How contingent should a communication robot be?

Fumitaka Yamaoka[1,2] Takayuki Kanda[1] Hiroshi Ishiguro[1,2] Norihiro Hagita[1]

[1]*ATR IRC Laboratories*
Kyoto 619-0288
Japan

[2]*Osaka University*
Osaka 565-0871
Japan

yamaoka@atr.jp, kanda@atr.jp, ishiguro@atr.jp, hagita@atr.jp

ABSTRACT

The purpose of our research is to develop lifelike behavior in a communication robot, which is expected to potentially make human-robot interaction more natural. Our previous research demonstrated the importance of a robot's contingency for lifelikeness [1]. On the other hand, perfect contingency seems to give us a non-lifelike impression. In order to explore the appropriate contingency for communication robots, we developed a robot system that allows us to adjust its contingency to an interacting person in a simple imitative interaction. As a result of an experiment, we identified the relationships between the degree of contingency and the subjective impressions of lifelikeness, autonomy, and preference. However, the experimental result also seems to suggest the importance of the complexity of interaction for investigating the appropriate contingency of communication robots.

Categories and Subject Descriptors

H.5.2 **[Information Interfaces and Presentation]**: User Interfaces -Interaction styles, I.2.9 **[Artificial Intelligence]**: Robotics

General Terms

Design, Experimentation, Human Factors, Verification

Keywords

Lifelike behavior, Contingency, Human-robot interaction, Communication robot

1. INTRODUCTION

Our research goal is to develop a "communication robot" that behaves as a peer partner and supports our daily activities by providing communication support as well as physical support. For the communication purpose, we believe that humanoid robots are particularly suitable. The human-like bodies of humanoid robots enable people to intuitively understand their gestures and cause people to unconsciously behave as if they were communicating with humans. That is, if a humanoid robot effectively uses its body, people will communicate naturally with it. Many researchers have used humanoid robots in order to accomplish this kind of human-like natural communication with people. Previous works showed the effective use of body properties in communication, such as head movements, facial expressions, and arm gestures [2] [3] [4] [5]. However, it is not clear yet what kind of behavior will make it possible to communicate with people naturally.

We believe that it is important for a communication robot to approach humans as natural communication partners. In general, humans do not attempt to communicate with inanimate things because we unconsciously recognize that the inanimate cannot be a communication partner. The literature in developmental psychology has shown that infants acquire the ability to distinguish animate from inanimate objects at an early stage, where the inanimate is addressed as being non-communicative [6]. Therefore, "lifelike" behavior is essential for robots that are to engage in natural communication.

Table 1 Animate - Inanimate Distinction Characteristics

	Characteristic properties	Animate	Inanimate
a	Onset of motion	can move by itself	is moved by others
b	Line of trajectory	moves irregularly	moves smoothly
c	Form of causal action	can move at a distance	moves from contact
d	Pattern of Interaction	motion against other's approach	
		contingent	non-contingent
e	Type of causal role	role in interaction	
		only recipient	agent or recipient
f	Purpose of action	motion looks like	
		goal-directed	without goal
g	Influence of mental states	motion looks	
		intentional	accidental

We have already investigated the effect of "lifelike" behavior for human-robot interaction [1]. An infant distinguishes the animate from the inanimate based on seven characteristics: five motion related (a ~ e) and two psychological (f, g) properties [6], which are described in Table 1. We can easily distinguish animate from inanimate based on these properties. For example, consider the differences between a ball and a dog based on the findings. A ball always doesn't react to our approach, while a dog does, for example, by running away or approaching us (d). A ball always plays the recipient role in interaction with others, while a dog can play both recipient and agent roles. For instance, a dog runs away from our approach but sometimes bites us (e). Although psychological properties are subjective, we usually interpret a dog's purpose and mental condition more easily than a ball's. For example, "a dog moves toward food because it is hungry" (f) (g). Thus, according to these properties, balls are inanimate, and dogs are animate. We considered that a robot could make humans think of it as "lifelike" if its behavior satisfies these seven animate features. Thus, we developed a robot to satisfy them [1]. For example, it can behave in a contingent way in relation to the person interacting with it. As a result of experiments, we verified the effectiveness of the lifelike behavior as well as the importance of the contingent behavior. The importance of contingency for interactive robots was also demonstrated by Arita et al. [7].

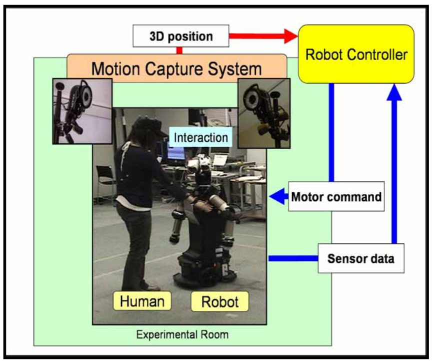

Fig. 1 Overview of system

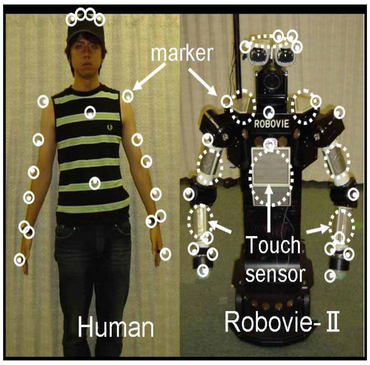

Fig. 2 Human and Robot

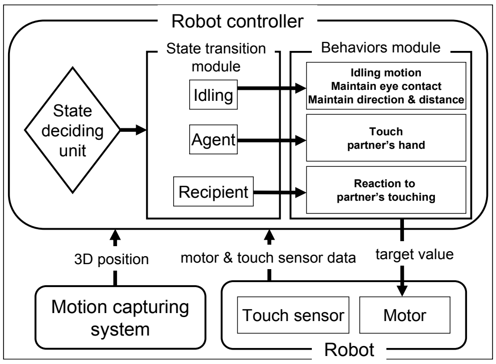

Fig. 3 System configuration of "lifelike"

However, just how much contingency makes humans feel that something is "lifelike" and "communicative" it has not yet been investigated. "Contingency" is defined as a correspondence of one's behavior to another one's behavior. Although it is ambiguous, it has not been well defined yet. In the field of developmental psychology, it is said that infants associate highly contingent behavior with the animate, but perfectly contingent behavior with the inanimate. For example, a ceiling light in a room can be turned on/off by a switch, which is perfectly contingent but not at all lifelike and communicative. We believe that a "lifelike" robot needs a certain level of contingency, but it should not have perfect contingency. In this paper, we will try to address this issue with a subjective experiment wherein we developed a robot and controlled its degree of contingency by changing the ratio of time that the robot imitates the subject's behavior.

Our research approach is also unique in terms of methodology, which bypasses the difficulties of developing the cognitive ability of a robot. There are mainly two research directions for developing communication robots. One is to develop the cognitive abilities of a robot, including visual, auditory, tactile, and any other sensor information. The other is to design robot behavior in order to make human-robot communication more natural. We believe that these two research directions are separable. However, until now the latter research has been waiting for the improvement of the former one. We take the latter approach by using a motion capturing system as a robot's visual sensor. We believe that this approach enables us to acquire important findings for the development of communication robots.

2. SYSTEM CONFIGURATION

The system configuration, which is described below, was utilized in both our previous experiment (section 3) and this experiment (section 4).

2.1 System outline

The system consists of a humanoid robot, sensors, and Robot-Controller. An overview of the system is shown in Figure 1. A motion capturing system captures the body motion data of humans and robots. Based on the motion data, the Robot-Controller recognizes human behavior and commands the robot to behave according to the human's behavior.

2.2 Humanoid robot "Robovie"

We used a humanoid robot named "Robovie," characterized by its human-like body expressions (Fig. 2) [8]. Its human-like body consists of eyes, a head, and arms that generate complex body movements required for communication. Robovie has two 4 DOF arms, a 3 DOF head, and two 2 DOF eyes. Thus, its body has sufficient expressive ability to make human-like gestures. In addition, it has two wheels to move (forward-reverse travel and rotation).

2.3 Sensors

We integrated touch sensors and a motion capturing system into the system. A total of eight touch sensors are attached to the robot's body (head, belly, right or left upper arm, lower arm, and shoulder) and are used to check whether a human touches the robot's body, including the broken line in Fig. 2. The motion capturing system acquires 3-dimensional numerical data on human and robot body movements. It consists of 12 sets of infrared cameras with an infrared irradiation 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 the cameras' pictures. In our experimental environment, the system's time resolution is 60 Hz and the spatial resolution is about 1 mm. The position of each marker is shown, which includes the solid line in Fig. 2.

2.4 Robot-Controller

The Robot-Controller obtains human behavior from the sensors. The data from the motion capturing system informs the motion data of a human and the robot. The data from touch sensors informs of contact with humans. Based on these data, the Robot-Controller executes the robot's behavior according to human behavior. We can change this Robot-Controller according to the purpose of the experiment. In previous experiments, we designed this to make the robot perform various behaviors which satisfy the seven properties of "lifelike." In this experiment, we designed this to make the robot imitate a human's behavior based on the degree of contingency. The details of the Robot-Controller are described in the third and fourth sections.

3. "LIFELIKE" ROBOT BEHAVIOR

Based on findings in developmental psychology, we have implemented a lifelike robot behavior and verified its effectiveness with an experiment. Although this is already reported in [1], we will briefly describe it since it has a strong relationship with the current study about contingency.

We developed the robot's behavior to satisfy seven features, which are shown in Table 1, for animate existence according to

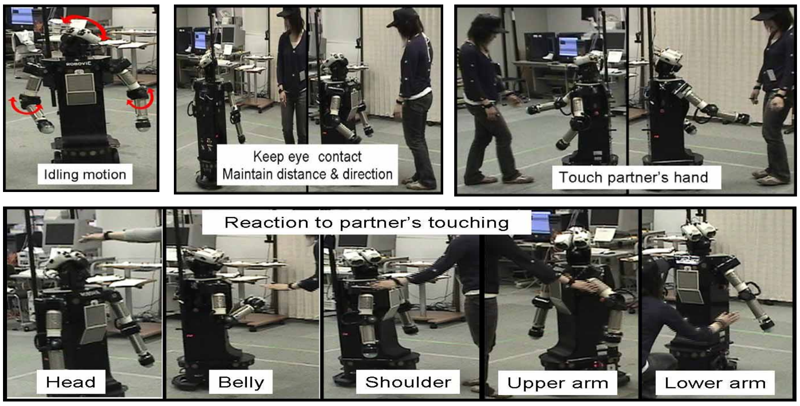

Fig. 4 Behaviors

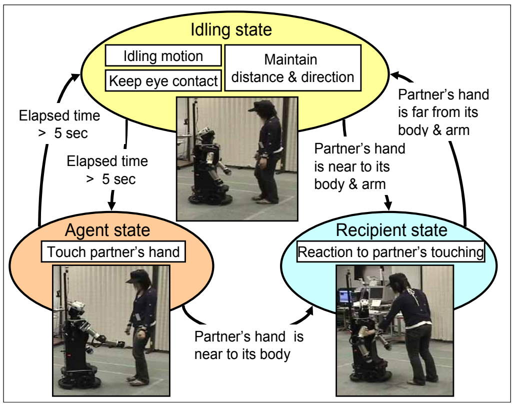

Fig. 5 State transition

developmental psychology. In our experiment, the robot didn't utter sounds because we believed that a robot without utterances can still be an "lifelike" object, like an animate being, other than a human. The system flow is shown in Fig. 3.

3.1 Robot Controller – Lifelike robot behavior

We developed the Robot-Controller for an autonomous humanoid robot that performs "lifelike" actions and autonomously selects appropriate behaviors according to human behavior.

[Behaviors] The different behaviors managed by the Robot-Controller for our robot are implemented as below:

♦ ***Idling motion*** (Fig. 4 upper left) **-** The robot performs an idling motion, moving its arm and neck at intervals.

♦ ***Maintain eye-contact*** (Fig. 4 upper middle) **-** The Robot-Controller forces the robot to track its partner's face by controlling its eye and neck motors.

♦ ***Maintain distance and direction*** (Fig. 4 upper middle) **-** The Robot-Controller makes the robot maintain a distance and direction from a partner. The distance, about 60 cm, is selected so that the robot's arms cannot touch the partner's body. The direction is towards the face of the robot's partner.

♦ ***Touching a partner's hand*** (Fig. 4 upper right) **-** The robot attempts to touch the partner's hand by making its hand approach the partner's hand by controlling its arms and wheels

♦ ***Reaction to partner's touching*** (Fig. 4 lower part) **-** When the distance between a partner's hand and each touch panel is less than 30 cm or when the touch sensor of the robot reacts, the robot decides that the partner is trying to touch the robot. When this occurs, the robot reacts to the approaching partner's hand and performs a behavior that represents intention, which in our case, is that it dislikes being touched. Before the partner can touch the robot's body, the robot tracks the partner's hand by controlling its eye and neck and dodges the partner's hand by controlling its arms and wheels. As shown in the lower part of Fig. 4, such dodging behavior is different for each touch part (eight patterns according to eight touch parts).

[State transition] The Robot-Controller selects from the following three states, according to the situation and commands the robot to behave based on this state (Fig. 5).

➢ **Recipient State -** The robot performs "*Reaction to partner's touching*."

➢ **Idling State**

The robot performs "*Idling motion*", "*Maintain eye contact*", and "*Maintain distance and direction*" when the partner does not try to touch it.

➢ **Agent State**

If the Idling state continues more than five seconds, the robot performs "*Touching partner's hand*" for five seconds. But, if the partner tries to touch the robot's body or arm, i.e., anything except for the robot's hand that is trying to touch the partner, the state changes from Agent to Recipient.

3.2 Considerations about our robot's animate properties

We developed a robot that can satisfy the seven properties of the findings, as described below.

◆ **Motion-related characteristics** - Concerning *a) onset of motion* and *b) line of trajectory*, these properties have already been satisfied by most of the existing robots. Our robot can move by itself, with nonlinear motion. On the other hand, for stand-alone robots, it is difficult to satisfy *c) form of causal action*, *d) pattern of interaction*, and *e) type of causal role* properties because the cognitive ability of the robots is too low. Our robot satisfies these properties by utilizing a motion capturing system. It can move without contact and react according to its partner's motion. In addition, it can change its role from agent to recipient or from recipient to agent.

◆ **Psychological characteristics** - Although characteristics *f) purpose of action* and *g) influence of mental state* depend on individuals' impressions, we believe that our robot satisfies these properties because of the following two behaviors. First, it avoids human contact, which could easily be understood as the purpose of an action. Similarly, a robot trying to touch a human hand is easily understood as having a purpose. These behaviors seem to satisfy characteristic *f*. Second, the three internal states of the robot- idling, agent, and recipient- are easily recognized by humans and are assumed to reflect the mental state of the robot. Thus, we believe that it also satisfies characteristic *g*.

3.3 EXPERIMENT - Effectiveness of the robot for "lifelikeness"

We conducted experiments with subjects to verify the effect of our robot with regard to "lifelikeness."

[Subjects] We used 23 university students as subjects in the experiment (11 men, 12 women) whose average age was 19.2.

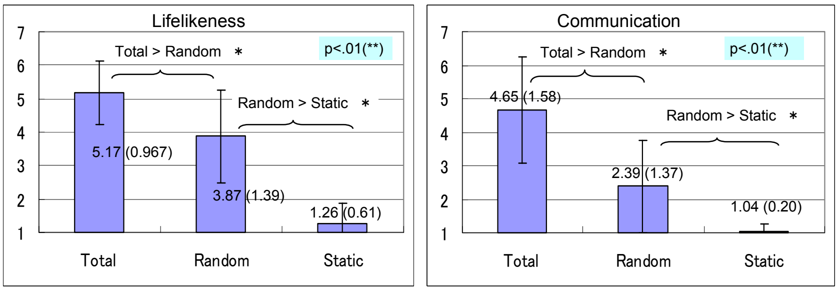

Fig. 6 Experimental result 1 – Impression evaluation

[Instruction for subjects] We instructed the subjects to interact with the robot. The experimental time per condition was a maximum of three minutes. Moreover, we instructed the subjects to stop interacting with the robot when they got bored.

[Experiment conditions] We set the following three conditions:

1. ***Total* condition**
The robot behaved according to human behavior and moved by the commands of the Robot-Controller. During interaction, the interaction records, which are the input data of each motor of the robot, were recorded for next subject's Random condition.

2. ***Random* condition**
The robot behaved randomly to human behavior. In other words, it didn't react to human behavior. The robot only replayed previous interaction records, recorded when it interacted with another subject in the Total condition. By utilizing this method, in the entire experiment, there is no difference between *Total* and *Random* conditions regarding the quality of the robot's movements.

3. **Static condition**
The robot stood still during the interaction.

[Evaluation method] We administered a questionnaire to obtain subjective evaluations for every condition. The questions of the questionnaire are the degree of "lifelikeness" and "communication." Subjects answered each question on a 1 to 7 scale, where 1 is the lowest evaluation and 7 is the highest.

[Subjects' impressions of the robot] Figure 6 shows the results of subjects' impression evaluation for the robot in each condition. As a result of the within-subject design ANOVA, there was a significant difference regarding "lifelikeness," and "communication." Moreover, for each of the significant items, a least significant difference (LSD) method provided a multiple comparison among all conditions as follows:

- **Lifelikeness** (F(2,22)=101.99, p<.01)
  Value of "Total" > Value of "Random" > Value of "Static" (MSe=0.895, p<.05)
- **Communication** (F(2,22)=58.99, p<.01)
  Value of "Total" > Value of "Random" > Value of "Static" (MSe=1.296, p<.05)

These results proved that humans recognize the differences between each condition, and the "*Total*" condition had the highest evaluation regarding "Lifelikeness," and "Communication."

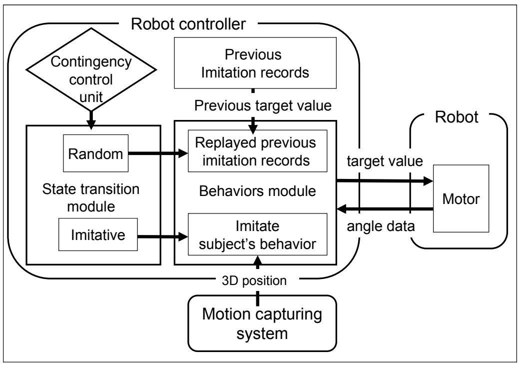

Fig.7 System flow of the imitation experiment

3.4 Summary

We have verified the effectiveness of a robot developed to satisfy animate features as described in the findings of developmental psychology. Even though the robot's motion of the "*Total* condition" is the same as that of the "*Random* condition" in terms of the quality of motion, experimental results showed a significant difference between the "*Total* condition" and the "*Random* condition". This result suggests that to be contingent toward a partner's motion is an important property for making humans feel that a robot is "lifelike" and a "communication partner."

4. CONTINGENCY AND IMPRESSION

As shown in the previous section, the experimental result demonstrated the importance of "contingency," but the appropriate degree of contingency was yet unclear. We then investigated how much contingency in a robot makes humans feel that it is "lifelike" and a "communicative object." We choose an imitation setting for the experiment because it is a simple situation where we can adjust the degree of contingency. We controlled the degree of contingency by changing the ratio of time that the robot imitates the subject's behavior. Base on this method, we investigated the relationship between the degree of contingency and the subject's impression of the robot.

4.1 Robot controller - Imitation based on the degree of contingency

We developed a Robot-Controller for an autonomous humanoid robot that behaves toward a human's behavior based on a degree of contingency. The system flow is shown in Fig. 7.

[Imitative behavior control] The Robot-Controller calculates the destination angle of each joint of the robot's head and arms based

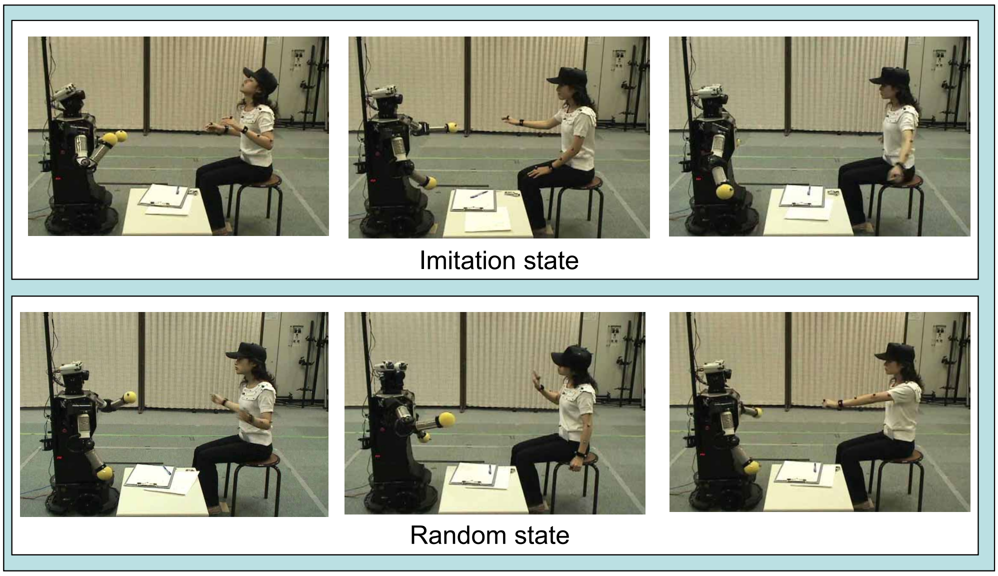

Fig. 8 Imitation and random states

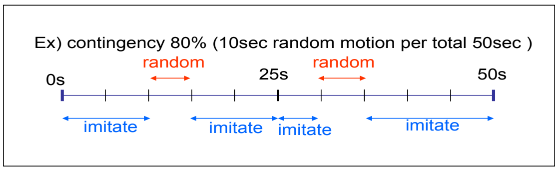

Fig. 9 Contingency control

on numerically obtained data of human body movements. The imitative method is as described below.

The position of the markers, which are given in the following explanation, is described as the position in each of the relative coordinates. (The position of all markers attached on each robot and subject are transformed from absolute coordinates to relative coordinates which center on the midpoint of each body. The midpoint of the body is between the position of the markers that are attached to the left and right shoulders.)

- **Imitative motion of the head**

We define the subject's marker attached to the left front head as $LFHD_S$, right front head as $RFHD_S$ and center back head as $CBHD_S$. When we define the midpoint between $LFHD_S$ and $RFHD_S$ as $CFHD_S$, the head vector of the subject's $\overrightarrow{Head_S}$ is

$$\overrightarrow{Head_S} = \overrightarrow{CBHD_S CFHD_A} \qquad (4.1.1)$$

In the same way, we also can calculate the head vector of the robot's $\overrightarrow{Head_R}$. The robot controls its head so that the angle between $\overrightarrow{Head_S}$ and $\overrightarrow{Head_R}$ becomes zero.

- **Imitative motion of arm**

We define the subject's marker attached to the left elbow as $LELB_S$, and left finger as $LFIN_S$. Normalization of the left upper arm vector $\overrightarrow{LUA_S}$ from the left shoulder to the left elbow is

$$\overrightarrow{LUA_S} = \frac{\overrightarrow{LSHO_S LELB_S}}{\left|\overrightarrow{LSHO_S LELB_S}\right|} \qquad (4.1.2)$$

Moreover, normalization of the left forearm vector $\overrightarrow{LFA_S}$ from the left elbow to the left finger is

$$\overrightarrow{LFA_S} = \frac{\overrightarrow{LELB_S LFIN_S}}{\left|\overrightarrow{LELB_S LFIN_S}\right|} \qquad (4.1.3)$$

In the same way, it also can calculate $\overrightarrow{RUA_S}, \overrightarrow{RFA_S}$ for the right arm.

Moreover, in the same way, it can obtain the robot's arm vector $\overrightarrow{LUA_R}, \overrightarrow{LFA_R}, \overrightarrow{RUA_R}$, and $\overrightarrow{RFA_R}$.

In the case where the robot imitates the motion of the subject's right arm, the robot controls its left arm so that both of the angles that are between $\overrightarrow{RUA_S}$ and $\overrightarrow{LUA_R}$, and between $\overrightarrow{RFA_S}$ and $\overrightarrow{LFA_R}$, become zero. In the same way, the robot imitates the motion of the subject's left arm.

[Contingency control] The robot had two states: imitative or random. In the imitative state, the robot behavior was contingent to the subject's behavior by imitating the subject's behavior (A scene showing the imitative state is shown in the lower part of Fig. 8). In the random state, the robot behavior was not contingent to the subject's behavior because it behaved randomly to the subject's behavior (A scene showing the random state is shown in the upper part of Fig. 8). We controlled the degree of contingency by changing the ratio of time that the robot imitates the subject's behavior.

In our experiment, we define five seconds as one section in which the robot is either in the imitative or random state. The contingency is defined by the percentage of the imitative sections in a five-section block, which is a total of 25 seconds. In the random section, the robot replayed previous interaction records, which had been recorded when it interacted with another subject in the imitative state. Imitative and random sections are randomly allocated based on the degrees of contingency (This example is described in Fig. 9).

4.2 Experimental method

Since the difference in robot behavior was subtle among the different degrees of contingency, we conducted a set of comparisons in a controlled experiment setting where the robot performed a simple interaction of imitation.

[Subjects] We used 20 university students as subjects in the experiment (7 men, 13 women) whose average age was 19.1.

[Instruction] We instructed the subjects to move their arm and head, and to observe the robot's behavior toward their behavior. Moreover, we instructed the subjects to follow the following instructions.

- To face front toward the robot while sitting in a chair
- To always move your arms and head
- Not to move (tilt, twist) your upper body

[Experiment conditions] The experiment conditions consist of a total of six patterns with contingency levels of 0, 20, 40, 60, 80 and 100 %. When the robot was in the random state, it recalled behaviors from past interaction records, recorded when it had interacted with an experimenter in the imitative state. The experimental time for each trial was 50 seconds. The delay of reaction was set at 1 second.

[Evaluation method] We utilized a paired comparison method as the evaluation method. After the subjects interacted with the robot in two trials with different contingency levels selected from among six possible levels, we asked which trial seemed "lifelike", which seemed "autonomous", and which one the subjects preferred. The number of comparisons is ${}_6C_2=15$ times.

4.3 Experimental results

The result of the paired comparison is shown in Table 2. The number on each of the columns means how many of the subjects selected the pattern against the pattern on the row. For example, in the case where it compares 0% with 20% contingency, 12 subjects chose 0% (8 subjects chose 20%) concerning the evaluation of "lifelike".

[Analysis based on the Bradley method] We used the Bradley method to analyze the relationship between the degree of contingency and the degree of each impression [9]. The details of this method are as follows:

We hypothesized a model in which each degree of contingency has a degree of impression evaluation, which is inherent and invariable. That is, we consider that each degree of evaluation against each pattern is defined as $\pi_0, \pi_{20}, \pi_{40}, \pi_{60}, \pi_{80}, \pi_{100}$. For ease of analysis, we defined this as follows;

$$\sum_i \pi_i = \pi_0 + \pi_{20} + \pi_{40} + \pi_{60} + \pi_{80} + \pi_{100} = 1$$

Table .2 Experimental result – paired comparisons

lifelike	0	20	40	60	80	100	total	Pi
0		12	10	10	9	10	51	0.171
20	8		9	10	8	10	45	0.141
40	10	11		13	9	6	49	0.161
60	10	10	7		12	11	50	0.166
80	11	12	11	8		10	52	0.176
100	10	10	14	9	10		53	0.182

autonomy	0	20	40	60	80	100	total	Pi
0	0	10	10	15	14	15	64	0.252
20	10	0	11	13	12	14	60	0.220
40	10	9	0	9	10	13	51	0.162
60	5	7	11	0	12	14	49	0.152
80	6	8	10	8	0	13	45	0.132
100	5	6	7	6	7	0	31	0.079

preference	0	20	40	60	80	100	total	Pi
0		6	5	4	5	4	24	0.053
20	14		12	7	3	6	42	0.109
40	15	8		11	5	5	44	0.118
60	16	13	9		8	8	54	0.169
80	15	17	15	12		9	68	0.274
100	16	14	15	12	11		68	0.274

Based on this, when the 0% pattern is compared with the 20% pattern, the probability that the 0% pattern LFA_R is selected is $\frac{\pi_0}{\pi_0 + \pi_{20}}$, and the probability that the 20% pattern is selected is $\frac{\pi_{20}}{\pi_0 + \pi_{20}}$. However, in the case of the actual experiment, the result has random noise. Therefore, the goal of analysis was to obtain the estimate value p_i of π_i based on experimental data. The estimate value p_i is obtained by the equation as follows:

$$\frac{f_i}{p_i} = n\sum_{j \neq i} \frac{1}{p_i + p_j} \qquad (4.3.1)$$

$$\sum_i p_i = 1$$

where t is the number of patterns, and n is the number of subjects. f_i is defined as the number of times that pattern i is selected among $n \cdot (t-1)$ times of judgment. Pattern i is compared with another $(t-1)$ pattern per subject.

In this paper, we used the approximation method below to calculate this equation (4.3.1). Based on experimental data, for example, in the case of "lifelike",

$f_0 = 51, f_{20} = 45, f_{40} = 49, f_{60} = 50, f_{80} = 52, f_{100} = 53$. When the approximate solution was calculated by defining that the zero order approximate solution of each estimate value, which are $p_0, p_{20}, p_{40}, p_{60}, p_{80}, and\ p_{100}$, is proportional to f_i, each zero order approximate solution is calculated as follow;

$$p_0^{(0)} = \frac{f_0}{\sum_i f_i}, p_{20}^{(0)} = \frac{f_{20}}{\sum_i f_i}, \cdots\cdots, p_{100}^{(0)} = \frac{f_{100}}{\sum_i f_i}$$

When these values are substituted to the right side of the equation (4.3.1), each first order approximate solution is obtained. For example, the first order approximate solution of pattern 0% $p_0^{(1)}$ is obtained by calculating the equation below.

$$\frac{51}{p_0^{(1)}} = 20 \cdot \sum_{j \neq i} \frac{1}{p_i^{(0)} + p_j^{(0)}} = 20 \cdot \left(\frac{1}{p_0^{(0)} + p_{20}^{(0)}} + \cdots + \frac{1}{p_{80}^{(0)} + p_{100}^{(0)}} \right)$$

In the same way, $p_{20}^{(1)}, p_{40}^{(1)}, \cdots, p_{100}^{(1)}$ are obtained. Every time we get the approximate solution, we need to check that the total of the approximate solution is one ($\sum_i p_i^{(m)} = 1$). If the total is not one, we need to prorate each approximate solution. When these values are substituted to the equation (4.3.1) again, the second order approximate solution is obtained. This calculation is continued until the solution converges. As a result of convergence, the final solution is obtained.

The final solution p_i of this experiment is shown in Table 2.

➢ ***The matching of the model***

The matching of the model examined by the goodness-of-fit test is as follows:

$$x_0^2 = \sum \sum \frac{(X_{ij} - X_{1ij})^2}{X_{1ij}} \qquad (4.3.2)$$

where X_{ij} is the number of judgments that i is better than j.

X_{1ij}, which is the expected value of X_{ij}, is calculated by $X_{1ij} = n \cdot \frac{p_i}{p_i + p_j}$.

If this x_0^2 is under the 5 percent point of X distribution where the degree of freedom is $({}_tC_2 - t + 1)$, the validity of π_i and the matching of the model are revealed.

Based on the result,

"lifelike": $x_0^2 = 6.89 < 18.307 = x^2(10, 0.05)$

"autonomy": $x_0^2 = 4.30 < 18.307 = x^2(10, 0.05)$

"preference" : $x_0^2 = 7.35 < 18.307 = x^2(10, 0.05)$

These results indicate the validity of π_i and the matching of the model because the model was not rejected.

➢ ***The difference of evaluation between each pattern***

Moreover, we evaluated the significant difference of evaluation between each pattern as follows:

$$B = n \sum_{i<j} \log(p_i + p_j) - \sum_i f_i \log p_i$$
$$x_0^2 = nt(t-1)\ln 2 - 2B \ln 10 \qquad (4.3.3)$$

If this x_0^2 is over the 5 percent point of x distribution where the degree of freedom is $(t-1)$, there is a significant difference between each pattern.

Based on the result,

"lifelike" $x_0^2 = 1.33 < 11.08 = x^2(5, 0.05)$

"autonomy" $x_0^2 = 23.46 > 11.08 = x^2(5, 0.05)$

"preference" $x_0^2 = 50.91 > 11.08 = x^2(5, 0.05)$

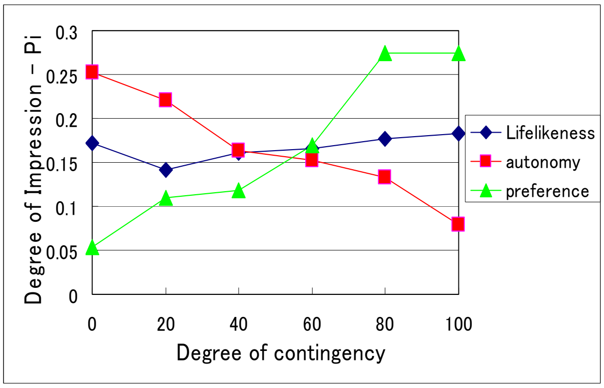

Fig. 10 Experimental result – comparison of Pi

These results indicate that there is a significant difference between each pattern in the case of "autonomy" and "preference".

[Summary of results] As a result, we obtained a model which is the relationship between the degree of contingency and each impression evaluation, as shown in Fig. 10. We found that a high contingency was associated with a good subjective impression on preference, while a low contingency was associated with autonomy.

4.4 Discussion

[Summary of the findings] We intended to identify the appropriate degree of contingency for lifelikeness in a communication robot. Since the difference in robot behavior was subtle among the different degrees of contingency, we conducted a set of comparisons in a controlled experiment setting where the robot performed a simple interaction of imitation. As a result, we found that a high contingency was associated with a good subjective impression on preference, while a low contingency was associated with autonomy. That is, subjects preferred the controllable robot but did not see autonomy in it.

Lifelikeness was, however, independent of the degree of contingency, which was contrary to our expectation. This result seems inconsistent with the result from our previous research [1] (also briefly reported in Section 3), where there was a significant difference between the *Random* and *Total* conditions, each of which had a different contingency. We believe that this inconsistency was caused by the complexity of interaction. The experimental condition determining whether the robot imitates the human's behavior or not was simpler than the previous one (we intentionally chose a simpler interaction to conduct an iterative comparison for the subtle difference). Several subjects answered in the free description that their criterion of evaluation for lifelikeness was the smoothness of the robot's motion. Thus, the role of contingency was low in the situation and subjects tended to feel that it was lifelike based on the trajectory of motion when it was simple interaction. In addition, it might also be affected by the fact that subjects were more aware of the robot's motion due to the imitative situation. People feel this type of lifelikeness when they see the robot objectively, in something like a biological motion [10].

Thus, one of the important lessons we learned from the experiment was that contingency has a relationship with complexity, which might be not separable in a controlled experiment. We believe that the current findings were unfortunately not applicable to the ideal communication robot with complex interaction capability, though the findings might be applicable to a simpler interactive robot.

[Lifelikeness and autonomy in communication robots] The experimental result reminds us that lifelikeness apart from contingency does not help a robot to communicate with people naturally. Similarly, although autonomy is a characteristic of the animate, subjects felt autonomy in the robot that was independent of their behavior, which is far from natural communication. These facts demonstrate the gap between an animate and a communication partner. Even a simple creature, such as an ant, has full animate characteristics, but we usually do not intend to communicate with it. Rather, only a few intelligent creatures, such as dogs and humans, can be communication partners (in a wide sense), which makes people feel both autonomy and a high contingency in them. In other words, we have only considered lifelikeness and contingency, which caused a failure in our work with respect to applying the findings to communication robots.

From this consideration we established a hypothesis that "the effect of contingency depends on the complexity of the interaction, and both autonomy and a high contingency in addition to lifelikeness will help a communication robot to interact with people naturally." We named this as "***Contingent system hypothesis***". Figure 11 illustrates our hypothesis between the contingency and complexity of the interaction for autonomy. In a simple interaction, as the contingency becomes higher, the subjective autonomy becomes lower as if it is close to a machine that simply follows a human's instructions, which was verified in this experiment (lower line A of Fig. 11). On the other hand, we believe that as the interaction becomes more complex, the subjective autonomy will be high even assuming a certain level of contingency (upper line B of Fig. 11).

Our future work should include an investigation of this relationship among complexity, autonomy, and contingency that people feel in a communication robot. Particularly, robots with autonomy and high contingency should be investigated.

5. CONCLUSION

We developed a robot system to investigate the appropriate level of contingency for a communication robot, in a series of research for lifelikeness in natural human-robot interaction. The robot was designed to use the information from a motion capturing system about human body movements and was prepared for a simple imitative experiment. By controlling the contingency of the robot's behavior toward humans, we investigated the relationships between the degree of contingency and subjective impressions. As a result, we found that an independent robot, which tends to behave randomly, gave an impression of autonomy, and that a controllable robot, which tends to follow a humans' behavior, gave a good impression to the subjects. However, the lifelikeness was independent from the contingency, which seems to be due to the overly simple setting of the interaction. Thus, our future work should include steps to identify the relationship between contingency and the complexity of the interaction for natural human-robot interaction.

6. ACKNOWLEDGMENTS

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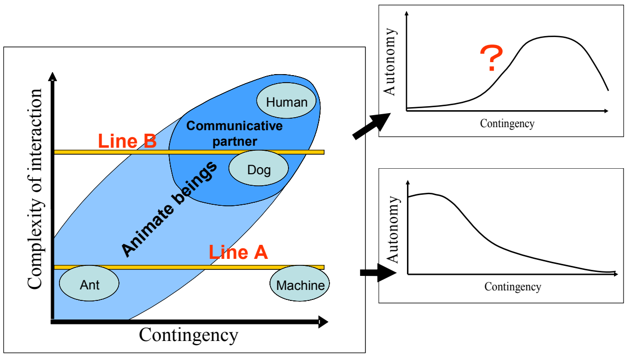

Fig. 11 ***Contingent system hypothesis*** – The relationship between Contingency and Complexity of interaction

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