Communication Robots for Elementary Schools

Takayuki Kanda[*] Hiroshi Ishiguro[*†]
[*]ATR Intelligent Robotics and Communications Labs. [†]Osaka University
Kyoto, Japan Osaka, Japan
kanda@atr.jp ishiguro@ams.eng.osaka-u.ac.jp

Abstract

This paper reports our approaches and efforts for developing communication robots for elementary schools. In particular, we describe the fundamental mechanism of the interactive humanoid robot, Robovie, for interacting with multiple persons, maintaining relationships, and estimating social relationships among children. The developed robot Robovie was applied for two field experiments at elementary schools. The first experiment purpose using it as a peer tutor of foreign language education, and the second was purposed for establishing longitudinal relationships with children. We believe that these results demonstrate a positive perspective for the future possibility of realizing a communication robot that works in elementary schools.

1 Introduction

Recently, many researchers have been struggling to realize a *communication robot*, which is considered as a robot that participates in human daily life as a peer-type partner, communicates with humans as naturally as humans do by making bodily gestures and utterances, and supports humans with its communication tasks. Research activities toward communication robots have led to the development of several practical robots, such as therapy tools (Dautenhahn & Werry, 2002; Wada, Shibata, et al., 2004) and those for entertainment (Fujita 2001), and such robots are enlarging their working scope in our daily lives.

We believe that elementary schools are a promising field of work for a communication robot. The robot could be a playmate with children, although its interaction ability is limited in comparison to humans' and it would have very few social skills. As these fundamental abilities of robots improve, we can enhance their role: they will probably be useful for education support and understanding and building human relationships among children as friends. In future, it perhaps will help to maintain safety in the classroom such as by moderating bullying problems, stopping fights among children, and protecting them from intruders. That is, *communication robots for elementary schools* can be a good entry point for studying how robots participate in human daily life as peer-type partners.

We have developed a communication robot called Robovie that autonomously interacts with humans by making gestures and utterances as a child's free-play (Kanda et al., 2004 a); however, Robovie is confronted with three major problems in elementary schools: 1) difficulties in sensing in the real world, 2) difficulties in maintaining relationships with humans for long periods, and 3) difficulties in social interaction with many people.

We are addressing these problems via the following approaches. For the first problem, we believe that ubiquitous sensors are very helpful in reducing the burden of recognition in the real world. For example, with RFID tags (a kind of ubiquitous sensor) a robot can recognize individuals and call their names during interaction, which greatly promotes the interaction (Kanda et al., 2003). For the second problem, we have employed a design policy of interactive behaviors, such as a pseudo-learning mechanism and talking about personal matters (Kanda et al. 2004 b). For the third problem, we are trying to enhance its social skills. Currently, the robot identifies individuals to adapt its interactive behaviors to each of them (Kanda et al., 2003), and estimates human relationships by observing the humans' interaction around it (Kanda et al., 2004c).

The developed robot was used for two field experiments in elementary schools. We believe our experiments are novel as the first trials of applying interactive humanoid robots for human daily lives for a long period. The first experiment's purpose was to apply a robot to motivate Japanese children to study English (Kanda et al., 2004 d). The robot demonstrated positive effects for the motivating purpose; however, it is one interesting finding that

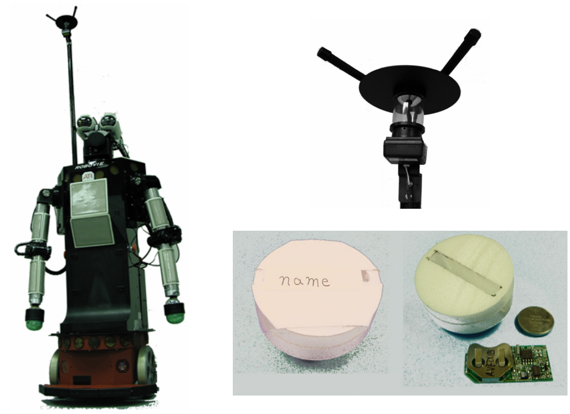


Figure 1: Robovie (left) and wireless tags

the robot started to become boring after a week during the two weeks of the experiment's duration. The second experiment's purpose was to sustain long-term relationships between children and the robot, and a mechanism was added to the robot to assist long-term interaction (Kanda et al., 2004 b). As a result, it could maintain active interaction in a classroom for a few weeks, and sustained long-term relationships with some of the children for the two months of the experiment.

Meanwhile, we analyzed its performance regarding friendship estimation among children (Kanda et al., 2004 c) for these two experiments, finding better estimation for the children who interacted with it for a long time. That is, the robot's ability for long-term relationships seems to positively affect its estimation performance, and the estimated result may also promote the establishment of relationships with children.

Although the most parts of the three difficulties still remain as an open challenge, we are optimistic for the future of communication robots, because we believe that the difficulties will be gradually solved through the approach of field experiments. For example, the ability of communication robots for long-term interaction was improved between these two experiments in elementary schools, which seemed to demonstrate a positive perspective for this future direction. Namely, by placing robots in daily-life fields even with a limited task as a part of an experiment, the abilities lacked and problems faced will become clearer, enabling us to improve the fundamental abilities of robots.

2 Robot system

2.1 Robovie

Figure 1 shows the humanoid robot "Robovie." This robot is capable of human-like expression and recognizes individuals by using various actuators and sensors. Its body possesses highly articulated

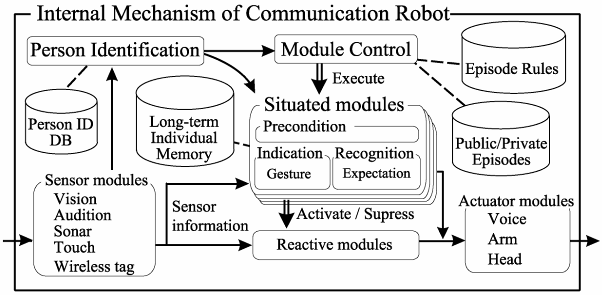


Figure 2: Software architecture of *Robovie*

arms, eyes, and a head, which were designed to produce sufficient gestures to communicate 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.

2.2 Person identification with wireless ID tags

To identify individuals, we used a wireless tag system capable of multi-person identification by partner robots. Recent RFID (radio frequency identification) technologies have enabled us to use contactless identification cards 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 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 by 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.

2.3 Software Architecture

Figure 2 shows an outline of the software that enables the robot to simultaneously identify multiple persons and interact with them based on an individual memory for each person. Our approach includes non-verbal information on both robots and humans, which is completely different from linguistic dialog approaches. To supplement the current insufficient sensor-processing ability, we employed an active interaction policy, in which the robots initiate interaction to maintain communicative relationships with humans. The basic components of the system are *situated modules* and *episode rules*. *Module control* sequentially executes *situated modules* according to the current situation and execution orders defined by

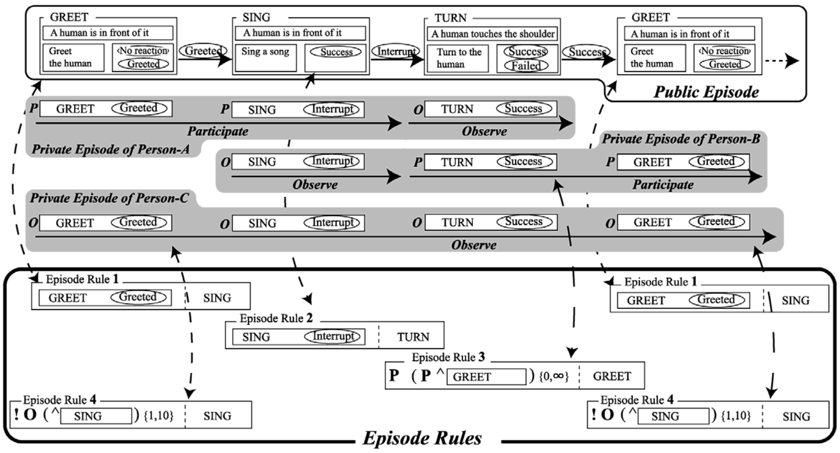


Figure 3: Illustrated example of episodes and episode rules for multiple persons

the *episode rules*. It is a completely bottom-up design that is quite different from others. Developers create *situated modules*, which execute a particular task in a particular situation, and *episode rules* that represent their partial execution order. The mechanism of interaction among humans is not yet known, so a top-down design approach is not yet possible.

The architecture includes four databases: *Person ID DB* to associate people with tag IDs, *episode rules* to control the execution order of *situated modules*, *public and private episodes* to sustain communications with each person, and *long-term individual memory* to memorize information about individual people. By employing these databases, the robot can track students' learning progress such as their previous answers to game-like questions.

The reactive modules handle emergencies in both movement and communication. For example, the robot gazes at the part of its body being touched by a human to indicate that it has noticed the touch, but continues talking. This hierarchical mechanism is similar to subsumption (Brooks 1986). In the situated and reactive modules, inputs from sensors are pre-processed by sensor modules such as English speech recognition. Actuator modules perform low-level control of actuators. In the following, we explain the *situated modules, person identification*, and *module control* in more detail.

Situated Modules.

As with an adjacency pair (a well-known term in linguistics for a unit of conversation such as "greeting and response" and "question and answer"), we assume that embodied communication forms by the principle of the action-reaction pair. This involves certain pairs of actions and reactions that also include non-verbal expressions. The continuation of the pairs forms the communication between humans and a robot.

Each situated module is designed for a certain action-reaction pair in a particular situation and consists of precondition, indication, and recognition parts. By executing the precondition part, the robot determines whether the situated module is in an executable situation. For example, the situated module that performs a handshake is executable when a human is in front of the robot. By executing the indication part, the robot interacts with humans. In the handshake module, the robot says "Let's shake hands" and offers its hand. The recognition part recognizes a human's reaction from a list of expected reactions. The handshake module can detect a handshake if a human touches its offered hand.

Person Identification.

Clark classified interacting people into two categories: participants, who speak and listen, and listeners, who listen only (Clark, 1996). Similar to Clark's work, we classify humans near the robot into two categories: participants and observers. The *person identification* module provides persons' identities, as well as their approximate distance from the robot. Since the robot is only capable of near-distance communication, we can classify a person's role in interaction based on his/her distance. As Hall discussed, there are several distance-based regions formed between talking humans (Hall, 1990). A distance of less than 1.2 m is "conversational," while a distance from 1.2 m to 3.5 m is "social." Our robot recognizes the nearest person within 1.2 m as the participant, while others located within a detectable distance of the wireless tag are observers.

Module Control (Episodes and Episode Rules)

We define an *episode* as a sequence of interactive behaviors taken on by the robot and humans. Internally, it is a sequence of *situated modules*. *Module control* selects the next *situated module* for execution by looking up *episodes* and *episode rules*. There are "public" and "private" *episodes* as shown in **Fig. 3**. The *public episode* is the sequence of all executed *situated modules*, and the *private episode* is an individual history for each person. By memorizing each person's history, the robot adaptively tailors its behaviors to the participating or observing persons.

The *episode rules* are very simple so that developers can easily implement many rules quickly. They guide the robot into a new episode of interaction and also give consistency to the robot's behaviors. When the robot ends an execution of *the* current *situated module*, all *episode rules* are checked to determine the most appropriate next *situated module*. Each *situated module* has a unique identifier called a ModuleID. The *episode rule* "<*ModuleID A=result_value*>*ModuleID B*" stands for "if module *A* results in *result_value*, the next execution will be module *B*." Then "<…><…>" stands for the sequence of previously executed *situated modules*. Similar to regular expressions, we can use selection, repetition, and negation as elements of *episode rules*.

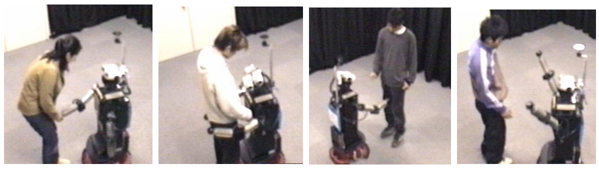
Furthermore, if "P" or "O" is put at the beginning of an *episode rule*, that *episode rule* refers to *private episodes* of the current participant or observers. Otherwise, the *episode rules* refer to *public episodes*. If the first character in the angle bracket is "P" or "O," this indicates that the person experienced it as a participant or an observer. Thus, "<P ModuleID=result value>" is a rule to represent that "if the person participated in the execution of ModuleID and it resulted in the result value." Omission of the first character means "if the person participated in or observed it."

Figure 3 is an example of *episodes* and *episode rules*. The robot memorizes the *public episode* and the *private episodes* corresponding to each person. *Episode rules* 1 and 2 refer to the *public episode*. More specifically, *episode rule* 1 realizes sequential transition: "if it is executing GREET and it results in Greeted, the robot will execute the situated module SING next." *Episode rule* 2 realizes reactive transition: "if a person touches the shoulder, the precondition of TURN is satisfied, after which the robot stops execution of SING to start TURN." Also, there are two *episode rules* that refer to *private episodes*. *Episode rule* 3 means that "if all modules in the current participant's *private episode* are not GREET, it will execute GREET next." Thus, the robot will greet this new participant. *Episode rule* 4 means "if the person hears a particular song from the robot once, the robot does not sing that song again for a while."

2.4 Implemented interactive behaviors

General design

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 can utter more than 300 sentences and recognize about 50 words.



(a) shake hands (b) hug (c) paper-scissors-rock (d) exercise

Figure 4: Interactive behaviors

The interactive behaviors appeared in the following manner based on some simple rules. The robot sometimes triggered 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, 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 restarted its idling or moving-around behaviors.

Design for long-term interaction

Moreover, we utilized the person identification functions to design 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 ten behaviors to a child who has never interacted with it, though it exhibits 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-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).

3 Field experiments

This section reports on our previous field experiments with Robovie. The first experiment was purposed for foreign language education (Kanda et al., 2004 d), but there was no mechanism for long-term interaction implemented in Robovie. The second experiment was purposed for promoting longitudinal interaction with the mechanism for long-term interaction (Kanda et al. 2004 b). This section also reports on performances of friendship estimation (Kanda et al., 2004 c) among children through these two experiments.

3.1 First experiment: Peer tutor for foreign language education

3.1.1 Method

We performed two sessions of the experiment at an elementary school in Japan for two weeks. Subjects were the students of three sixth grade classes. There were 109 sixth grade students (11-12 years old, 53 male and 56 female). The session consisted of nine school days.

Two identical Robovie robots were placed in a corridor connecting the three classrooms, although there were no mechanisms for long-term interaction as reported in Section 2.4 implemented at that time. Children could freely interact with both robots during recesses. Each child had a nameplate with an embedded wireless tag so that each robot could identify the child during interaction.

3.1.2 Results

Since the results were reported in (Kanda et al. 2004 d) in detail, here we only briefly describe the results, with a particular focus on longitudinal interaction.

Results for Long-term Relationship

Figure 5 shows the changes in relationships among the children and the robots during the two weeks for the first-grade class. We can divide the two weeks into the following three phases: (a) first day, (b) first week (except first day), and (c) second week.

(a) First day: great excitement. On the first day, many children gathered around each robot. They pushed one another to gain a position in front of the robot, tried to touch the robot, and spoke to it in loud voices.

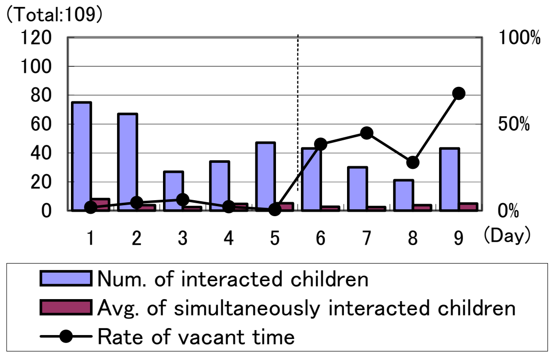


Figure 5: Transition of number of children playing with the robot (First experiment)

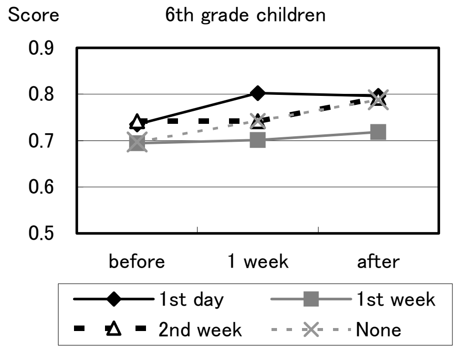


Figure 6: Improvement of children’s English listening test scores (First experiment)

(b) First week: stable interaction. The excitement on the first day soon waned, and the average number of simultaneously interacting children gradually decreased. In the first week, someone was always interacting with the robots, so the rate of vacant time was still quite low. The interaction between the children and the robots became more like inter-human conversation. Several children came in front of the robot, touched it, and watched its response.

(c) Second week: satiation. It seemed that satiation occurred. At the beginning, the time of vacancy around the robots suddenly increased, and the number of children who played with the robots decreased. Near the end, there were no children around the robot during half of the daily experiment time. The way they played with the robots seemed similar to the play style in the first week. Thus, only the frequency of children playing with the robot decreased.

Results for Foreign Language Education

We conducted an English listening test three times (before, one week after, and two weeks after the beginning of the session). Each test quizzed the students with the same six easy daily sentences used by the robots: “Hello,” “Bye,” “Shake hands please,” “I love you,” “Let’s play together,” and

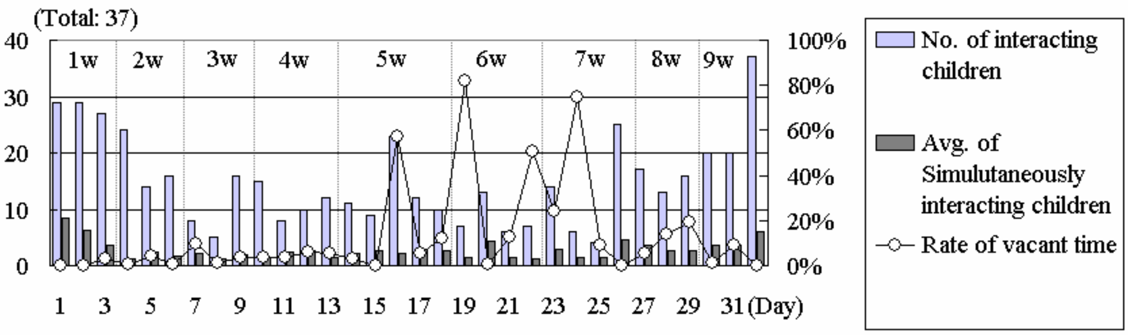


Figure 7: Transitions of the interaction between children and the robot (Second experiment)

(a) Beginning of the first day: Children formed a line

(b) showing nameplate

(c) "I can't see" behavior preferred

Figure 8: Scene of the second experiment

"This is the way I wash my face" (phrase from a song), but in different orders.

As a result, there were statistically significant improvements in their listening tests and the improvements were related to the interaction patterns of children (**Figure 6**: score represents the rate of correct answers in the listening test). Although the improvements were still quite low (less than 10% in the rate of correct answers), we believe that these results suggests a possibility of realizing a future communication robot that works in an elementary school and is equipped with a powerful language education ability.

3.2 Second experiment: Longitudinal interaction

3.2.1 Method

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 two months, including 32 experiment days. (There were 40 school days, but eight days were omitted because of school events.) We put the robot into a classroom, and the children were able to freely interact with it during the 30-minute 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 it, which is used for later analysis of their interaction and friendship estimation. We also administered a questionnaire that asked the children' friendship with other children.

3.2.2 Results

Observation of Long-term Interaction

Figure 7 indicates 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 and explain the interaction's transitions during those two months by describing these phases.

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

Children were crowded around the robot on the first and second days (Fig. 8-a). 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.

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

About ten children came around the robot every day, 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 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, with this behavior com-

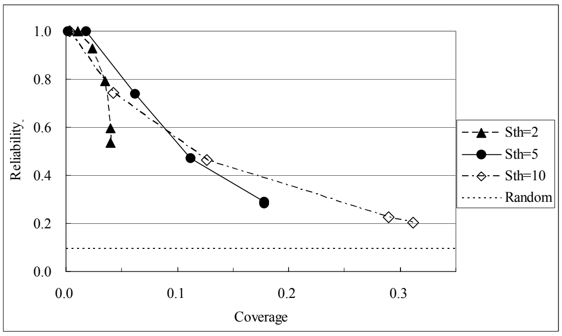


Figure 9: Friendship estimation results for the first experiment

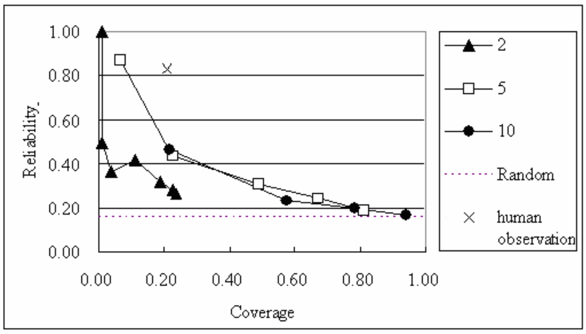


Figure 10: Friendship estimation results for the second experiment

ing into fashion among them. 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-learning mechanism, and these behaviors caught their attention.

- When the robot's eye was hidden (Fig. 8-c), 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 sang along with it.

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

The number of children who came around the robot increased during these two weeks, though 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 the students that the robot would leave the school at the end of the ninth week.

The "confiding of personal matters" behavior became well-known among the children, and many children around the robot were absorbed in asking the robot to tell these matters. They made a list of the personal matters they heard from the robot on the blackboard.

3.3 Friendship estimation

3.3.1 Method

We have proposed a method of friendship estimation by observing interaction among children via a robot (Kanda et al., 2004 c). This subsection briefly reports the method of estimation and estimation performances for these two field experiments.

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

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

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

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

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 one second.

3.3.2 Results

Based on the mechanism proposed, 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. 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

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

Figures 9 and **10** indicate the results of estimation with various parameters (S_{TH} and T_{TH}) for these experiments. In the figures, *random* represents the reliability of random estimation, where we assume that all relationships are friendships (for example, since there are 212 correct friendships among 1,332 relationships, the estimation obtains 15.9% reliability with any coverage for later experiment). 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.

As a result, our method successfully estimated 5% of the friendship relationships with greater than 80% accuracy (at "S_{TH}=5") and 15% of them with nearly 50% accuracy (at "S_{TH}=10") for the first experiment (**Fig. 9**). It also successfully estimated 10% of the friendship relationships with nearly 80% accuracy and 30% of them with nearly 40% accuracy for the second experiment (**Fig. 10**).

4 Discussions and Future directions

4.1 Role of communication robots for elementary school

One promising role for communication robots in elementary schools is as a peer tutor. Through its interaction ability, Robovie had a positive effect as the peer tutor for foreign language education. However, current robots' abilities for interacting with humans are still very limited, strongly restricting the performances of the robot for language education task or other education tasks.

A more realistic role is currently behaving as a kind of friend with children and potentially bringing mental-support benefits, which is similar to a therapy robot (Wada, Shibata, et al., 2004). It is perhaps a substitution for pet animals but, what is more, we can design and control the robot's behavior so that it can more effectively produce benefits.

We believe that the mental-support role will be integrated into the robot's role as a peer tutor. For example, a communication robot might be able to *maintain safety* in a classroom. That is, the robot will be friend with children and, at the same time, report the problems such as bullying and fighting among children to the teacher so that teacher can change the robot's behavior to moderate the problems.

Figure 11: An interaction scene between children and a robot with a soft skin sensor

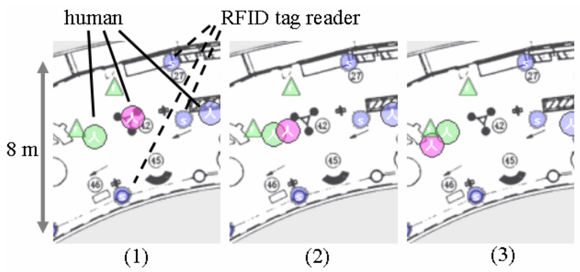


Figure 12: Position estimation with several RFID tag readers

4.2 Sensing in real world

It is difficult to prepare a robust sensing ability for robots in real world. Regarding Robovie, at elementary school, image processing and speech-recognition functions worked not as well as they did in the laboratory. Contrary, tactile sensing worked robustly. We believe that it is one of the most promising future directions, at least next several years, to use more tactile-based interaction for communication robots in elementary schools. **Figure 11** shows our robot with a soft skin sensor, which features a precise recognition capability in both spatial and temporal resolution on tactile sensing.

However, very limited information can be obtained only by using sensors attached to a robot's body. For example, a robot has difficulty in correctly identifying the person it is interacting with from among hundreds of candidates, which stands in contrast to robots being able to consistently recognize individuals with RFID tags (a kind of ubiquitous sensor). With RFID, the robot can call a child's name in interaction, which greatly promotes interaction.

Moreover, ubiquitous computing technology offers greater potential, in particular with sensors attached to an environment. **Figure 12** shows an example where humans' positions were recognized by using several RFID tag readers embedded in an environment. As those examples illustrate, it is important to make environments more intelligent so that a communication robots can behave as if it is more intelligent.

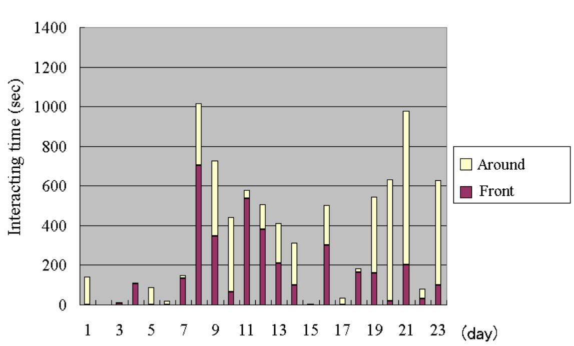


Figure 13: An example of analyzing longitudinal interaction (transition of a child's place)

4.3 Longitudinal interaction

Robots have a strong novelty effect. In other words, since robots are very novel for typical people, people are eager to interact with robots in the beginning, but rapidly become bored with them.

The second experiment indicated that the behavior design for longitudinal interaction (described in Sec. 2.4) contributed to keep children's interest longer. We believe that such an approach of adding contents (interactive behaviors) will be effective. However, this direction is gradually falling into the region of art rather than engineering.

There is other approach we should try: establishment of user models on longitudinal interaction. In these two experiments, we have observed three phases of interaction "great excitement," "stable interaction," and "saturation." If the robot can identify each person's phase of longitudinal interaction from sensory input, it can easily adjust its behavior to keep interaction more stable. For example, if a person is becoming saturated, it would exhibit some new behaviors. **Figure 13** is an example of analysis on long-term interaction. Here, we can see a change in the user's interaction patterns.

4.4 Social skills

Toward advancing the social skills of communication robots, we implemented two functions. One is that by identifying individuals around the robot, it alters its interactive behaviors to adapt to each person. The other is friendship estimation based on the observation of interaction among humans with RFID tags. Although current estimation performance is still quite low, we believe that we can improve it by using other sensory information, such as distance between people. This is one of our important future works.

Meanwhile, even with current performance, friendship estimation probably enables us to promote interaction between children and Robovie. For example, it would say "please take *child A* to play together," to *child B*, where *child A* and *B* are estimated as friends, thus it can make the interaction more enjoyable. Such positive relationships are rather easy to use.

On the contrary, it is difficult to identify negative relationships. For example, rejected and isolated children are identified by analyzing sociograms (a graph about social networks), which requires accurate estimation of relationships among all children. If more accurate estimation could be realized so that we can analyze sociograms based on the estimation, usage of such estimations could form the basis of interesting research themes on the social skills of communication robots. We believe that it will require a more interdisciplinary research, because in psychology, there is much knowledge about humans' strategy on communication, such as Heider's balance theory. At the same time, ethical problems should be more considered when robots start to estimate negative relationships or intervene in humans' relationships.

Research into the social skills of communication robots will be very important when the robots eventually participate in human society, and the functions we described here will be probably contribute a small part to developing social skills. We hope that there will be much research performed on this topic.

5 Conclusion

This paper reported our approaches and efforts to develop communication robots for elementary schools. The developed robot, Robovie, was applied to two field experiments at elementary schools. The result from the first experiment indicated that a communication robot will be able to support human activity with its communication abilities. The result from the second experiment indicated that we can promote longitudinal relationships with children by preparing some software mechanisms in the communication robot. In addition, the result from the friendship estimation indicated that a communication robot will be able to possess some social skills by observing human activities around it. We believe that these results demonstrate a positive perspective for the future possibility of realizing a communication robot that works in elementary schools.

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