A two-month field trial in an elementary school for long-term human-robot interaction

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***Abstract*— Interactive robots participating in our daily lives should have the fundamental ability to socially communicate with humans. In this paper, we propose a mechanism for two social communication abilities: the forming long-term relationships and the estimating friendly relationships among people. The mechanism for long-term relationships is based on three principles of behavior design. The robot we developed, Robovie, is able to interact with children in the same way children do. Moreover, the mechanism is designed for long-term interaction along the following three design principles: 1) it calls children by name using RFID tags; 2) it adapts its interactive behaviors for each child based on a pseudo development mechanism; and 3) it confides its personal matters to the children who have interacted with the robot for an extended period of time. Regarding the estimation of friendly relationships, the robot assumes that people who spontaneously behave as a group together are friends. Then, by identifying each person in the interacting group around the robot, it estimates the relationships between them. We conducted a two-month field trial at an elementary school. An interactive humanoid robot, Robovie, was placed in a classroom at the school. The results of the field trial revealed that the robot successfully continued interacting with many children for two months, and seemed to have established friendly relationships with them. In addition, it demonstrated reasonable performance in identifying friendships among children. We believe that these results demonstrate the potential of current interactive robots to establish social relationships with humans in our daily lives.**

***Index Terms*— human-robot interaction; long-term interaction; longitudinal study; field trial; friendship estimation;**

I. INTRODUCTION

OUR objective is to develop a communication robot that operates in an everyday environment, such as a school or a museum, to provide support for people through interactions using body movements and speech. Several researchers are endeavoring to develop interactive robots and communication robots. Aibo was the first interactive robot to prove successful on the commercial market [1], since it behaves as if it were a real pet. Recently, Shibata et al. utilized a seal-type pet robot as a therapy tool [2]. Breazeal and her colleagues developed the face robot Kismet, and they are exploring the sociable aspects of robots based on their learning ability [3]. Nakadai and his colleagues developed a humanoid head that tracks a speaking person with visual and auditory data [4], while Burgard et al. developed a museum tour guide robot [5] with robust navigational skills that behaved as a museum orientation tool. These research efforts seem to be devoted to “communication robots” that are embedded in human society.

We have selected a humanoid robot to achieve our objective because its physical structure enables it to interact with people using human-like body movements such as shaking hands, greeting, and pointing. We expect human-like interaction to be important for motivating people to naturally interact with the robot and for improving its perceived friendliness towards people. Previous work in robotics has also demonstrated the effective usage of body properties in communication, such as facial emotions [3], head orientation [4], pointing [6, 7, 8, 9], and synchrony of motions [10].

The important problem yet to be solved is how communication robots should participate in our daily lives. A robot in a museum [5, 11, 12] is a successful example of participation; but it is an example of only brief interaction and is limited to people who see the robot for the first time. Although some of these installations were long-term, each interaction with visitors was short-term and not repeated. By contrast, in our previous work, an interactive humanoid robot was placed in an elementary school and continued interacting with the same children for two weeks [13]. The results of that study suggested the possibility that a robot can indeed motivate children to learn a foreign language by interacting with them in that language. The effectiveness of a robot for education has also been demonstrated by e-learning robots in home environments [14].

At the same time, however, our previous work [13] reveals a shortcoming in the robot’s capability for long-term interaction: At first children crowded around the robot, actively interacting with it for the first week, but during the second week the interactions gradually became less active. Thus, we believe that the capability for long-term interaction is one important characteristic that such a robot should have.

In this study, we design interactive behaviors for long-term interaction and report how our design principles promote such interaction. Note that there are a few recent works on human-robot long-term interaction. Tanaka et al. demonstrated

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a successful long-term interaction based on interactive dancing [15], and interaction with therapy robots continued long-term [2] [16]. However, the information these robots can provide is limited, since the interaction is restricted to the type with non-verbal communication. We believe that a robot that interacts with people verbally suffers from more difficulty with long-term interaction because people expect more from it and easily discover the lack of this capability. A study on a receptionist robot, Valerie, demonstrated that frequently updating daily episodes and personal matters that the robot reveals to people promotes continued text-based conversation with the robot [17]. In other words, it revealed that updating the contents promotes long-term interaction.

We also focused on the social ability of friendship estimation that a robot should acquire. Since friendship is tightly connected to social relationships, friendship estimation is essential for accomplishing more general social relationship estimation. For example, it could be a future application for a classroom-based robot to help solve bullying problems or the problem of rejected children. In psychology, it has been proved that there is a correlation between children's group behavior and the valence of their relationships [18, 19, 20]. In our previous study, we found that a robot can estimate children's friendship [21, 22]; the performance was, however, limited due to an insufficient amount of data, since the interaction with the robot did not continue for a long time. Thus, our hypothesis is that if a robot can establish friendly relationships with people for an extended time, it will be able to more accurately estimate relationships among people because it observes their interactions around itself for a longer period of time.

The rest of this paper is organized as follows. In Section II, we explain the system configuration of the developed system. The longitudinal experiment at an elementary school is reported in Section III. In Section IV, we discuss the contributions of this research. Our conclusions are presented in Section V.

II. AN INTERACTIVE HUMANOID ROBOT

A. Hardware

Figure 1 shows the humanoid robot "Robovie" [23]. The robot is capable of human-like expression and recognizes individuals by using various actuators and sensors. Its body possesses highly articulated arms (with four DOF), eyes (two DOF), and a head (three 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 RFID tags

To identify individuals, we used a radio frequency identification (RFID) tag system capable of multi-person identification by the robots. Recent 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 an RFID 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 real time via the software. Because the RFID tag system provided the robots with a robust means of identifying many children simultaneously, the robots could exhibit some human-like adaptation by recalling the interaction history of a given person, as explained in detail in [24].

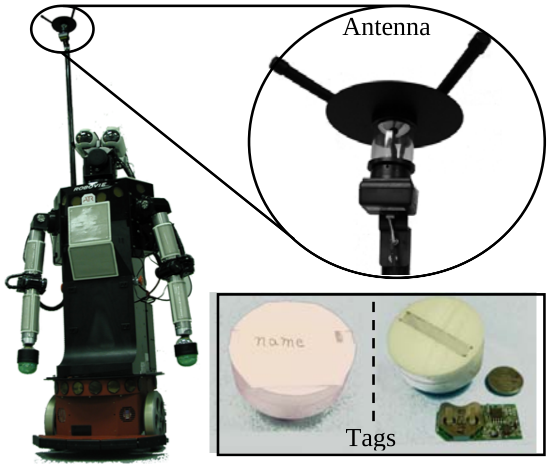

Figure 1: Robovie and RFID tags

C. Interactive Behaviors for Long-term Interaction

1) General design

Robovie features a software mechanism for performing consistent interactive behaviors [25]. 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 which are interactive behaviors such as shaking hands, hugging, playing rock-paper-scissors, 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 ten are moving-around behaviors. In total, the robot can 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, touch me," and it exhibited idling or moving-around behaviors until the child responded. Once the child reacted, Robovie 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) Three Design Principles for Long-term Interaction

Moreover, we propose three design principles of interactive behaviors for long-term interaction that are based on the person identification functions.

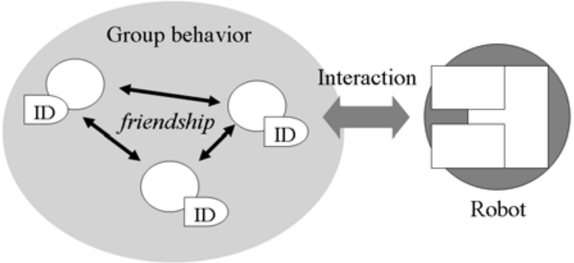

Figure 2: Estimating humans' friendly relationships

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.

Calling children's names

The first principle was calling the children's names. In some interactive behaviors, the robot called a child's name if that child was within a certain distance. For instance, in an interactive behavior, the robot would speak, "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.

Pseudo-development

The second principle is pseudo-development: the more a child interacts with the robot, the more types of interactive behavior it will display to the child. For example, it shows at most ten behaviors to a child who has never interacted with it. However, it may show up to 100 behaviors to a child who has interacted with it for 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-development mechanism is often employed by interactive pet robots like Aibo.

Confiding personal matters

The third principle 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 engage in further interaction. 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. Estimating Humans' Friendly Relationships

Our approach to estimating humans' friendly relationships consists of the two functions described below (**Fig. 2**). Since humans have friendly relationships, they tend to form groups. We have adopted this tendency, programming the robot to induce humans to perform spontaneous group behavior with its interactive behaviors.

1) Friendship and observation of group behavior

Friendship is defined as a close, mutual, and voluntary dyadic bilateral relationship, which is often formed based on similarity among individuals, common interests, and common activities [26]. It is a well-grounded finding from psychological research that children at a very young age engage in dyadic relationships, for example, in the form of pretend play. Then, with age, they increase the size, from dyadic to more than triadic, and complexity of their relationships. As they grow up, they form many different peer relationships in the form of social networks, and as children gradually establish social networks, each child attains a different social status [20, 27].

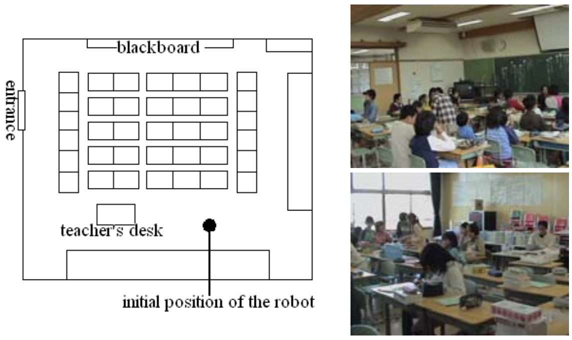

Figure 3: Environment of the elementary school

A sociometric test has been used to investigate peer relationships and social networks, and this lets a human directly answer with the names of others whom he or she likes or dislikes. This method has been validated as a reliable assessment of human-peer relationships. It categorizes each child's social status into one of the following groups: popular, average, neglected, and rejected [28, 29]. This method has been widely employed to determine the relationships in a classroom or a company.

As an alternative, observation-based methods have been developed for identifying peer relations and social status. A child's behaviors toward friends are different from those toward non-friends. This difference has been investigated through more than 80 research papers [30]. For example, positive engagement (talk, smiling, and laughter) was observed more often among friends rather than among non-friends. How children form groups and behave within these groups is associated with their friendly relationships. While children usually play with their peers, there seems to be some gender difference in the size of play groups [18]. Ladd et al. investigated the associations between observed group behavior and relationships among group members. They coded video footage of children's play with four behavioral measures: cooperative play, rough play, unoccupied, and teacher-oriented. Their observations revealed that a child's cooperative play is associated with positive nominations, while his or her rough play is related to negative nominations. In addition, they revealed that past behavior successfully predicted the current peer status; for example, time spent in cooperative play was a significant predictor of positive nomination [19]. Coie et al. investigated the difference between popular and rejected children in terms of their behavior and revealed the relationship between rejected children and their aversive behaviors [20]. We believe these findings support the notion that social robots (or other systems that can observe human behaviors) can

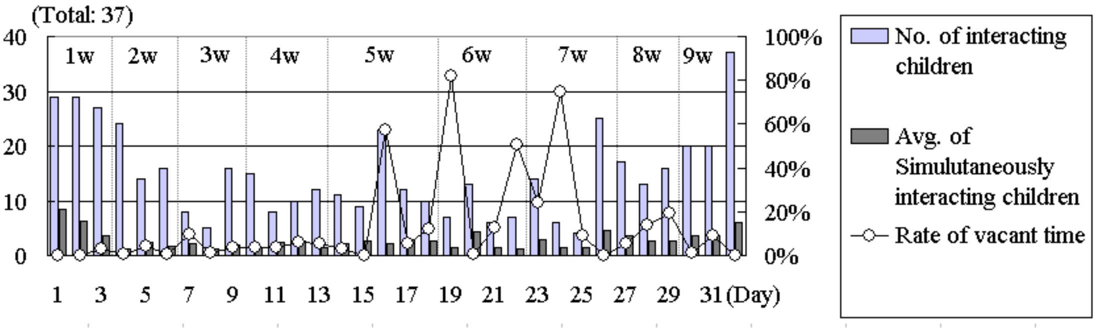

Figure 4: Transitions of the interaction between children and the robot

recognize humans' peer relationships and social status by observing their group behavior.

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, since humans often behave as a group, 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. In this study, we observe spontaneous group behavior caused by a robot and confirm the effectiveness of this strategy.

3) Algorithm for estimating friendly relationships

From a sensor (in this case, RFID ID tags and a 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 persons A and B simultaneously interact with the robot (T_{AB}, which is equivalent to T_{BA}). We 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} (Eqs. 2 and 3). In our trial, we set Δt to 1 sec.

III. LONGITUDINAL STUDY IN AN ELEMENTARY SCHOOL

We conducted a longitudinal field trial 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 trial.

A. Setting

We performed a field trial 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 trial period consisted of 32 actual 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**), and the children were able to freely interact with it during a 30-minute recess after lunch time[1].

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

Since the robot's arm movements could be dangerous to the children if they get too close, a human assistant kept a distance between the robot and children when they came close to the robot. She also asked the children to wear their RFID nameplates if they were not wearing the nameplates when they approached the robot. She did not provide any further assistance.

B. Observation of Long-term Interaction

Figure 4 illustrates the transition of interaction with children. The dotted lines separate the nine weeks during the two-month period. We classify the nine weeks into three principal phases, following [13], 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 there was always someone 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**).

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[1] the experimental protocol was reviewed and approved by the institutional review board of ATR

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

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

Figure 5: Scenes of the experiment during 1st-2nd weeks

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

Everyday, about ten children came around the robot, and some of them played with it. When it was raining, the children who usually played outside played with the robot and, as a result, the number of children interacting with it increased. During these five weeks, the number of interacting children gradually decreased and vacant time increased. The "confiding of personal matters" behavior first appeared in the fourth week gained popularity (**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 personal matters, the robot did not reveal any. Child D was watching the scene and told child C the robot's personal matters that the robot had told child D before.

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

- When the robot's eyes were covered (**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 cover 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 eighth week, the class teacher told them that the robot would leave the school at the end of the ninth 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: Scenes of the experiment during 3rd-7th weeks

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

Figure 7: Scenes of the experiment during 8th-9th weeks

The "confiding of personal matters" behavior became well known around the children, and many children around the robot were absorbed in asking the robot to speak about these matters. They made a list of the personal matters 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 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 (four males and six 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.

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

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 / Statistical test result (*p<.05)
Gender (male/female)	not significant
Friendship motivation (Q.1)	0.35 *
Mechanical interest (Q.2)	-0.40 *
Usual playing place (Q.3)	significant *

Table 3: Multiple regression analysis for interacting time

attributions	value
Gender	-0.003
Friendship motivation (Q.1)	0.315
Mechanical interest (Q.2)	-0.331
Usual playing place (Q.3)	0.232

(The value corresponds to the coefficient (standardized partial regression coefficients), which appears in the equation of the regression (4). Since the regression was proved to be significant, each value represents how the attributions related to the interacting time.)

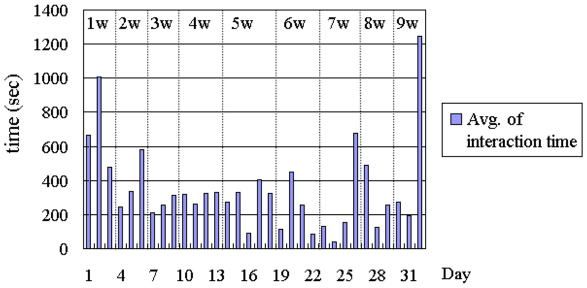

Figure 8: Average interaction time
(more than 16 days: 10 children)

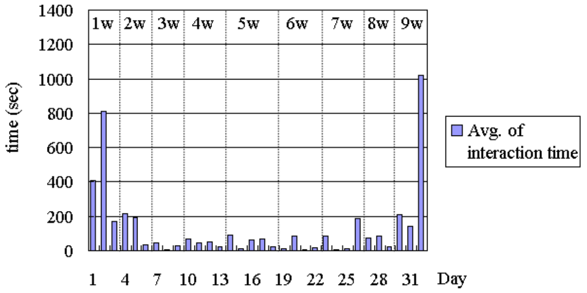

Figure 9: Average interaction time
(less than or equal to 16 days: 27 children)

who played a shorter time ("less than half" group) seemed only to have played with the robot in the first and third phases. That is, the children in the "more than half" group established friendly relationships with the robot and continued playing with it, so there was almost always someone playing with it.

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 used 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 a significant positive correlation with the interaction time, and the mechanical interest (Q.2) has a significant negative correlation. This result may seem surprising, since mechanical interest could be a motivation to interact with the robot, particularly in the beginning. Our interpretation is that for long-term interaction it is important to motivate humans to be a peer-type friend with such a social robot rather than to use it as a tool or machine.

We also tested the effect of gender and Q.3 with an ANOVA (analysis of variance). The result revealed a significant difference in the usual-playing-place factor (Q.3: outdoors type or 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 (F(1,35)=2.37, p=.13). **Table 2** displays these results of correlation (Q.1 and Q.2) and the comparison with the 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:

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

In Eq. 4, 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 coefficient of the equation is 0.567, meaning 32% of the interaction time is explained by the regression. The significance of the model is revealed by the ANOVA (F(4,32)=3.79, p<.05).

This verifies that the more a child wanted to be friends with the robot and the less the child wanted to know its mechanism, the longer he/she played with the robot. It also suggested 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 it.

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

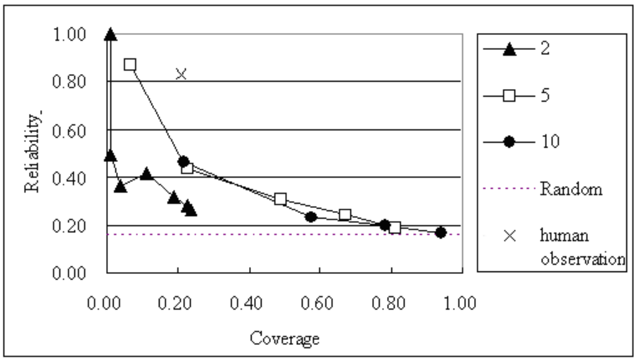

Figure 10: Illustration of friendship estimation results

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

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 instead of the rate of correct classification used in machine learning and pattern recognition research. This is similar to the evaluation of an information retrieval technique such as a Web search.

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:

$$Coverage = \frac{\textit{correct relationships in estimated relationships}}{\textit{all correct relationships}}$$

$$Reliability = \frac{\textit{correct relationships in estimated relationships}}{\textit{estimated relationships}}$$

Fig. 10 present the results of estimation with various parameters (S_{TH} and T_{TH}). In the **Fig. 8**, *random* is plotted as the result of random estimation in order to show the lower boundary of the estimation. The reliability of the *random* estimation is equal to the chance rate (since there are 212 correct friendships among 1,332 relationships, the estimation obtains 15.9% reliability with any coverage). This chance rate is constant for any coverage. Each of the other lines in the figure represents an estimation result with a different S_{TH}, having 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 only a small effect on the tradeoff. Here, S=5 and S=10 give similar performance for the friendship estimation, and S=2 provides better estimation when coverage is very small. As a result, for example, our method successfully estimated 7% of all friendship with 88% accuracy (S_{TH}=5, left-most data point) and 23% of them with nearly 44% accuracy (S_{TH}=5, at second data point from the left).

IV. DISCUSSION

A. Contributions

One important contribution of this study is that it demonstrated that the developed interactive robot, along with the proposed design principles, sustained long-term relationships with children. Such capability of long-term interaction is indispensable for robots to participate in our daily lives. For instance, in our previous field trial at the elementary school [13], the robot became boring for children after the first week. If, however, the robot could continue interaction for longer, its performance for motivating foreign language study may reach a level suitable for application in the real world.

Moreover, this study revealed that the robot can estimate children's friendships. In particular, thee results suggested that the long-term interactions improve friendship estimation performance. This outcome leads to the possibility of a communication robot that plays with children in a classroom and moderates problems in their relationships, such as a bullying. Of course, ethical issues should be carefully considered.

Thus, this paper demonstrated an example where a robot established a friendly relationship with children. It has two fundamental social capabilities: long-term interaction and estimation of friendships. We believe that these functions will be essential for robots that will participate in our daily lives.

B. Effect of behavior design for long-term interaction

The experimental results show that the robot continued friendly interaction for two months with the children who were more interested 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 field trial and the children's comments.

1) Calling of names

Many children seemed to find this behavior interesting, which is similar to [13], trying to get the robot to call their names. One child showed his nameplate to the robot's camera; another child told the robot his name. One possible explanation is that children started a kind of competition of getting attention from the robot, and they started many behaviors including the showing of the nameplates. This seems one clue that children want to be distinguished as individuals by the robot, which is one of the most fundamental social interaction. Note that since it is also effective in short-term interaction [11], the name-calling behavior should not be too strongly emphasized in the design of long-term interaction.

2) Pseudo-development

Some of the children noticed that the number of behaviors exhibited by the robot increased over time. For example, a child commented, "Since the vocabulary of the robot increased, it became easy to talk with it." However, a child who had not often interacted with the robot at the beginning tried to play with it later but found it boring. He commented, "Robovie can talk, but it always talks about the same things." We believe that this mechanism contributed to maintaining long-term

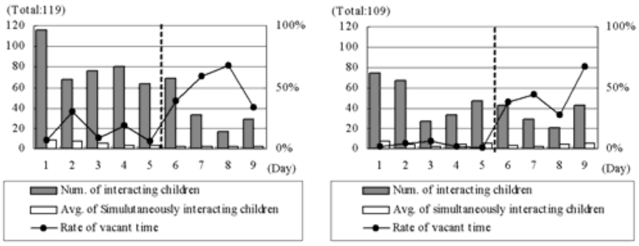

Fig. 11: Interaction time with robots of 1st grade students and 6th grade students in the previous elementary school study [13]

interaction; however, it is necessary to control the increase rate of behaviors in a more appropriate way.

3) Confiding personal matters

The robot exhibited these behaviors as part of the pseudo-development design. That is, the longer a child interacted with it, the more personal matters Robovie confided. Some children competed with each other to find out the greatest number of the robot's personal matters. One child commented: "I played with Robovie to investigate its personal matters." Near the end of the second month, the children who often played with the robot started to list the personal matters they had heard from it on the classroom blackboard. These examples show that the revelation of its personal matters contributed to holding the children's attention on the robot at least for those who played with it often.

C. Interests of children

Children's interests also affected their interaction. The children who wanted to be friends with the robot but did not want to know about its mechanism tended to maintain a long-term friendly interaction with the robot. We believe this result suggests 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 Robovie as if it were a creature-like entity or a peer-type friend.

Obviously, we do NOT intend to suggest that robotics research should focus on how to change a child's preference for the sake of facilitating better interaction. Some children prefer to play with the robot while others prefer to play elsewhere depending on their preference. However, further improvements to robots' interactive abilities, 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 utilize children's interests to produce better interaction, such as by trying to hide its internal mechanism or by being friendlier with children.

D. Comparison with a previous field trial at an elementary school

Our previous study [13] was with the same robot, Robovie, for a period of two weeks. In that study, the robot was placed in both first-grade and sixth-grade classrooms. One of the findings was that the robot interacted with children to some degree, but the activity of the interactions decreased after the first week (**Fig. 11**, from [13]).

In contrast, **Fig. 8** indicates that during the current trial the robot kept interacting with children after the first week. There were only five days in the entire period of the trial when vacant time was greater than 20%, showing that most of the time some children were interacting with the robot.

Here, we discuss possible findings by comparing the difference in the robot's settings between the two field trials.

Language spoken by the robot

In the previous work, since we intended to observe the effects on foreign language education, the robot only spoke English to Japanese children. Its utterances were spoken in the recorded voice of a native English speaker, which were too fast and fluent for Japanese children who have never heard them before to understand. In contrast, the robot in this study spoke Japanese to Japanese children, which enabled them to understand the robot and to establish friendly relationships with it.

Thus, the language could be one major barrier for children to overcome to interact with the robot. For language education, the robot might need to use the children's native language in order to establish relationships as well as the foreign language in order to teach it.

Interactive behaviors and design principles

In the previous field trial, the name-calling behavior had been already implemented, which also encouraged children to interact with the robot. For instance, a child did not seem to understand English at all; however, once she heard the robot say her name, she became quite pleased and began interacting with the robot more frequently. In this study, we included the name-calling behavior in the design principles. During the field trial, this behavior also attracted children and promoted interaction.

Moreover, two additional principles were introduced. One is the pseudo-development mechanism, where the robot increased the number of its interactive behaviors as the total length of its interaction with each child increased. The other is the confiding of its personal matters. This behavior gradually became well known among children in the second phase described in Section III B, and motivated them to interact with the robot more during the second and third phases of the experiment.

Location of the robot

There was also a difference in the robot's location. In the previous field trial, the robot was placed in a corridor between classrooms, since there were three classrooms and two identical robots. Thus, children in a classroom did not strongly feel ownership toward the robot against other children in another classroom.

In contrast, in this study the robot was placed inside the classroom, a setting that seemed to increase children's affinity for the robot. For example, when a visitor came to the classroom, children in the classroom voluntarily explained about the robot. One child described her impression that, “One day, a robot, Robovie, came to our classroom. In the course of two months, the robot became another person belonging to our classroom.” Comments like this indicate that children developed an idea of “our robot.” Perhaps this is similar to the situation where a class feeds a pet animal. (In Japanese schools, often a class feeds a pet, such as a goldfish, a mouse, or a rabbit).

E. Friendship estimation

Estimation results

Experimental results show that Robovie successfully estimated, for example, 7% of all friendships (retrieved by subjective questionnaire) with nearly 88% accuracy and 23% of them with nearly 44% accuracy. This result is almost two times better than that of our preliminary study [21, 22]. We believe that this improvement is due to the amount of 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 administered this field trial estimated the friendships among the children without knowing their questionnaire answers. This resulted in a 21.2% coverage with 83.3% accuracy (plotted in **Fig. 8** as “human observation”). We believe that this indicates the upper boundary of the robot’s estimation performance. Since humans more precisely observe 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 communication.

Sociogram

After investigating friendships, psychologists and sociologists often draw “sociograms” that represent humans’ social network within a class in a school. **Fig. 12** shows an example of a sociogram. In the graph, each node represents a child and each edge represents a friendship between two children. There is an established technique to analyze a sociogram, which enable us to identify popular children, rejected children (ones who want to have friends, but is not considered to be a friend by others), and isolated children (ones who do not have any friends) [19, 29]. One reason why psychologists want to identify rejected and isolated children is that they often suffer from bullying. Thus, for class teachers, such information is very helpful.

If more accurate estimation could be realized in a way similar to a human observer, we believe that the robot can make sociogram from the estimation; then, the usage of such estimations will form the basis of interesting research themes on the social skills of social robots. For instance, a robot may be able to identify bullying and moderate it (Fig. 11). We believe that it will require a more interdisciplinary research. For example, there is much knowledge about humans’ strategy on communication in psychology, such as Heider’s balance theory [31].

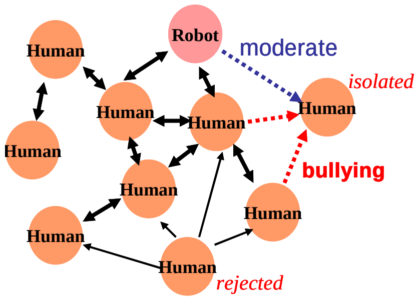

Figure 12: A sociogram (as an example only, not developed from this study) and its applications

F. Perspective for longer term installation

One might question how much our pseudo-development approach is applicable for longer term installations. We believe that such a pseudo-development can be accomplished by human developers. For example, a robot system in an elementary school might download new content from the Internet and gradually increase the variety in its behavior.

Another concern might be raised about number of personal matters. We believe that the number of personal matters of the robot is not limited, as the number of personal matters of humans is not limited. Moreover, in particular if we target a period of several years, we can allow the robot to download new content from the network, so that it is not necessary to pre-implement all of the content. Thus, we believe that our design policies for long-term interaction are applicable for longer-term installations.

Of course, long-term interaction capability is composition of various factors. Extending of duration for longer time probably requires better capability in general. That is, longer-term interaction will be more promoted by better interaction capability in various aspects, such as vision processing, speech recognition, number of capable physical tasks and plays, memory, and so forth.

G. Limitations

Since we only conducted the field trial for the elementary school once as a case study, the generality of our findings is limited. Unfortunately, it is very costly to conduct such a field trial multiple times. Moreover, since there were 37 children in the class, we are guaranteed a certain degree of variety and number of subjects for both longitudinal study for long-term relationships and estimation of friendship.

In addition, note that the comparison with the previous study in this discussion is done in a rough manner, since these field trials were, of course, not prepared as controlled experiments, which is common practice in psychology and HCI. Nevertheless, we believe that it is still worthy to compare these because running field trials is expensive.

V. CONCLUSION

This paper reported a two-month field trial on the interaction between elementary school students and the developed interactive humanoid robot Robovie. Robovie features interactive behaviors designed into it along with three design principles for long-term interaction: 1) calling of children's names, 2) pseudo-development mechanism, and 3) confiding of its personal matters.

The field trial'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 (two-thirds of the class) became bored with the robot after approximately five to seven weeks.

Regarding friendship estimation, Robovie successfully estimated, for example, 7% of the friendly relationships with nearly 88% accuracy and 23% of them with nearly 44% 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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