Friendly social robot that understands human's friendly relationships

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Abstract— **This paper reports our novel approach to developing a social robot. The developed robot is able to identify relationships among humans from their physical behaviors as it establishes long-term relationships with humans. This interactive humanoid robot attracts humans to interact with it and, as a result, induces them to perform their group behaviors in front of it. The robot recognizes friendly relationships among humans by simultaneously identifying each person in the interacting group. We conducted a two-month experiment in an elementary school. As a result, the robot successfully continued friendly interaction with many children for the two months, and demonstrated reasonable performance in identifying friendships among children. We believe this ability to maintain friendly relationships with humans and to identify human relationships is essential to behaving socially.**

Keywords-human-robot interactiont;field trial; friendhisp estimation; long-term interaction;

I. Introduction

Recent progress in robotics has brought with it a new research direction known as "interaction-oriented robots," which are designed to communicate with humans and to be able to participate in human society. We are trying to develop such an interaction-oriented robot that can function as a partner in our daily lives. As well as providing physical support, these robots will supply communication support such as route-guidance.

Several researchers are endeavoring to realize such interaction-oriented robots. Aibo was the first interactive robot to prove successful on the commercial market [1], since it behaves as if it were a real animal pet. Breazeal and her colleagues developed the face robot Kismet, and they are exploring the sociable aspects of robots produced through its learning ability [2]. Okuno and his colleagues developed a humanoid head that tracks a speaking person with visual and auditory data. In addition, they controlled the personality of the robot by changing the tracking parameter [3]. Burgard and his colleagues developed a museum tour guide robot [4] that was equipped with robust navigational skills and behaved as a museum orientation tool. These research efforts also seem to be devoted to "social robots" that are embedded in human society.

Humans have the natural ability to identify others' intentions, which is widely known as the joint-attention mechanism in developmental psychology [5]. We believe that this is an essential function of being social for both humans and robots to be social. Scassellati developed a robot with a joint-attention mechanism that follows others' gazes in order to share attention [6]. Kozima and his colleagues also developed a robot with a joint-attention mechanism [7]. In these systems, the robots identify humans' intentions from their behaviors. Furthermore, a robot system can estimate a human's subjective evaluation of the robot by observing his/her body movements [8]. However, these research works mainly focused on the social behaviors among two or three people. Little work in robotics research has attempted to handle social behavior within the larger human society. To enable a robot to be social, we believe that the robot needs to read relationships among humans.

In sociology, sociometric (a matrix that represents relationships) and socio-gram (a direct graph that illustrates the sociometrics) methods have been used to represent relationships among humans. A sociometric test is a subjective test that extracts relationships. It lets a human directly answer the names of others whom he/she likes and dislikes. It has been widely used to identify the relationships in a classroom or a company.

In computer science, several research works have analyzed human relationships. Watts and Strogatz conducted a computer simulation to find a simple model for global human society, named small-world networks [9]. Eveland et al. analyzed online communication on a computer-supported collaborative work (CSCW) system [10]. They plotted each user's data on a socio-gram according to the amount of online communication among them. Nomura and her colleagues developed a web-analyzing system to retrieve humans' online relationships [11]. As opposed to these research works on human relationships using a CSCW system or web pages, we believe that the recent robotics and ubiquitous sensor technologies enable us to analyze real human relationships in our daily life.

This paper reports our approach to making an interactive robot read human relationships, an ability that is probably essential for interactive robots to become social. We have developed an interactive humanoid robot named Robovie that autonomously interacts with humans. Since the robot attracts humans to interact with it and induces the humans to perform group behaviors in front of it, the robot can recognize friendly relationships among humans by simultaneously identifying each person in the interacting group. We have also implemented interactive mechanisms for supporting long-term relationships to keep children interested in the robot for a long period of time.

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We conducted a two-month experiment in an elementary school. As a result, the robot continued friendly interaction with children for the two months, and demonstrated reasonable performance in identifying friendships among the children. We believe that the findings from the long-term interactions can also help us to find ways of establishing friendly relationships between children and social robots.

II. AN INTERACTIVE HUMANOID ROBOT

A. Hardware

Figure 1 shows the humanoid robot "Robovie" [12]. The robot is capable of human-like expression and recognizes individuals by using various actuators and sensors. Its body possesses highly articulated arms (with 4 DOF), eyes (2 DOF), and a head (3 DOF), which were designed to produce sufficient gestures for communicating effectively with humans. The sensory equipment includes auditory, tactile, ultrasonic, and vision sensors, which allow the robot to behave autonomously and to interact with humans. All processing and control systems, such as the computer and motor control hardware, are located inside the robot's body.

B. Person identification with wireless ID tags

To identify individuals, we used a wireless tag system capable of multi-person identification by the robots. Recent radio frequency identification (RFID) technologies enable us to use contactless identification cards and chips in practical situations. In this study, children were given easy to wear nameplates (5 cm in diameter) in which a wireless tag was embedded. A tag (Fig. 1, lower-right) periodically transmitted its ID to the reader, which was installed on the robot. In turn, the reader relayed received IDs to the robot's software system. It was possible to adjust the reception range of the receiver's tag in realtime from software. The wireless tag system provided the robots with a robust means of identifying many children simultaneously. Consequently, the robots could show some human-like adaptation by recalling the interaction history of a given person, which is explained in detail in [13].

C. Interactive Behaviors for Long-term Interaction

1) General design

"Robovie" has a software mechanism for performing consistent interactive behaviors [14]. The objective behind the design of Robovie is that it should communicate at a young child's level. One hundred interactive behaviors have been developed. Seventy of them are interactive behaviors such as shaking hands, hugging, playing paper-scissors-rock, exercising, greeting, kissing, singing, briefly conversing, and pointing to an object in the surroundings. Twenty are idle behaviors such as scratching the head or folding the arms, and the remaining 10 are moving-around behaviors. In total, the robot could utter more than 300 sentences and recognize about 50 words.

The interactive behaviors appeared in the following manner based on some simple rules. The robot sometimes triggered the interaction with a child by saying "Let's play,

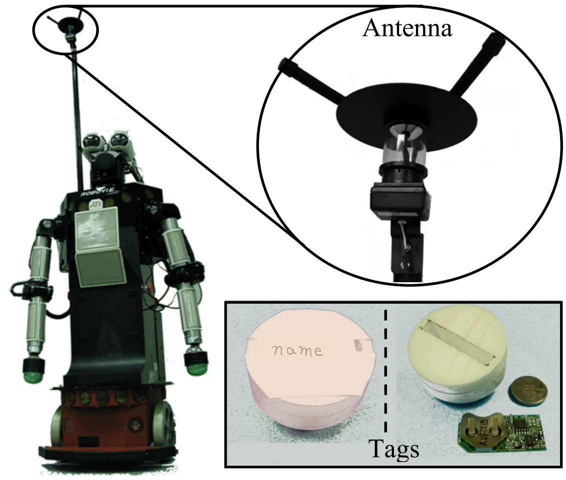

Figure 1: Robovie and Wireless tags

touch me," and it exhibited idling or moving-around behaviors until the child responded; once the child reacted, it continued performing friendly behaviors as long as the child responded. When the child stopped reacting, the robot stopped the friendly behaviors, said "good bye," and re-started its idling or moving-around behaviors.

2) Design for long-term interaction

Moreover, we utilized the person identification functions to design the interactive behavior for long-term interaction. The first idea was calling the children's names. In some interactive behaviors, the robot called a child's name if that child was at a certain distance. For instance, in an interactive behavior, the robot speaks "Hello, Yamada-kun, let's play together" when the child (named Yamada) came across to the robot. These behaviors were useful for encouraging the child to come and interact with the robot.

The second idea is pseudo-learning. The more a child interacts with the robot, the more types of interactive behavior it will show to the child. For example, it shows at most 10 behaviors to a child who has never interacted with it. However, it shows 100 behaviors to a child who has interacted with it more than 180 minutes. Since the robot gradually changes interaction patterns along with each child's experience, the robot seems as if it learns something from the interaction. Such a pseudo-learning mechanism is often employed by the interactive pet robots like Aibo.

The third idea is having the robot confide personal-themed matters to children who have often interacted with it. We prepared a threshold of interacting time for each matter so that a child who played often with the robot would be motivated to further interact with the robot. The personal matters are comments such as "I like chattering" (the robot tells this to a child who has played with it for more than 120 minutes), "I don't like the cold" (180 minutes), "I like our class teacher" (420 minutes), "I like the Hanshin-Tigers (a baseball team)" (540 minutes).

D. Reading Humans' Friendly Relationships

Our approach to reading humans' friendly relationships consists of the two functions described below (**Figure 2**). Since humans have friendly relationships, they behave in a

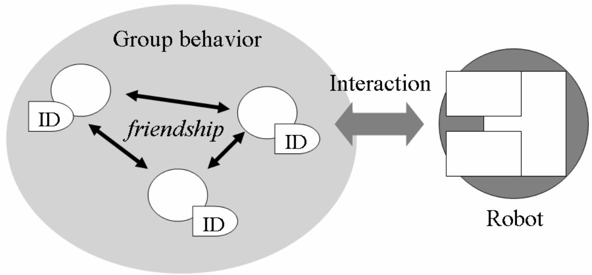

Figure 2: Reading humans' friendly relationships

Robot identifies multiple people in front of it simultaneously; as a result, it recognizes friendship among them, because the robot's interactive behaviors cause the group behavior.

group. Meanwhile, a robot induces humans to perform spontaneous group behavior with its interactive behaviors.

1) Group behavior and friendship

Like and dislike are two of the essential relationships among humans. Humans change their opinions based on like and dislike relationships, which is well-known as Heider's balance theory [15]. If a person's friend has an opposing opinion, the person would change his/her opinion to be agreeable with the friend's opinion. Humans establish friendship based on their mutual "like" relationships of each other. In developmental psychology, Ladd et al. found that even children form their own group and behave with the group based on their friendship [16]. In other words, if we observe such a group's behavior, we can estimate the friendships among the members.

2) Interactive robot causes spontaneous group behavior

Our interactive humanoid robot Robovie autonomously interacts with humans. By executing interactive behaviors, the robot attracts humans to interact with it; on the other hand, humans often behave in a group, so the robot induces humans to perform group behaviors in front of it. As a result, the robot can recognize friendly relationships among humans by simultaneously identifying each person in the interacting group.

We might read such friendly relationships by simply observing humans' group behaviors in their daily life. However, humans sometimes behave as a group because it is necessary or required. For example, the activity "humans collaborate to carry a heavy box" does not always indicate friendly relationships among them. Thus, we believe that it is better to read human relationships by observing spontaneous group behavior such as interaction with the robot. We believe that robots will carry out various communication tasks in our daily lives in the future such as foreign language education [17], and humans will freely interact with a robot even in these applications.

3) Algorithm for reading friendly relationships

From a sensor (in this case, wireless ID tags and receiver), the robot constantly obtains the IDs (identifiers) of individuals who are in front of the robot. It continuously accumulates the interacting time of person A with the robot (T_A) and the time that person A and B simultaneously interact with the robot (T_{AB}, which is equivalent to T_{BA}). We

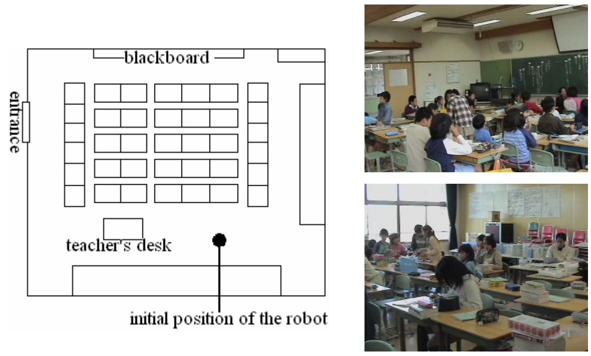

Figure 3: Environment of the elementary school

define the estimated friendship from person A to B ($Friend(A \rightarrow B)$) as:

$$Friend(A \rightarrow B) = if\,(T_{AB} \,/\, T_A > T_{TH}), \quad (1)$$

$$T_A = \Sigma\ if\,(observe(A) \text{ and } (S_t < S_{TH})\,) \cdot \Delta t, \quad (2)$$

$$T_{AB} = \Sigma\ if\,(observe(A) \text{ and } observe(B) \text{ and } (S_t < S_{TH})\,) \cdot \Delta t\ , \quad (3)$$

where $observe(A)$ becomes true only when the robot observes the ID of person A, $if()$ becomes 1 when the logical equation inside the bracket is true (otherwise 0), and T_{TH} is a threshold of simultaneous interaction time. We also prepared a threshold S_{TH}, and the robot only accumulates T_A and T_{AB} so that the number of persons simultaneously interacting at time t (S_t) is less than S_{TH} (equations 2 and 3). In our trial, we set Δt to one second.

III. LONG-TERM INTERACTION IN ELEMENTARY SCHOOL

We conducted a field experiment in an elementary school for two months with the developed interactive humanoid robot. In this section, we report the knowledge that we acquired from the results of this experiment.

A. Experimental Setting

We performed an experiment at an elementary school in Japan for two months. Subjects were 37 students (10-11 years old, 18 male and 19 female) who belonged to a certain fifth-grade class. The experiment lasted for 2 months including 32 experiment days. (There were 40 school days, but 8 days were omitted because of school events.) We put the robot into a classroom (**Fig. 3**). The children were able to freely interact with the robot during a 30-minutes recess after lunch time.

We asked the children to wear nameplates in which a wireless tag was embedded so that the robot could identify each child. The robot recorded the recognized tags during interaction to calculate each child's interacting time with the robot, which is used for later analysis of their interaction and friendship estimation. We administered a questionnaire that asked the children's friendship with other children and interest in the robot.

B. Observation of Long-term Interaction

Figure 4 indicates the transition of interaction with children. The dotted lines separate the nine weeks during

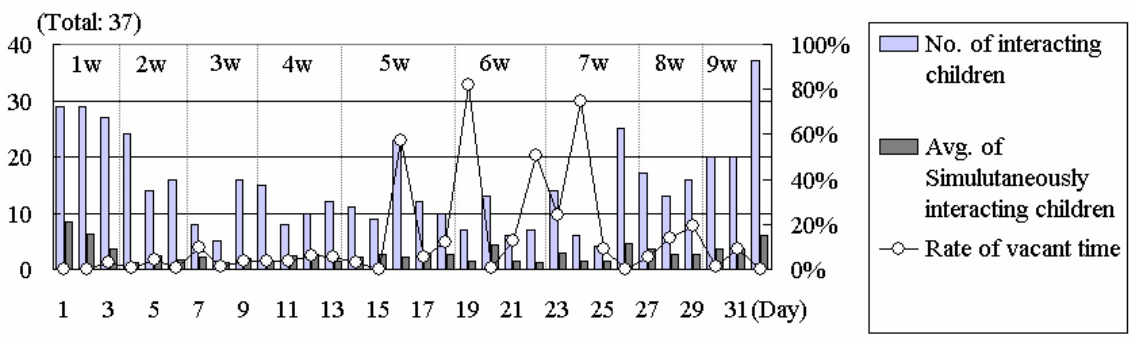

Figure 4: Transitions of the interaction between children and the robot

(a) Beginning of the first day *(b) Children formed a line*

(c) Showing nameplate *(d) Hugging behavior*

Figure 5: Scene of the experiment during 1st-2nd week

(a) Listening to "confiding of personal matters" *(b) "I can't see" behavior preferred*

(c) Attracting her attention *(d) Singing with the robot*

Figure 6: Scene of the experiment during 3rd-7th week

the two-month period. We classify the nine weeks into three principal phases, following [17], and explain the interaction's transitions during the two months by describing these phases.

First phase (1st-2nd week): Robovie caused big excitement

Children were crowded around the robot on the first and second days (Fig. 5-a). At most, 17 children simultaneously stayed around it on the first day. They started to form a line to play with it (Fig. 5-b). During the first two weeks, it still seemed so novel to the children that someone always stayed around the robot, and the rate of vacant time was nearly 0, while the number of gathered children gradually decreased. There were several interesting scenes:

- Many children were attracted by the robot's name calling behavior.
- Several children tried to get the robot to call their names by showing their nameplates to the robot's eye and omnidirectional camera (Fig. 5-c).
- Hugging behavior was a favorite of the children (Fig. 5-d).

Second phase (3rd-7th week): Stable interaction to satiation

Everyday, about ten children came around the robot, and some of them played with the robot. When it was raining, the children who usually played outside played with the robot, and, as a result, the number of children

(a) writing robot's personal matters they heard *(b) farewell party: every child played with it*

Figure 7: Scene of the experiment during 8th-9th week

interacting with it increased. During these five weeks, the interacting children gradually decreased and the vacant time increased. The "confiding of personal matters" behavior first appeared in the 4th week, and it came into fashion among them (**Fig.6**-a). In this phase, we observed the following interesting scene.

- Child A observed the "confiding of personal matters" and told her friend, "the robot said that if you play with it for a long time, it will tell you a secret."
- Child B told the robot, "Please tell me your secret (personal matters)!"
- Although Child C asked the robot about the personal matters, the robot didn't tell this. Child D was watching the scene and told child C the robot's personal matters that the robot told child D before.

Table 1: Questionnaire for attribution and its result

Questionnaire	result
Q1: Do you want to be friends with the robot?	avg. 3.89 (s.d. 0.84)
Q2: Do you want to know the mechanism of the robot?	avg. 4.38 (s.d. 0.83)
Q3: Do you usually play outdoors or indoors?	outdoor: 26 indoor: 11

Table 2: Correlation between attributions and interaction

	Correlation / Statistic test result (*p<.05)
Gender (male/female)	not significant
Friendship motivation (Q.1)	0.35 *
Mechanical interest (Q.2)	-0.40 *
Chance (Q.3)	significant *

The robot gradually performed new behaviors according to the pseudo-learning mechanism, and these behaviors caught their attention.

- When the robot's eye was hidden (Fig. 6-b), it brushed off the obstacle and said "I can't see." This new behavior was so popular that many children tried to hide the robot's eyes.
- The robot started singing a song, and the observing children joined it in singing the song.

Third phase (8th-9th week): Sorrow for parting

The number of children who came around the robot increased during these two weeks. However, the number of children who played with the robot did not increase. Many of them simply came around and watched the interaction for a while. We believe that the teacher's suggestion affected them. On the first day of the 8th week, the class teacher told them that the robot would leave the school at the end of the 9th week.

The "confiding of personal matters" behavior became well-known around the children. Many children around the robot were absorbed by asking the robot to tell these matters. They made a list of the personal matters that they heard from the robot on the blackboard (**Fig.** 7-a). One of the robot's personal matters, "I like the class teacher," was the most preferred among them. When the robot said it, some children ran out of the classroom to tell it to the teacher.

On the last day, the children held a farewell party for the robot. They formed a line and played with the robot one by one (Fig. 7-b).

Children who played with the robot for a long time

To investigate these three phases in detail, we classified the children into two groups along with each child's number of interaction days with the robot: "more than half" (the children who played with it more than 16 days out of the 32 experiment days) and "less than half" (the children who played with it fewer than or equal to 16 days). Ten children (4 males and 6 females) were classified into the "more than half" group. **Figure 8** indicates their average interaction time with the robot. On the other hand, there were 27 children (14 males and 13 females) classified into the "less than half" group. **Figure 9** indicates the average interaction time of the "less than half" group members.

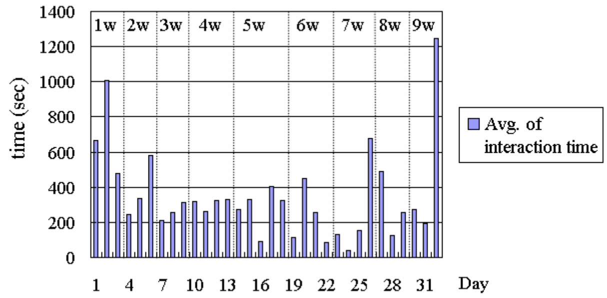

Figure 8: Average interaction time (more than 16 days children)

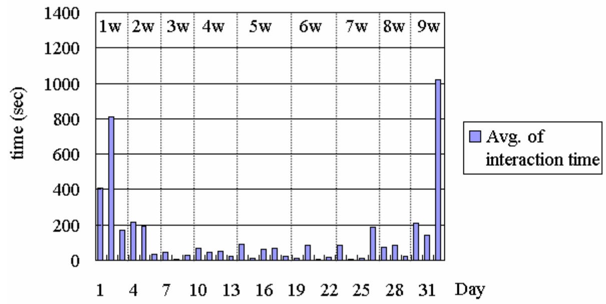

Figure 9: Average interaction time (less than or equal to 16 days children)

Comparing these graphs, it seems that the children who played longer ("more than half" group) continued playing with the robot over the two months. On the other hand, the children who played a shorter time ("less than half" group) seemed only to have played with the robot in the first and third phases. This finding is reflected in Figure 4. That is, the children in the "more than half" group established friendly relationships with the robot and continued playing with the robot, so someone was almost always playing with the robot.

C. Influence of Children's Attributions for the Interaction

We investigated how the children's attributions (interest, motivation, and so forth) affected their interaction with the robot. **Table 1** shows the questionnaire and the results for the attributions of children. This questionnaire consisted of three questions (Q.1 and Q.2 were used with 1-to-5 scales).

We calculated the Peason correlation between interaction time and Q.1 and Q.2. (Since the number of data is 37, each correlation value whose absolute value is larger than 0.3246 is statistically significant.) Thus, the friendship motivation (Q.1) has significant positive correlation with the interaction time, and the mechanical interest (Q.2) has significant negative correlation. We also tested the effect of gender and Q.3 with ANOVA (analysis of variance). As a result, there is a significant difference in the chance factor (Q.3: outdoors type and indoors type) ($F(1,35)=4.39$, $p<.05$). That is, the children who usually played inside tended to interact with the robot longer than others. There is no significant difference between genders

Table 3: Multiple regression analysis for interacting time

attributions	term	coefficient	value
Gender	A_g	α_g	-0.003
Friendship motivation (Q.1)	A_f	α_f	0.315
Mechanical interest (Q.2)	A_m	α_m	-0.331
Chance (Q.3)	A_c	α_c	0.232

*(Each **term** and **coefficient** (standardized partial regression coefficients) in the table appears in the equation of the regression (4). Since the regression was proved to be significant, each value (right-most column) represents how the attributions related to the interacting time.)*

(F(1,35)=2.37, p=.13). **Table 2** shows these results of correlation (Q.1 and Q.2) and the comparison with ANOVA (gender and Q.3).

Furthermore, we conducted a multiple regression analysis for the interaction time with the attribution. The estimated multiple linear regressions are:

$$Interaction\ time = \alpha_g \bullet A_g + \alpha_f \bullet A_f + \alpha_m \bullet A_m + \alpha_c \bullet A_c + \alpha_{const} \quad (4)$$

In the equation, A_g , A_f , A_m , and A_c indicate the individual attributions, which correspond to the left-most column in Table 3. As a result of the multiple linear regression analysis, standardized partial regression coefficients were obtained, as shown in right-most column in Table 3. The multiple correlation coefficients of the equation is 0.567, thus 32 % of the interaction time is explained by the regression. The validity of the regression is proved by ANOVA (F(4,32)=3.79, p<.05).

This verifies that the more a child wants to be friends with the robot and the less the child wants to know the mechanism of the robot, the longer he/she played with the robot. It also proved that the children who usually played inside interacted with it longer. Gender difference does not seem to contribute to the interaction time at all. These analysis results seem to suggest that the motivation of being a peer-type friend with the robot (not regarding it as a mechanical tool) helps children to maintain stable interaction with the robot.

D. Results for understanding social relationships

Based on the mechanism proposed in Section II-D, we estimated friendly relationships among children from their interaction with the robot and analyzed how the estimation corresponds to real friendly relationships. Since the number of friendships among children was fairly small, we focused on the appropriateness (coverage and reliability) of the estimated relationships. Questionnaire responses indicated 212 friendships among a total of 1,332 relationships; thus, if we suppose that the classifier always classifies a relationship as a non-friendship, it would obtain 84.1% correct answers, which would mean that the evaluation is completely useless. Thus, we evaluated our estimation of friendship based on reliability and coverage, which are defined as follows.

Reliability = number of correct friendships in estimated friendships / number of estimated friendships

Table 4: Estimation results with various parameters

coverage		T_{TH} *(simultaneously interaction time)*					
reliability		0.3	0.2	0.1	0.05	0.01	0.001
S_{TH} *(no. of simultaneously Interacting children)*	2	0.01	0.01	0.04	0.11	0.23	0.24
		1.00	0.50	0.36	0.41	0.28	0.26
	5	0.00	0.00	0.07	0.23	0.67	0.81
		-	-	0.88	0.44	0.24	0.19
	10	0.00	0.00	0.00	0.22	0.78	0.94
		-	-	-	0.47	0.2	0.17

('-' indicates that no relationship was estimated, so reliability was not calculated)

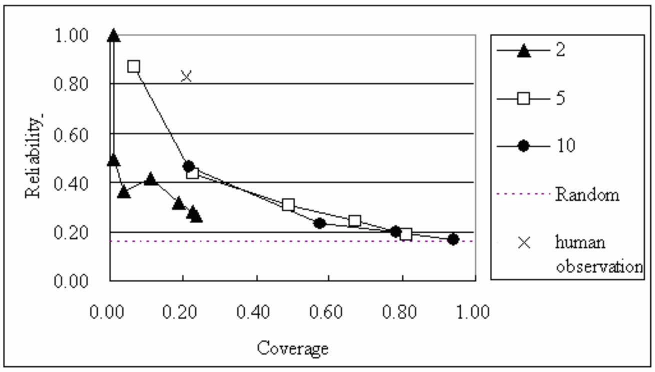

Figure 10: Illustration of friendship estimation results

(Each line corresponds to S_{TH} (2, 5, and 10). Each point of these lines corresponds to a certain T_{TH} in Table 4. "Human observation" indicates the result of estimation by a human experimenter, discussed in section IV-C.)

Coverage = number of correct friendships in estimated friendship / number of friendships from the questionnaire

Table 4 and **Figure 10** indicate the results of estimation with various parameters (S_{TH} and T_{TH}). In Fig. 8, *random* represents the reliability of random estimation, where we assume that all relationships are friendships (since there are 212 correct friendships among 1,332 relationships, the estimation obtains 15.9% reliability with any coverage). In other words, *random* indicates the lower boundary of estimation. Each of the other lines in the figure represents an estimation result with a different S_{TH}, which has several points corresponding to different T_{TH}. There is obviously a tradeoff between reliability and coverage, which is controlled by T_{TH}; S_{TH} has a small effect on the tradeoff. S=5 and S=10 has similar performance for the friendship estimation, and S=2 performs better estimation when coverage is very small. As a result, our method successfully estimated 10% of the friendship relationships with nearly 80% accuracy and 30% of them with nearly 40% accuracy.

IV. DISCUSSIONS

A. Effect of behavior design for Long-term interaction

The experimental results show that the robot continued friendly interaction with children for two months, although these children were the pupils who had higher motivation to be friends with the robot. Here, we investigate how the behavior design described in Section II-C contributed to the long-term interaction by analyzing the episodes of the experiment and the children's comments.

1) Calling of names

Many children seemed to find this behavior interesting, which is similar to [17]. They tried to get the robot to call their names. One child showed his nameplate to its camera; another child told the robot his name. We believe this performance indicates is one of the most fundamental abilities for social interaction.

2) Pseudo-learning

Some of the children noticed that the number of the robot's behaviors increased. For example, a child commented, "Since the vocabulary of the robot increases, it became easy to talk with the robot." However, a child who had not often interacted with the robot at the beginning tried to played with the robot later but found it boring. He commented, "Robovie can talk, but it always speaks about same thing." We believe that this mechanism contributed to maintaining long-term interaction; however, we need to control the increase rate of behaviors in a more appropriate way.

3) Confiding personal matters

The robot exhibited these behaviors along with the pseudo-learning design. That is, the longer the child interacted with it, the more personal matters it confided. Some of them competed with each other in finding out a greater number of its personal matters. A child commented that "I played with Robovie to investigate its personal matters." Near the end of the two month, the children who often played with the robot started to list up the personal matters they had heard from it on the classroom black board. These episodes show that the revelation of its personal matters contributed to keeping the children's attention on the robot at least for those who often played with it.

B. Attributions of children

Children's attributions also affected their interaction. The children who wanted to be friends with the robot but did not want to know its mechanism tended to maintain long-term friendly interaction with the robot. We believe this result suggests that it is important to motivate humans to be a peer-type friend with such a social robot rather than use it as a tool or machine. In fact, children who interacted with it for a long time reported, "Robovie seems lonely and wants to talk," "although Robovie is a robot, I feel it has a human-like presence," and "when I interacted with Robovie, I felt as if I had interacted with a human friend. Perhaps, this is because I got accustomed to interacting with it." These comments also suggest that these children treated it as if it were a creature-like existence or a peer-type human child.

Obviously, we do NOT intend to suggest that robotics research should focus on how to change a child's attribution for the sake of facilitating better interaction. Due to each child's attributions, some of them prefer to play with the robot while others prefer different modes of play. However, further improvements to robots' interactive ability, which the field of robotics can certainly contribute to, will probably promote better long-term interaction, such as our attempts described in section II. Additionally, an interactive robot could possibly utilize children's attribution to have better interaction, such as trying to hide its internal mechanism, or letting children feel more friendship with it.

C. Friendship estimation

Experimental results show that Robovie successfully estimated 10% of the friendly relationships (retrieved by subjective questionnaire) with nearly 80% accuracy and 30% of them with nearly 40% accuracy. This result is almost two times better than that of our preliminary study [18]. We believe that this improvement is due to the amount of the data obtained over the two months. In other words, since Robovie maintained friendly relationships with the children for a long time, the estimation of friendship improved.

In addition, we roughly compared the robot's performance with a human's estimation. The human experimenter who administrated this experiment estimated the friendships among the children without knowing their questionnaire answers; this resulted in 21.2% coverage with 83.3% accuracy (plotted in figure 8 as "human observation"). We believe that this indicates the upper boundary of the robot's estimation performance. Since humans observe more precise interactions among others as well as proximity, robots will also need to observe other verbal and non-verbal interactions to improve estimation, such as body orientation, language communication among humans, and emotional aspects in the communication.

V. CONCLUSION

This paper reported a two-month experiment on the interaction between elementary school students and the developed interactive humanoid robot Robovie, which has interactive behaviors designed for long-term interaction. The experiment's results reveal that the children who treated Robovie as a peer-type friend established friendly relationships and continued interacting with it for the entire two months. Meanwhile, the children who did not consider Robovie as such a partner (the majority of the class) got bored with the robot after approximately 5-7 weeks. We believe that important future work is to improve the robot's interactive ability such that this period of 5-7 weeks is extended onto scales of several months, a year, and more. If these lengthier periods are achieved, we believe they will enable robots to establish friendly relationships such as the ones that exist between humans.

Regarding the friendship estimation, Robovie successfully estimated 10% of the friendly relationships with nearly 80% accuracy and 30% of them with nearly 40% accuracy. We believe that the establishment of long-term interaction and the estimation of friendships are fundamental abilities for a social robot that is designed to participate in our daily lives.

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REFERENCES

[1] M. Fujita, AIBO; towards the era of digital creatures, *Int. J. of Robotics Research,* Vol. 20, No. 10, pp. 781-794, 2001.

[2] C. Breazeal and B. Scassellati, A context-dependent attention system for a social robot, *Proc. Int. Joint Conf. on Artificial Intelligence(IJCAI'99),* pp. 1146-1151, 1999.

[3] H. G. Okuno, K. Nakadai, and H. Kitano, Realizing audio-visually triggered ELIZA-like non-verbal behaviors, *PRICAI2002, LNAI 2417, Lecture Notes in Artificial Intelligence,* Springer-Verlag, pp. 552-562, 2002.

[4] W. Burgard, A. B. Cremers, D. Fox, D. Hahnel, G. Lakemeyer, D. Schulz, W. Steiner, and S. Thrun, The interactive museum tour-guide robot, *Proc. of National Conference on Artificial Intelligence,* pp. 11-18, 1998.

[5] C. Moore and P. J. Dunham (eds), *Joint Attention: Its Origins and Role in Development,* Lawrence Erlbaum Associates, 1995.

[6] B. Scassellati, Investigating Models of Social Development Using a Humanoid Robot, *Biorobotics,* MIT Press, 2000.

[7] H. Kozima and E. Vatikiotis-Bateson, Communicative criteria for processing time/space-varying information, *Proc. IEEE Int. Workshop on Robot and Human Communication,* 2001.

[8] T. Kanda, H. Ishiguro, M. Imai, and T. Ono, Body Movement Analysis of Human-Robot Interaction, *Int. Joint Conf. on Artificial Intelligence (IJCAI2003),* pp. 177-182, 2003.

[9] D. J. Watts and S. H. Strogatz, Collective dynamics of 'small-world' networks, *Nature,* Vol. 393, Issue 6684, pp. 440-442, 1998

[10] J. D. Eveland and T. K. Bikson, Evolving electronic communication networks: an empirical assessment, *Proc. of the 1986 ACM conference on Computer-supported cooperative work,* pp. 91-101, 1986.

[11] S. Nomura, S. Oyama, T. Hayamizu, and T. Ishida, Analysis and Improvement of HITS Algorithm for Detecting Web Communities, *The 2002 International Symposium on Applications and the Internet,* pp. 132-140, 2002.

[12] H. Ishiguro, T. Ono, M. Imai, and T. Kanda, Development of an interactive humanoid robot "Robovie" -An interdisciplinary approach, R. A. Jarvis and A. Zelinsky (eds.), *Robotics Research,* Springer, pp. 179-191, 2003.

[13] T. Kanda, T. Hirano, D. Eaton, and H. Ishiguro, Person Identification and Interaction of Social Robots by Using Wireless Tags, *IEEE/RSJ International Conference on Intelligent Robots and Systems,* pp.1657-1664, 2003.

[14] T. Kanda, H. Ishiguro, M. Imai, T. Ono, and K. Mase, A constructive approach for developing interactive humanoid robots, *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS2002),* pp. 1265-1270, 2002.

[15] F. Heider, The psychology of interpersonal relations, Wi1ey, 1958.

[16] G. W. Ladd, J. M. Price, and C. H. Hart, Preschooler's behavioral orientations and patterns of peer contact: predictive of peer status? in S. R. Asher and J. D. Coie (eds.) *Peer rejection in childhood,* Cambridge University Press, pp. 90-115, 1990.

[17] T. Kanda, T. Hirano, D. Eaton, and H. Ishiguro, A practical experiment with interactive humanoid robots in a human society, *Third IEEE International Conference on Humanoid Robots (Humanoids),* 2003.

[18] T. Kanda and H. Ishiguro, Reading human relationships from their interaction with an interactive humanoid robot, *Int. Conf. on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (IEA/AIE),* pp. 402-412, 2004.