Specifically, we investigated aspects of conveying the iformation and aspects of smoothness. Aspects of smoothness is aspects of reliable communication and aspects of sympathetic interaction. Thus, the following questions were used in the questionnaire. The subjects answered each question on a 1-to-7 scale, where 1 stands for the lowest evaluation and 7 stands for the highest evaluation.

- Aspects of conveying information
  - Time to recall the route
  - Easiness of teaching the route to the partner
- Aspects of reliable communication

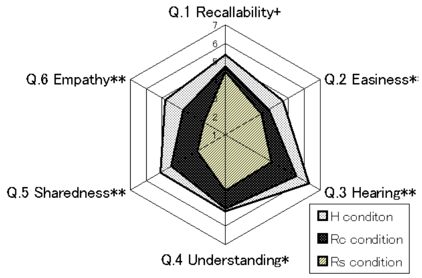


Fig. 11. Comparision of subjective evaluation between Human condition, Robot cooperative condition, and Robot static condition

  - The partner's listening to the guidance
  - The partner's understanding of the guidance
- Aspects of sympathetic interaction
  - Your feelings of sharing information with the partner
  - Your empathy with the partner.

B. Experimental hypothesis and predictions

The hypothesis and prediction for the experiment are as follows:

[Hypothesis]

Due to the embodied cooperative behavior of the $Learner$, the $Teacher$ teaches the route more smoothly.

[Prediction]

The embodied cooperative behavior of the $Learner$ positively affects the $Teacher$. As a result, subjective evaluation of $Teacher$ to $Learner$ of reliable and sympathetic aspects under the R conditions with embodied cooperative behaviors will be better than under the Rs condition without an embodied cooperative behavior.

C. Experimental results

By analyzing the experimental result, we verified the hypothesis and prediction in Section IV-B.

[Verification of prediction]

Table III shows the average, standard deviation, and the result of analysis of variance (ANOVA) among H, Rs, and Rc conditions of the six items on the questionnaire. The comparison is also illustrated in Figure 11.

As a result of ANOVA, there is a significant difference in Q.2, Q.3, Q.4, Q.5, and Q.6, and nearly a significant difference in Q.1. For each of the significant items, an LSD (least significance difference) method provided a multiplex comparison among the H, Rs, and Rc conditions as follows:

- Q.2 ($MSe = 2.1594, p < .05$)
  The value of H condition $>$ The value of Rc condition
  The value of H condition $>$ The value of Rs condition
- Q.3 ($MSe = 1.6873, p < .05$) Q.6 ($MSe = 1.6633, p < .05$)
  The value of H condition $>$ The value of Rc condition $>$ The value of Rs condition
- Q.4 ($MSe = 2.0218, p < .05$) Q.5 ($MSe = 1.8649, p < .05$)
  The value of H condition $>$ The value of Rs condition
  The value of Rc condition $>$ The value of Rs condition

Only for speculation, an LSD method was applied to Q.1, which showed a significant difference between H condition and Rs condition ($MSe = 2.5984, p < .05$).

These results proved that subjective evaluation for the robot with embodied cooperative behaviors (Rc) is higher among all aspects of communication compared with the robot without body movements and voice (Rs), while subjective evaluation for Rc was lower than H condition in Q.2 "Easiness" Q.3" "Listenig," and Q.6 "Empathy." In total, we confirmed prediction that the $Learner$'s subjective evaluation for $Teacher$ in Rc condition is better than that of Rs condition. That is, the positive effect of embodied cooperative behavior of the $Learner$ on the $Teacher$ was verified.

[Verification of the body movements effects and the the vocal effects]

Detailed analysis of above verification is performed as follows. Table IV shows the average and standard deviation values. It also describes the results of two-way factorial ANOVA among Rc, Rb, Rv and Rs, where the two factors are "body movements" and "voice" which comprise the embodied cooperative behaviors. The Rc condition has both factors, but the Rb condition has only the factor of body movements, the Rv condition has only the factor of voice, and the Rs condition has neither factors.

As a result of the two-way factorial ANOVA, there is a significant simple main effect for the body movements factor in Q.3, Q.5, and Q.6, and almost no significant effect in Q.4. For the voice factor, there is a significant simple main effect in Q.5. There is significant statistical interaction between the body movements factor and the voice factor in Q.3 and Q.5. Since there is a statistical interaction in Q.5 "Sharedness" and a simple main effect of the body movements factor in Q.6 "Empathy," the aspects for sympathetic communication are affected by both the body movements factor and the voice factor of the cooperative body movements. Both factors also affect the aspects for reliable communication (Q.3 "Listening" and Q.4 "Understanding"). Thus, the harmony of the body movements factor and voice factor promote sympathetic and reliable communication. Regarding the effects for conveying information aspects, no significant effect is caused by the body movements factor nor the voice factor.

V. Discussions

A. Hypothesized effect of embodied cooperative behavior on aspects for the conveying information

Regarding the subjective evaluation on the aspects for conveying the information, there is nearly a significant effect of embodied cooperative behavior (Rc condition) compared to the static robot (Rs condition) in Q.1 "Recallability". This suggests the positive effects of embodied cooperative behavior on the aspects for conveying the information, even though these effects are not so large as

TABLE III

AVERAGE VALUE AND ANALYSIS OF SUBJECTIVE EVALUATION BETWEEN H CONDITION, RC CONDITION AND RS CONDITION

question	Question 1 Recallability	Question 2 Easiness	Question 3 Listening	Question 4 Understanding	Question 5 Sharedness	Question 6 Empathy
H conditon(40 subjects)	5.375(1.4796)	4.675(1.4392)	6.275(1.0619)	5.175(1.3937)	5.100(1.3166)	4.775(1.2297)
Rc condition(20 subjects)	4.750(1.8028)	3.750(1.7130)	5.500(1.6044)	5.050(1.6051)	4.400(1.5694)	3.650(1.4244)
Rs condition(20 subjects)	4.450(1.6694)	3.250(1.2513)	3.950(1.5035)	4.050(1.2763)	2.800(1.2400)	2.35(1.2680)
Result of ANOVA (F(2,77))	p=.090 (+) F=2.48	p<.01 (**) F=6.97	p<.01 (**) F=21.36	p=.015 (*) F=4.41	p<.01 (**) F=18.93	p<.01 (**) F=24.02
Multiplex comparison	H > Rs	H > Rc H > Rs	H > Rc Rc > Rs	H > Rs Rc > Rs	H > Rs Rc > Rs	H > Rc Rc > Rs

TABLE IV

COMPARISON OF SUBJECTIVE EVALUATION BETWEEN ROBOT CONDITIONS

question	Question 1 Recallability	Question 2 Easiness	Question 3 Listening	Question 4 Understanding	Question 5 Sharedness	Question 6 Empathy
Rc condition(20 subjects)	4.750(1.8028)	3.750(1.7130)	5.500(1.6044)	5.050(1.6051)	4.400(1.5694)	3.650(1.4244)
Rb condition(21 subjects)	4.429(1.8048)	3.667(1.7416)	5.762(0.8891)	4.571(1.5353)	4.381(1.4992)	3.762(1.5134)
Rv condition(20 subjects)	5.050(1.5381)	3.350(1.4244)	5.150(1.2680)	4.450(1.3169)	4.400(1.2312)	3.000(1.2566)
Rs condition(20 subjects)	4.450(1.6694)	3.250(1.2513)	3.950(1.5035)	4.050(1.2763)	2.800(1.2400)	2.35(1.2680)
Factor of body movements F(1,77)	p=.681 (n.s.) F=0.17	p=.239 (n.s.) F=1.41	p<.01 (**) F=13.76	p=.084 (+) F=3.06	p=.013 (*) F=6.50	p<.01 (**) F=11.43
Factor of voice F(1,77)	p=.229 (n.s.) F=1.47	p=.792 (n.s.) F=0.07	p=.112 (n.s.) F=2.59	p=.174 (n.s.) F=1.88	p=.011 (*) F=6.82	p=.383 (n.s.) F=0.77
Interaction F(1,77)	p=.719 (n.s.) F=0.13	p=1.00 (n.s.) F=0.00	p=.014 (*) F=6.29	p=.921 (n.s.) F=0.01	p=.013 (*) F=6.50	p=.215 (n.s.) F=1.56

those of the other aspects. We believe that the Learner's embodied cooperative behaviors will promote the Teacher's behaviors. That is, the Teacher will easily recall such geometric information by performing body movements such as pointing and looking in the indicated direction, which will be encouraged by the Learner's behavior, and easily teach it to the Learner. Our future work will involve verifying this hypothesis by developing the robot with more sophisticated embodied cooperative behavior.

B. Grade of the influence of each factor in the effect of interaction

As a result of the experiment, statistical interaction was found between the body movement factor and the vocal factor in Q.3 "Listening" and Q.5 "Sharedness" (Table IV). That is, there was a combination effect of these two factors. To investigate the contribution of each factor, we conducted ANOVA between Rb and Rv conditions. As a result, it is nearly a significant difference that the Rb condition is larger than the Rv condition in Q.3 ($p < .10$). Thus, it is suggested that the effect for "Listening" is greatly affected by the body movements factor rather than the voice factor. Moreover, since there are the simple main effect of both factors as well as statistical interaction between them in Q.5, it seems that these two factors cause a ceiling effect. In other words, each factor has sufficient effects on the subjective evaluation to make the effect of their mixture not seem so much bigger than that of each of them. We believe that the subjects received adequate signals of sharing the information from the robot merely by voice or body movements.

VI. CONCLUSIONS

This paper reported the development of an autonomous interactive humanoid robot that is capable of embodied cooperative behaviors corresponding to a human's behaviors. In previous research, we have developed an interactive robot Robovie [9], [10], verified the importance of embodied cooperative behavior (spatial and temporal synchrony of motion) from humans [5], [6], and fundamental effect of embodied cooperative behavior from remote-controlled robot [11]. In this paper, we reported the autonomous mechanism for selecting appropriate robot behavior and verified the effect of the mechanism. In addition, we analyzed the effect of each of body movement and utterance where we found that rather body movements affected on empathy and feelings of listening. We believe these findings again make it clear the importance of embodiment in human-robot communication.

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