Psychological analysis on human-robot interaction

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Abstract

For realizing a robot working in human society, interaction with humans is the key issue. We have developed a robot that interacts with humans based on visual recognition. This robot has two vision systems: an omnidirectional vision system for acquiring necessary visual information and a binocular stereo vision system. The binocular vision system indicates what the robot is looking at and is not used for locomotion. Gaze control plays an important role in human-robot interaction. This paper reports how the robot's gaze influences subjects' impressions of the robot. With a statistically significant number of robot observers, we employed psychological methods, the semantic differential method (SD), and factor analysis. This careful psychological analysis of robot impressions is the first trial in robotics. Through the experiment, we have found that the impressions mainly consist of four factors: familiarity, enjoyment, activity, and performance. The computer skills of subjects affect their impressions of the robot.

1. Introduction

Recently, there are many research approaches to developing social robots in robotics and artificial intelligence. A *social robot* is a robot that interacts with humans and participates in human society. For example, a pet robot is one example. Our purpose is to build social robots. One of the important aspects of developing social robots is affinity with the human. Since affinity emerges through human-robot interaction, evaluating their interaction is necessary for social robots.

Many researchers have evaluated human-robot interaction; mostly they did not evaluate a whole robot but an action of a robot. Shibata and his colleagues developed a dog-like robot and performed psychological experiments to evaluate human-machine interaction [1]. Sato and his colleagues proposed a contact interaction robot, with which a person can interact by touching [2]. It is shown in their report that contact-interaction relieves anxiety and moderates painfulness. They also investigated subjects' impressions of reactive actions and concluded that passive reactions produce familiar and comfortable impressions. It is interesting that they used "familiarity" to measure impressions of the robot. However, these researches purposed to study a pet robot and used small stuffed animal robots. Thus, it is difficult to apply these results to robots that have complex mechanisms.

There are, however, several research approaches aimed at realizing complex social robots. A *complex robot* has a complete body, consists of a complex mechanism, and behaves autonomously based on sensory information. Inooka and his colleagues performed an evaluation on a robot arm [3]. They used a semantic differential method (SD) to provide humanlike motions for the arm. Kobayashi and his colleagues developed a "face robot" that can make facial expressions [4]. To make facial expressions is one of the key functions for social robots. They also developed robot that can gaze at the person with whom it is talking [5]. However, these research focused on particular parts or motions of the complex robots. That is, they lacked evaluations of interaction between humans and complex robots that have a complete body.

Ogata and his colleagues developed a robot that has a self-preservation function. They studied emotional communication between humans and the robot by evaluating people's impressions of the robot [6]. In realizing social robots, this is indispensable. However, they used only a few adjective pairs and performed the evaluation at an exhibition of industrial robots where only interested people attend. Thus, it is not a sufficient result to help develop social robots.

We report here a psychological experiment on subjects' impressions of a complex robot. We have concentrated on gaze control, which powerfully influences a subjective evaluation of the robot's intelligence. Through the experiment, we have verified the hypothesis that:

> *A robot gives intelligent impressions, not only by possessing functions, but also by expressing the functions.*

It is not proper to focus just on gaze control by making a robot that only has a head, because it unnaturally limits the range of possible situations and gives impressions different from those of a whole body robot. A robot that can interact with humans autonomously lets observers easily attribute various intentions to the robot based on its gaze-related movement.

We used the SD method [7] for the evaluation. Factor analysis reveals what kinds of factors were used in the evaluation. We have designed the experiment to apply factor analysis. Generally, more than 100 data points are required for factor analysis. We obtained these by having over 50 subjects observe the robot twice. We determined the adjective-pairs for the SD scales by referring to past psychological research and preliminary experiments.

Our results confirmed our hypothesis that gaze control promotes human-robot interaction. Furthermore, it was found that the computer skills of subjects affect their impressions of the robot. This paper reports the experiment in detail, analyzes the results, and discusses remained problems. We consider this is the first report for psychological evaluation of an intelligent robot based on an enough number of subjects.

2. Experiment on Impressions

2.1. Robot

Fig. 1 shows the developed robot. The size of the robot is 1.3 m height and 0.6 m in diameter. The robot has four kinds of external sensors: a binocular stereo vision, an omni-directional vision sensor, eight ultra-sonic sensors, and sixteen tactile sensors. The stereo vision system and the omni-directional vision sensor can rotate with three degrees of freedom: roll, pitch, and yaw. The robot has two pairs of wheels in both sides. Each pair of wheels are chained and driven by a motor. The wheel consists of eight ellipsoid cylinders specially designed for turn motion. That is, the robot can turn by giving different velocities to the motors. The robot can work while three hours with a battery power supply.

Here, the robot does not usually acquire visual information from the stereo vision for the behaviors, since the purpose of the paper is to verify the importance of gaze control. The omni directional vision sensor acquires visual information needed for the robot. The stereo vision is principally used for expressing its function.

2.2. Implementation of robot tasks

The robot moves in the corridor, which is 1.6 m width (shown in Fig. 2). The robot goes out the laboratory and moves along the corridor.

In our previous works, we proposed a robot architecture based on situated modules [8], which enables us to progressively develop a robot system. In the architecture, a *situated module* is a program that performs a particular robot behavior in a particular local environment. It allows us to easily develop robot control programs by combining *situated modules*. This control program for the robot was developed based on the architecture. It needed 20 *situated modules* to navigate it in the environment.

2.3. Communication by gaze control

The gaze control denotes to move the camera direction of the robot to its path, obstacles, the person it found, and so forth. The robot communicates with human by the gaze control, which expresses its internal states, and appears for observers that the robot expresses its intentions. For example, when the tactile sensor is activated, the robot turns the gaze direction to the sensor. Then, observers around the robot recognize that the robot intentionally looks the sensor. Like the example, our robot expresses its

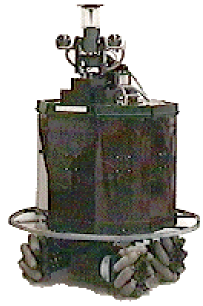


Fig. 1: Developed robot

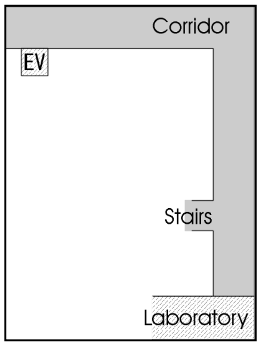


Fig. 2: Environment

functions, which is redundant for the task (in this paper, the task is navigation and interaction with human).

If the robot finds a person when it is moving along the corridor, it stops and starts interacting with him/her. The robot turns its camera direction to him/her at first (Fig. 3,left), then turns toward him/her, follows him/her, and expresses functions for interaction by moving the camera (Fig.3, right). The robot obtains all necessary visual information from the omnidirectional vision sensor or before starting gazing motions, and then the robot does not access visual information during the gaze control. Accordingly, the gaze control is not necessary for the robot to acquire external information.

2.4. Design of experiment

The purpose of the experiment was to evaluate the impressions of the robot that represents its internal state by controlling its gaze. To make a comparison with the robot, the robot that does not control its gaze was evaluated. The compared robot has the same body, functions, and performance as the robot that controls the gaze, yet the camera direction of the compared robot is fixed straight ahead. Each of subjects observed the two robots one by one. Subjects were randomly divided into two observing groups; subjects in one group (named MN group) observed the robot with gaze control (M-condition: camera moves condition) at first, and then they observed the robot without gaze control (N-condition: camera fixed condition). Subjects in the other group (NM group) observed those robots in reverse order. In short, the experiment was performed along a within-subjects design.

Each subject observed one of the robots for 5 minutes per observation. Then, they answered a questionnaire to rate in 28 adjective pairs (in Japanese) with 1-to-7 scales

Fig. 3: Communication by gaze control

based on the SD method. Subjects were given 5 minutes to rate the adjective pairs. After the answer about the first observation, each subject promptly observed the other robot and rated the adjective pairs again. Finally, they answered about noticeable parts of appearance and motions of the robot. To investigate to what subjects pay attention and what kind of actions they do, we did not give any special instruction to subjects. About the employment of subjects, the first and second year students of Kyoto University were recruited, and 66 students were employed on a first-come, first-served basis (mean age was 19.5).

3. Results

3.1. Results of Questionnaires

Table 1 shows the results of the ratings. The adjective pairs in the table are translated from Japanese words used in the questionnaires. Results of 7 subjects were omitted because of the errors of the robot or their uncertain observations. The mean values are the result of the two observations (N and M condition) of the 59 subjects. The ratings are based on the 1-to-7 scales, where 7 means fitted positive adjectives very well (adjectives in the leftmost-column in the table 1).

Concerning noticeable aspects of the robot's appearance and motions, many subjects answered "the wheel mechanism was impressive" and "the robot's cameras (a stereo vision system) seemed like eyes." Several subjects received mechanical impressions from the keyboard of the computer inside the robot body and electrical cables. Subjects also thought that the dark color and the square shape of the robot gave mechanical impressions.

Adjective pairs		Mean	S.D.
Kind	Cruel	4.20	1.22
Favorable	Unfavorable	4.36	1.42
Friendly	Unfriendly	4.33	1.58
Safe	Dangerous	4.78	1.44
Warm	Cold	4.05	1.26
Pretty	Ugly	4.90	1.27
Frank	Rigid	3.69	1.48
Distinct	Vague	3.70	1.70
Accessible	Inaccessible	4.15	1.60
Light	Dark	3.75	1.51
Altruistic	Selfish	3.90	1.34
Humanlike	Mechanical	3.08	1.58
Full	Empty	3.79	1.34
Exciting	Dull	4.87	1.67
Pleasant	Unpleasant	4.62	1.29
Likable	Dislikeable	4.66	1.43
Interesting	Boaring	4.53	1.63
Good	Bad	4.62	1.28
Complex	Simple	4.54	1.74
Rapid	Slow	3.02	1.37
Quick	Slow	2.95	1.35
Agitated	Calm	3.14	1.38
Active	Passive	4.33	1.46
Brave	Cowardly	3.81	1.50
Showy	Quiet	3.03	1.24
Cheerful	Lonely	3.86	1.38
Sharp	Blunt	3.81	1.55
Intelligent	Unintelligent	4.32	1.54

Table 1: Evaluated adjective pairs and the results

The means and standard deviations of the ratings of 59 subjects for 28 adjective pairs. The ratings are based on the 1-to-7 scale, where 7 on the scale is very fitted to positive adjectives (shown in the leftmost-column).

	Factor Ⅰ	Factor Ⅱ	Factor Ⅲ	Factor Ⅳ	Communality
Kind	**0.747**	0.238	−0.160	0.076	0.646
Favorable	**0.727**	0.436	0.052	0.265	0.792
Friendly	**0.708**	**0.505**	0.170	−0.092	0.794
Safe	**0.697**	−0.058	−0.214	−0.020	0.535
Warm	**0.693**	0.279	0.093	0.027	0.568
Pretty	**0.609**	**0.563**	0.087	0.121	0.710
Frank	**0.596**	0.286	0.264	−0.086	0.514
Distinct	**0.588**	−0.055	−0.056	0.034	0.353
Accessible	**0.574**	0.132	0.046	0.023	0.349
Light	**0.524**	0.398	0.467	−0.254	0.716
Altruistic	**0.516**	0.247	−0.221	0.266	0.447
Humanlike	0.492	0.192	0.318	0.114	0.393
Full	0.389	0.205	0.308	0.272	0.362
Exciting	0.131	**0.827**	0.231	0.109	0.765
Pleasant	0.359	**0.744**	0.241	−0.003	0.741
Likable	0.447	**0.716**	0.070	0.021	0.718
Interesting	0.157	**0.676**	0.345	0.216	0.647
Good	0.454	**0.594**	0.073	0.142	0.584
Complex	−0.072	0.495	0.184	0.299	0.373
Rapid	0.085	0.081	**0.796**	0.369	0.783
Quick	0.084	0.093	**0.794**	0.267	0.717
Agitated	−0.318	0.155	**0.713**	−0.078	0.640
Active	0.089	0.325	**0.584**	−0.037	0.456
Brave	−0.252	0.007	**0.584**	−0.001	0.405
Showy	0.131	0.198	**0.576**	0.070	0.393
Cheerful	0.358	0.443	**0.537**	−0.202	0.654
Sharp	0.051	0.176	**0.510**	**0.578**	0.628
Intelligent	0.208	0.425	0.146	**0.508**	0.503
Expl. Var	5.85	4.70	4.29	1.35	16.19

Table 2: Factor matrix (Varimax rotated)

The factor matrix retrieved by factor analysis and Varimax rotation. These factors (I to IV) were interpreted by referring factor loadings over 0.5 (shown with boldface), and named familiarity, enjoyment, activity, and performance factor, respectively.

3.2. Factor analysis

Factor analysis was performed on the SD method ratings for the 28 adjective pairs. Based on the difference in eigenvalues, we adopted a solution that consists of 4 factors. Cumulative proportion of the final solution was 57.8%. The retrieved factor matrix was rotated by a Varimax method (shown in table 2). The factor matrix contains factor loadings, which are the correlations of each variable and the factor. For example, "kind" has 0.747 loading on Factor I, and it denotes strong correlation.

We interpreted the factors, by referring to the adjective pairs that have loadings greater than 0.5 in table 2. The first factor was named ***familiarity factor*** because several familiarity adjectives, such as "Kind" and "Accessible," had high loadings on only the first factor. Since enjoyment adjectives such as “Exciting” and “Pleasant” highly loaded on the second factor, it was named ***enjoyment factor***. The third factor was evidently named ***activity factor***. We considered that “Sharp” is related to responsiveness of the robot. Thus, “Sharp” and “Intelligent” are the adjectives to evaluate the performance of the robot. The fourth factor was thereby named ***performance factor***.

Standardized factor scores S_{ik} enable us to easily understand the results. For factor *k* and observation *i*, S_{ik} was computed from factor score F_{ik} by standardizing as an average *0* and a standard deviation *1*. Observation *i* was one of the 118 observations of the 59 subjects. Relation among a factor matrix $F(F_{ik})$, an observation data matrix $X(X_{ij})$, and a matrix of factor loadings $\Lambda(\lambda_{jk})$ can be written in the form:

$$X = F\Lambda' + E,$$

where $E(E_{ij})$ is a unique factor matrix, and X_{ij} is the observation data of *i*-th observation and *j*-th variable (an evaluation for *j*-th adjective pair). Consequently, four factor scores were computed: S_{i1} = familiarity score, S_{i2} = enjoyment score, S_{i3} = activity score, and S_{i4} = performance score.

3.3. Comparisons based on experiment conditions

Comparison as within-subjects design

Each subject observed the robot with gaze control (M-condition) and the robot without gaze control (N-condition) one by one. For each of the two observing groups, the two kind conditions of observations are compared. Table 3 provides the means and standard deviations of the factor scores for each condition.

The gaze control is designed to give friendly impressions about our robot and to aid understanding of the robot. We consider that the effect of gaze control on impressions is independent of the observing orders. The hypothesis that we wish to test is:

> **Hypothesis 1: The robot with gaze control gives more familiar, enjoyable, active, and high-performance impressions than the robot without gaze control.**

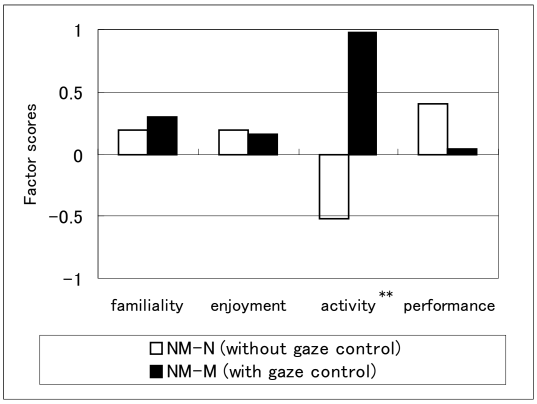
Graph 1 and 2 show the comparisons between N and M condition in each observing group. T-test proved that activity scores are significantly different between the two conditions in the NM-group, and enjoyment scores are significantly different in the MN-group. Thereby, the hypothesis has partly been confirmed.

Meanwhile, the result is different between the two groups. We consider that the subjects became tired and got accustomed to observing the robot, and that caused the difference. In the second observations, the subjects in MN-group faced a robot similar to the robot they watched at first. For this reason, some of them hardly noticed the absence of gaze control. Consequently, activity scores are not significantly different in the MN-group. On the other hand, at the second observations, the subjects in the NM-group noticed the change of the gaze. Thus, it caused the significant difference in activity scores.

	Group	NM		MN	
	Condition	NM-N	NM-M	MN-M	MN-N
	Num. of subjects	29	29	30	30
The robot's impressions (factor scores)	Familiality	0.19	0.29	−0.04	−0.42
	Enjoyment	0.19	0.16	0.18	−0.52
	Activity	−0.52	0.98	−0.18	−0.26
	Performance	0.41	0.04	−0.23	−0.20
S.D. of the factor scores	Familiality	0.77	0.88	0.94	1.06
	Enjoyment	0.90	0.79	0.89	0.99
	Activity	0.76	0.83	0.85	0.60
	Performance	0.92	0.88	0.69	0.88

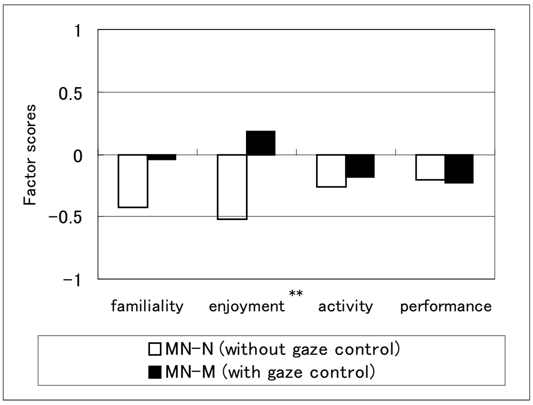
Table 3: Comparison of subject’s impressions in observing conditions

This is the means and standard deviations of the factor scores. The subjects of NM group observed the robot without gaze control (this observing condition is called NM-N), then observed another robot (this is called NM-M). The subjects of MN group observed those robots in reverse order (MN-M, MN-N).



Graph 1: Comparison in NM-group

The comparison in the group in which subjects observed the robot without gaze control at first. Activity scores are significantly different (p<0.01, where p means statistical significance of the comparison).

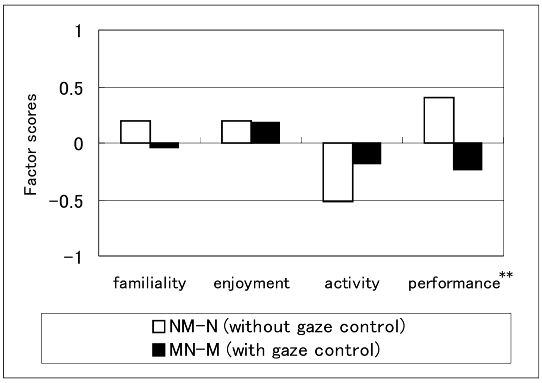


Graph 2: Comparison in MN-group

The comparison in the group in which subjects observed the robot with gaze control at first. Enjoyment scores are significantly different (p<0.01).

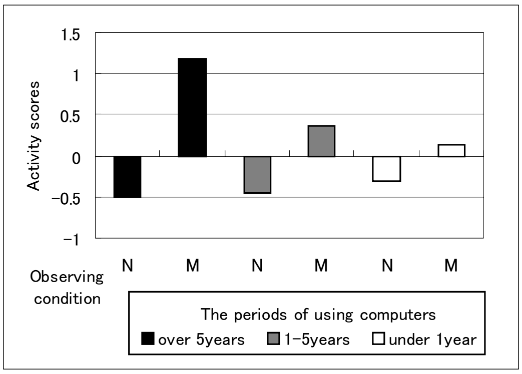
Comparison as between-subjects design

The comparisons in the two groups indicate that the carryover effects are as large as the effects of gaze



Graph 3: Comparison between the two groups

The comparison between the first observations of the two groups. "With gaze control" means the first observations of the MN-group. Performance scores are significantly different (p<0.01).



Graph 4: The use periods of computers and the gaze control effects

The comparison about the computer skill on activity scores. A LSD method shows that the subjects who chose "over 5years" evaluated the activity bigger than the others, in the M condition (presence of the gaze control) (p<0.05).

control. To examine the effects of gaze control, the initial observations in each group are compared following a between-subjects design (shown in graph 3). We wish to test the following hypothesis:

> **Hypothesis 2: The subjects who observe the gaze control motions receive more familiar, enjoyable, active, and high-performance impressions than the subjects who do not observe the motions.**

A t-test showed that only performance scores are significantly different, but it is contrary to the hypothesis. That is, the robot without gaze control gives more high-performance impressions than the robot with gaze control. We believe the disappointing ability of the robot caused it. In other words, gaze control reveals the poor performance of the robot, against expectation of subjects.

Classification of subjects by interests

To investigate the influence of the attributes of subjects, they were also inquired about computer skills and their interests in robots. Subjects answered a questionnaire that consisted of 11 questions. Subjects chose one suitable option among three options for the questions. For each question, ANOVA (analysis of variance) was applied to the factor scores. ANOVA detects the significant difference of means by comparing two independent variances; one variance responds within a group and another represents between groups.

ANOVA proved that a subject's level of interest in robotics affect impressions. Subjects who chose "I watch [robot contests] more than once a year" received more active impressions than subjects who chose "I have watched them more than once" (p<0.05, where p means statistical significance of the comparison). About SF movies, the subjects who answered "I often watch by choice" judged the robot less active than the others (p<0.05). (The other subjects answered "I sometimes watch" or "I do not watch by choice"). The subjects who chose "I am interested in [humanoid robots] and have often seen them" thought the robot more enjoyable than others do (p<0.05). The other subjects answered "I have seen it" or "I have never seen it."

Classification of subjects by computer skills

ANOVA also proved that the use periods of computers related to performance scores (p<0.05), and the subjects who were good at programming thought the robot more active than the other subjects thought (p<0.05). Besides, the statistical interaction on the impressions between the computer skills and gaze control is analyzed. The hypothesis we are testing is as follows:

> **Hypothesis 3: The subjects who have high computer skills receive different impressions from the subjects who have low computer skills, by observing the two robots.**

Mixed two-factorial MANOVA (multivariate analysis of variance) was applied on the factor scores for *the questionnaire results about computer skills* (between-subjects) and *the presence or absence of gaze control* (within-subjects). At first, MANOVA was applied to the computer experiences. Statistical interaction between the use periods of computers and gaze control is significant for activity scores and performance scores. About activity scores, difference between *the presence or absence of gaze control* is significant for the subjects whose use periods are *more than 5 years* or *between 1 year and 5 years*. About performance scores, difference is significant for the subjects who chose "more than 5 years."

An LSD (least significance difference) method was applied for activity scores, whose statistical interaction is significant. The LSD method is one of the multiple comparison methods to identify which comparisons among groups have significant differences. The mean of the subjects who answered "more than 5 years" is significantly higher than the mean of the others in the M condition (p<0.05). (The other subjects answered "between 1 year and 5 years" or "less than 1 year.") See Graph 4 for the illustration of the relationship between *the* *use periods of computer* and *the presence or absence of gaze control*. The LSD method was also applied for performance scores, whose statistical interaction is significant. The mean of the subjects who chose "more than 5 years" is significantly bigger than the mean of the other 2 groups in the N condition, in which the robot did not control its gaze ($p<0.05$).

MANOVA was also applied to computer programming skill. It proved the significance of the statistical interaction on performance scores between programming skill and gaze control. A multiple comparison showed that the scores of the subjects who answered "I sometime write programs" are significantly bigger than the scores of the subjects who answered "I have never written a program." (The other subjects answered "I have written one or some programs.")

The hypothesis was, therefore, confirmed. On activity and performance scores, there is statistical interaction between the computer skills and gaze control. The highly computer skilled subjects highly evaluated the activity of the robot with gaze control. They also highly evaluated the performance of the robot without gaze control.

4. Discussions

4.1. Effects of gaze control

Based on the psychological analysis of gaze control, we have concluded that:

- **Gaze control makes the robot impressions more enjoyable and active.**

That is, this gaze control is useful to promote human-robot interaction. The comparison between subjects showed that:

- **The robot that does not control its gaze gives more high-performance impressions than the robot that control its gaze.**

According to our analysis, this result owing to the disappointing ability of the robot. Subjects expected higher-performance behaviors that matched with the active gazing motions. Regarding the importance of having computer skills in forming a positive impression, we found that:

- **Subjects highly skilled at computers highly evaluated activity of the robot with gaze control. They also judged the robot with gaze control low in performance.**

That is, gaze control had a noticeably strong effect for the subjects whose computer skill were high.

After all, gaze control made the robot more enjoyable and active, and promotes human-robot interaction. Thus, the results of the experiment support the research hypothesis suggested in section 1.

4.2. Problems on the experiment

Although we could confirm the hypotheses, the experiment had several problems:

1) Subjects got tired of observing the robot the second time as they became accustomed to it.
2) The performance of the robot was lower than subjects expected.
3) The appearance gave mechanical impressions.

There was a big difference in the impressions between the two observing groups. Even if a within-subjects design suffers such a carryover effect, it is suitable for the experiments where differences among observations are too small or differences among subjects are too big. Concerning our experiment as a between-subjects design, there was no significant difference on familiarity, activity, and enjoyment scores. We expect mainly two reasons. One is that most of the subjects had not observed such an intelligent robot before. Thus, they evaluated our robot without comparing it to other robots. It caused an ambiguous evaluation. The other is that the differences between the two robots were too small. It is difficult to determine the best experimental design to evaluate an intelligent robot. Since intelligent robots are not so popular yet, complex experiments as ours should be performed along a within-subject design or with a comparative object.

The performance of the robot with gaze control was judged to be lower than the robot without gaze control. This result was probably owing to lower performance of the robot than subjects expected, and gaze control reveals the poor ability of the robot.

As regards the appearance of the robot, mechanical parts (e.g., the computer and other controlling equipment) have been carefully covered (as shown in Fig. 1). Subjects, however, answered that a keyboard inside the body and cables of the robot were notably mechanical. We need to ensure that impressions of an evaluated robot are not distorted by a failure to hide these items.

By the way, was the gaze control sufficient for representing the internal state? It was probably not sufficient. Because of the gaze control, many of subjects understood that the robot found them. On the other hand, many of subjects did not understand that the gazing behavior of the robot expressed its course when it navigated along a corridor. Several subjects answered, "It was cute that the robot looked around restlessly."

4.3. Impression evaluation on the robot behavior

The robot acts and reacts according to the situation and the actions of subjects. Consequently, the behavior of the robot varies with subject and situation. The data about actions of subjects and behaviors of the robot were obtained. The data enables us to analyze relation among the robot's behaviors, the subjects' actions, and their impressions.

Obstacle avoidance

When the developed robot touches an obstacle, the robot avoids it while gazing at it (Fig. 4). That is, the gazing motion indicates that the robot notices the obstacle the robot touches and is going to avoid it. Many of the

	Condition	N			M		
	Num. of Avoidance	0	> 2	P	0	> 2	P
	Num. of Observations	17	11		15	19	
Factor Score	Familiarity	−0.05	−0.08	0.96	0.37	0.02	0.32
	Enjoyment	0.09	−0.42	0.20	0.22	−0.01	0.34
	Activity	−0.37	−0.70	0.08 +	0.81	0.09	0.06 +
	Performance	0.06	−0.07	0.76	0.14	−0.32	0.14
Robot's Actions	Moved distance (m)	11.72	11.33	0.88	9.63	10.08	0.80
	Interacion time (sec)	158.1	122.1	0.06 +	149.9	124.3	0.08 +
Subject's Actions (% of subjects in a group)	Obstruct	0.41	0.55	0.76	0.40	0.42	1.00
	Cross	0.47	0.55	1.00	0.67	0.68	1.00
	Swing hands	0.06	0.09	1.00	0.13	0.11	1.00
	Hide eye(s)	0.00	0.45	0.01 **	0.13	0.05	1.00
	Eye contact	0.59	0.36	0.44	0.67	0.53	0.64
	Look inside	0.35	0.36	1.00	0.40	0.42	1.00

Table 4: The avoidance behavior and impressions

The comparison of the two behavior-patterns. *Subject's Actions* are the rate of the number of the subjects who took these actions in a group. About the factor scores, no significant difference is found. (in the table, "p" means statistical significance of the comparison)

Act. to people	Few	Many	p
Num. Of obs.	28	28	
Familiarity	−0.02	−0.18	0.54
Enjoyment	−0.10	0.53	0.01 *
Activity	−0.24	0.32	0.04 *
Performance	−0.17	0.11	0.28
Moved dist. (m)	12.70	7.07	0.00 **
Int. time (sec)	114.1	202.8	0.00 **
Obstract	0.21	0.68	0.00 **
Cross	0.39	0.64	0.11
Swing hands	0.07	0.25	0.14
Hide eye(s)	0.00	0.32	0.00 **
Eye contact	0.25	0.75	0.00 **
Look inside	0.29	0.50	0.17

Table 5: The robot actions to subjects

The comparison based on the execution times of the robot behavior "find a person." The enjoyment and activity are significantly different ($p<0.05$).

subjects answered that this motion was noticeable. We also analyze the effect of the gaze control while avoiding obstacles. Two subjects groups are compared for the analysis: the subjects in one group observed the avoidance behavior more than twice, the subjects in the other group did not observe it at all.

Table 4 shows the mean values of the impressions of the two behavior-patterns (over twice avoidance, no-avoidance) for each observing condition.[1] "Moved distance" indicates the average move distance of the robot during an observation. "Interaction time" denotes the average time for the robot to respond to the subjects. Here, "Obstruct," "Cross (cross the front of the robot)," "Swing hands," etc. mean the rates of the numbers of the subjects who took these actions.

The avoidance behavior gives a negative impression to the subjects. We consider that the gaze motion alleviates the deterioration of the intelligent impression, since the subjects understand the robot's intentions by the gaze motion. However, there is no statistically significant interaction between the behavior-patterns and the observing conditions.

Fig. 4: The obstacle avoidance

Fig. 5: The reaction

[1] In the table, we use '+' to denote almost significant ($p<0.1$), '*' to denote significant ($p<0.05$), and '**' to denote highly significant ($p<0.01$), where p means statistical significance of the comparison.

The robot actions for subjects

As regards the robot's actions to subjects, the most often executed behavior was "find and turn toward a person." Relation between this behavior and impressions is as follows:

Subjects are classified into two groups based on the number of times the behavior was executed. The first group (Many group) is defined as the top quarter (upper 25%) in the number of the robot behavior; the second group (Few group) is defined as the bottom quarter. The result is shown in Table 5. There are significant differences in the factor scores of enjoyment (Many 0.53 > Few -0.10 *) and activity (Many 0.32 > Few -0.24 *).

Concerning the robot's behavior, the differences in "Moved distance" and "Interaction time" are significant. The result shows that a moved distance decreased because the robot acted to the subjects. About the actions of the subjects to the robot, there are significant differences in "Obstruct," "Hide eye(s)" and "Eye contact." This is owing to the implementation of the robot. The robot reacts to human actions, which are detected as being nearby the robot or a big difference in camera images. This comparison can be summarized as follows: the more often the human acts to the robot, the more often the robot acts to the human.

Subjects actions to the robot

If more often human act to the robot, does human think the robot more enjoyable? Relation between the actions of subjects to the robot and the impressions are analyzed to examine it.

Subjects are classified into two groups based on the number of the fitted action categories of subjects. For example, a subject who did "Obstruct" and "Cross" fits 2 categories. The first group is defined as the top quarter (upper 25%) in the number of the categories fitting their actions; the second group is defined as the bottom quarter. As the result of comparison, the difference in the enjoyment scores is almost significant, but there is no significant difference in the impressions.

Although the robot is implemented to react to subjects, their actions do not affect so powerfully on impressions as the robot behavior. The two comparisons about the robot behavior and the subjects actions are summarized: *the closer the human and robot are during interaction, the more enjoyable the human's experience.*

4.4. Generality of the result

There are principally two factors to influence the generality of the experiment: the appearance and complexity of the robot. Here, we discuss about the generality of the result.

The impressions of the robot are not independent of its appearance. The human's impressions of the robot's actions improve with its appearance. Meanwhile, the answers of subjects about noticeable appearance showed that the robot has impressive eyes. Thus, even if the appearance of the robot is altered, the eyes of the altered robot will still attract attentions and give impressions similar to before. In addition, we think that functions rather than appearance give the robot intelligence. If a robot does not possess sufficient functions and subjects observe the robot for a long time, subjects will receive unintelligent impressions independently of its appearance.

Anyway, the result of the experiment depends on robot complexity, which consists of navigation functions, interaction functions, and the mechanism. We can make the robot more complex by implementing other functions such as voice communication, and installing other mechanism such as arms. This is one of our future works to make a robot with such a complex mechanism, to implement more intelligent and various functions, and to evaluate the complex robot.

Meanwhile, the experimental method is useful for the evaluation of the robot that has different complexity. It is remains as future work to evaluate robots of varying complexity. The results are still meaningful to evaluate the robots that are more complex (or less complex). Impressions will be ruled by similar factors to the retrieved four factors of this experiment, and the interests of subjects in robots will affect the evaluations.

4.5. Future work

Evaluating various appearances and complexity of a robot is one of the future works. Now, we are developing a robot named *Robovie* that is more complex in both behavior and appearance. Its arm mechanism enables human-like motions. It has enough sensors for human-robot interaction: binocular stereo vision, an omni directional vision sensor, sixteen ultra-sonic sensors, sixteen tactile sensors and ten collision-detecting sensors. The stereo vision system can rotate with three degrees of freedom for expressing its function by gaze control. It also has microphones and speaker so that it can communicate with human through voice. By using the robot, we are going to perform two types of experiments about human-robot interaction: studying human behavior toward the robot through psychology and cognitive science, and evaluating autonomous behavior of the complex robot.

Fig. 6: "ROBOVIE" The developing robot

5. Conclusion

In this paper, we have reported about experimentation on impressions of the developed robot, which behaves autonomously and interacts with humans. As the result of our experiment, the impressions of the robot chiefly consisted of four factors, and the gaze control of the robot promotes interaction with humans. The relation between computer skills and positive impressions of the robot was also revealed.

Although these results partly depend on the conditions of the experiment, the viewpoint of subjects (factors of the impressions) can be useful for other evaluations. The adjective pairs used in the experiment are also available for other studies. Evaluating interaction is a necessary approach towards "social robots." These experiments are an important clue for designing similar evaluations.

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