A Development Approach for Socially Interactive Humanoid Robot

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Abstract

This paper describes our social approach for an interactive humanoid robot that understands human social relationships. Our interactive robot autonomously interacts with humans with its human-like body properties, and as a result, induces humans' friendly group behavior in front of it. Based on these feature as well as inspired by the survey in psychology research about friendship, we suggest a friendship estimation model for the interactive robot, which is an ability that is probably essential for interactive robots to establish social relationships with humans. As a result of a field experiment, the fundamental part of the estimation model is supported. We believe these results suggest the positive perspectives of our development approach.

1. Introduction

Recent progress in robotics has brought with it a new research direction known as "interaction-oriented robots." These robots are different from traditional task-oriented robots, such as industrial robots, which perform certain tasks in limited applications. Interaction-oriented robots 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 will exist as a partner in people's daily lives. We believe these robots will not only used for entertainment, but also provide it with communication support task such as route-guidance and mental support task.

Several researchers are endeavoring to realize the interaction-oriented robots, such as Aibo, and Kismet [1]. Moreover, there are several research works that explore the application of the interactive robots. Shibata et al. successfully applied a seal-like pet robot Paro for mental care for elderly person [2]. Dautenhahn et al. has applied a simple interactive robot for autism therapy [3]. These research efforts seem to be devoted to social robots that are embedded in human society.

The research question we are struggling to solve is "how can interaction-oriented robot participate in human daily life, establish social relationships with humans, and contribute to the society?" In other words, our purpose is to realize a peer-partner robot that socially communicates with humans to support their daily lives.

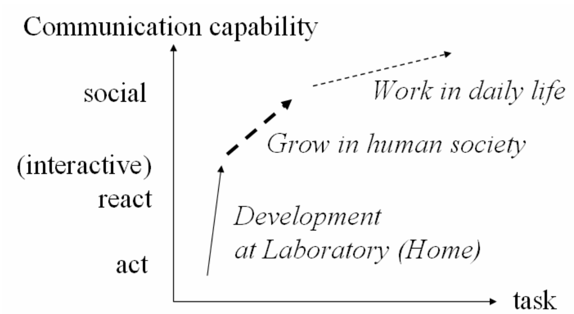

Figure 1: Development approach for social ability

We believe that the social ability of the robots will be greatly improved by putting these robots into human society. The initial tasks of the robot will be limited and perhaps not so important, because current interaction abilities of the robots are not so much as human infants' and the social skill is very little. However, we can improve the social skills of the robot in society by finding various problems that robots will suffers, which are similar development steps as human infants'. Figure 1 describes our development approach toward such the interaction-oriented robot.

Currently, robots are applied to work in our daily lives as interactive robots, and gradually growing their interactive abilities; but not to social works that requires to socially communicate with more than one people. While previous research works have developed robots' interactive abilities for only one people in front of the robots, we believe it is also indispensable to improve robots' social ability to make robots work in our daily lives, which is the approach described as broken lined arrow in the figure. We believe that robots' task will be emerged according to the improvements of robots' ability, even if current robots equipped with a little skills to accomplish useful tasks in human society.

We are achieving this development approach of making robots to gradually work in our daily lives for improving their social abilities as well as for exploring the possible tasks of the robots. While there are several learning-based approaches for understanding human-beings such as cognitive developmental robotics [4], we rather implement interactive behaviors into robots with a try-and-error manner [5]. Because, at an early stage of development, we do not know the appropriate strategy for learning-based development. Instead, we try to implement the interactive robot that is capable of socially communicating with humans, which is probably connected to such learning-based approach in future.

The first step of this development approach was a field trial in an elementary school where interactive robots behave as peer tutor of foreign language, as reported in [6]. The robot Robovie equipped with person identification function to distinguish children, such as for calling names of children, and simultaneously interacted with more than one child. As a result, it proved the positive possibility that interactive robots can motivate children to learn foreign language through the interaction with robots. Meanwhile, we have observed the group behavior among friend around the robot. For instance, a boy and his friend counted how many times the robot called their respective names, and his name was called more often, so he proudly told his friend that the robot preferred him. If the robot would understand their friendship, it could promote the interaction with the boys and the interaction between the boys. That is, the ability of friendship estimation will enable robots to mediate interaction between humans. Moreover, the friendship is tightly connected to social relationships (described in the next section in detail). Thus, this friendship estimation is essential to accomplish more general social relationship estimation, which probably make possible of the future social robot that helps to solve bullying problem or isolate children problem. In this paper, we report our approach to estimating human friendship by using an interactive robot, an ability that is probably essential for interactive robots to establish social relationships with humans.

2. Friendship estimation model from observation

2.1. Related research about friendship

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 which then increase in size and complexity with age, forming many different peer relationships in the form of social networks. As children gradually establish social networks, each child gets a different social status, such as popular, average, isolated, and rejected [7, 8].

A sociometric test have been used to investigate the peer relationships and social networks, which lets a human directly answer the name of others whom he/she likes and dislikes. It is well validated and considered as reliable forms of assessment for human peer relationships. It distinguishes each child's social status in the groups: popular, average, neglected, rejected and controversial [9, 10]. It has been widely used to determine the relationships in a classroom or a company.

On the other hands, there are observation-based methods for understanding peer relations and social status. Children forms group and behaves with the group, along with their friendly relationships. Children usually play with peers, while boys tend to play in group and girls tend to play with only 1 other girl [11]. Ladd et al. investigated the relationships between observed group behavior and their relationships. They coded videotape about children's play with the four of the behavioral measure: cooperative play, rough play, unoccupied, and teacher-orientation. It revealed that cooperative play was associated with positive nominations while rough play related to negative nominations. In addition, they revealed that past behavior was successfully predict the current peer status, such as time spent in cooperative play was significant predictor to positive nomination [8]. Coie et al. have investigated the difference between popular and rejected children in terms of their behavior, and revealed the relationships between rejected children and their aversive behaviors [12]. We believe these findings positively support the possibility that social robots can recognize humans' peer relationships and social status by observing their group behavior.

2.2. Friendship estimation model

Human behavior is largely based on social relationships which can be in the form of dyadic relationships, known as friendship, or larger groups known as social networks where there are complex peer relationships between different individuals. Since the previous research works have proved the correlations children's group behavior and their relationships [8, 11, 12], we believe we can estimate their peer relationships and social networks from observation of their group behavior. We focused on the *estimation* of peer relationships, which are the fundamental parts of the social network, as the early attempt for *recognition* of peer relationships and social network. Yet it is not *recognition* (find all correct information accurately) but *estimation* (partly find correct information with moderate accuracy), robots can utilize these obtained information to further promote human-robot interaction.

The basic idea is "a robot autonomously interacts with several children simultaneously to cause their spontaneous group behavior, and observe the group behavior to recognize their relationships," which is our hypothesis to verify. Our friendship estimation model is based on the association of social group behavior and social relations, which is inspired by previous

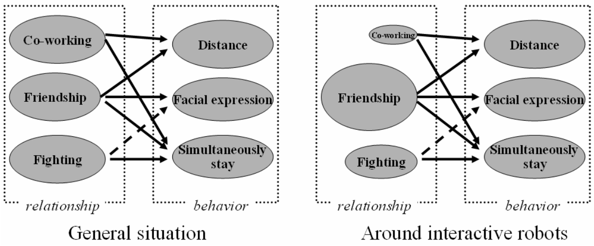

Figure 2: Relations between social relationships and group behavior

Figure 3: Scenes of friend accompanying behavior in front of an interactive humanoid robot

psychological research such as the above mentioned ones. In general, humans' social relationships affect on their group behavior, such as accompanying, distance among them, facial expression during conversation, and so forth. For instance, human is accompanied by friendly one, but not willingly approach to dislike one (accompanying and close distance). Sometimes, such the dislike relations might cause a quarrel or fight (distance will be close, but facial expression will be far from friendly). Meanwhile, official relationships rather than private one sometimes cause non-spontaneous group behavior. For instance, teacher may organize co-working activity such as "children collaborate to carry a heavy box." The left figure in Figure 2 describes these examples of the associations between group behaviors and peer relations in general situation.

On the other hand, according to our hypothesis, interactive robot mostly causes spontaneous friendly behaviors. In fact, we observed such the situation where a child is accompanied by his/her friend to interact with the robot as shown in Figure 4. We are going to verify this hypothesis in this paper later. Thus, we believe we can estimate such the friendly relationships by simply observing their group behavior. This idea is described in Figure 4-right. As the beginning step for the estimation, we will only utilize "accompanying" behavior that will be recognized by using wireless tag system.

2.3. Algorithm

Figure 4-left indicates the mechanism of the friendship estimation. From a sensor (in this case, wireless ID tags and receiver), the robot constantly obtains the IDs (identifiers) of individuals who are around it. The robot

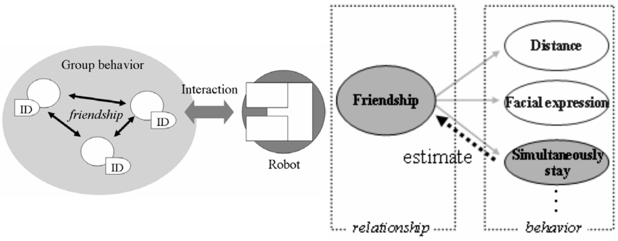

Figure 4: Current estimation model for friendship

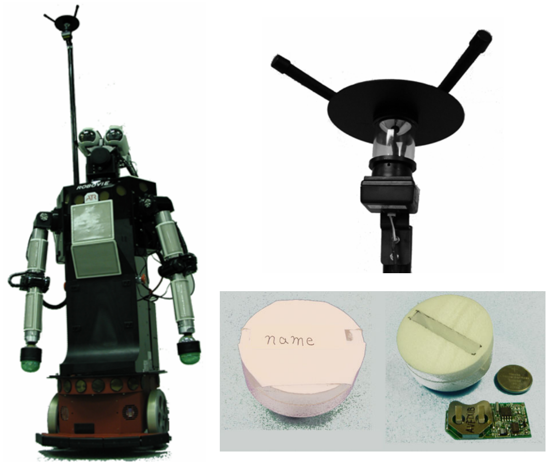

Figure 5: Robovie (left) and Wireless tags

continuously accumulates its interacting time with person A (T_A) and the time that person A and B simultaneously interact with it (T_{AB}, which is equivalent to T_{BA}). We define the estimated friendship from person A to B ($Friend(A \rightarrow B)$) as

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

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

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

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 (St) is less than S_{TH} (Eqs. 2 and 3). In our trial, we set Δt to one second.

3. Robovie: An Interactive Humanoid Robot

3.1. Hardware of An Interactive Humanoid Robot

Figure 5 shows the humanoid robot "Robovie" [13]. The robot is capable of human-like expression and recognizes individuals by using various actuators and sensors. Its body possesses highly articulated 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.

3.2. Person identification with wireless ID tags

To identify individuals, we used a wireless tag system capable of multi-person identification by partner robots (Detailed specification and system configuration is described in [14]). Recent RFID (radio frequency identification) technologies have enabled us to use contact-less 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. 4, 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.

3.3. Interactive behaviors

"Robovie" features a software mechanism for performing consistent interactive behaviors (detailed mechanism is described in [5]). 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.

Several interactive behaviors depended on the person identification function. For example, there was an interactive behavior in which the robot called a child's name if that child was at a certain distance. This behavior was useful for encouraging the child to come and interact with the robot. Another interactive behavior was a body-part game, where the robot asked a child to touch a body part by saying the part's name.

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,

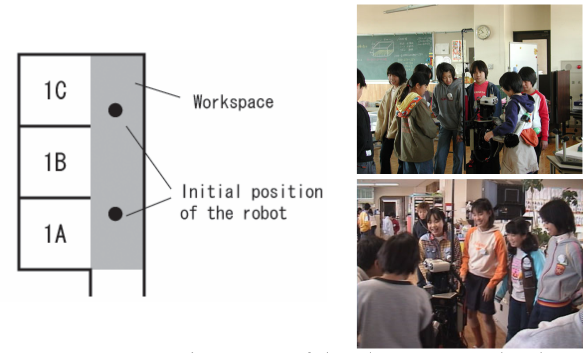

Figure 6: Environment of the elementary school

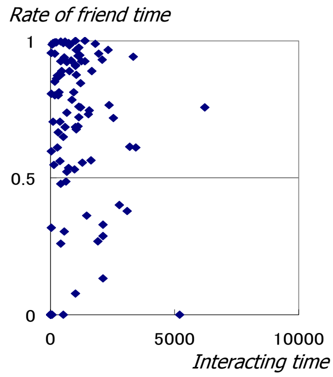

Figure 7: Frequency of friend accompanying behavior

it continued performing friendly behaviors for 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.

4. Experiment and Result

We conducted a field experiment in an elementary school for two weeks with the developed interactive humanoid robot, which was originally designed to promote children's English learning. As we reported in [4], the robots had a positive affect on the children. In this paper, we use the interaction data during that trial as a test-set of our approach to reading friendship from the children's interaction.

4.1. Method

We performed an experiment at an elementary school in Japan for two weeks. Subjects were sixth-grade students from three different classes, totaling 109 students (11-12 years old, 53 male and 56 female). There were nine school days included in those two weeks. Two identical robots were placed in a corridor that connects the three classrooms (Figure 6). Children could freely interact with both robots during recesses (in total, about an hour per day), and each child had a nameplate with an embedded

Table 1: Estimation results with various parameters

coverage		T_{TH} *(simultaneously interacting time)*					
reliability		0.3	0.2	0.1	0.05	0.01	0.001
S_{TH} *(num. of simultaneously Interacting children)*	2	0.01	0.02	0.03	0.04	0.04	0.04
		1.00	0.93	0.79	0.59	0.54	0.54
	5	0.00	0.02	0.06	0.11	0.18	0.18
		1.00	1.00	0.74	0.47	0.29	0.28
	10	0.00	0.00	0.04	0.13	0.29	0.31
		-	1.00	0.74	0.46	0.23	0.20

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

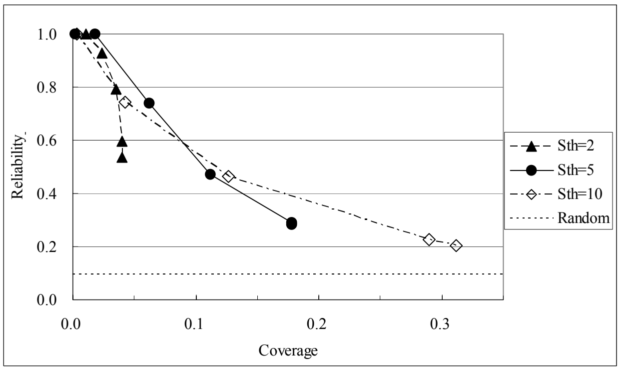

Figure 8: Illustrated estimation results

wireless tag so that each robot could identify the child during interaction.

We administered a questionnaire that asked the children to write down the names of their friends. This obtained friendship information was collected for comparison with the friendship relationships estimated by our proposed method.

4.2. Results for frequency of friend-accompanying behavior

As we compared the questionnaire on friendships and the interacting time with the robot, we found the higher frequency with which children interacted with the robot in the company of his/her friend (see Figures 7). Seventy-two percent of their interaction time with the robot was in the company of one or more friends. We believe that this result supports our hypothesis "our interactive robot mostly cause friendly accompanying behavior of children around it rather than the other behavior associated with non-friendly relationships, such as hostile, dislike, co-working". It implies we can estimate their friendship by even simply observing their accompanying behavior.

4.3. Results for friendship estimation

Since the number of friendships among children was fairly small, we focused on the appropriateness (coverage and reliability) of the estimated relationships. This is similar to the evaluation of an information retrieval technique such as a Web search. Questionnaire responses indicated 1,092 friendships among a total of 11,772 relationships; thus, if we suppose that the classifier always classifies a relationship as a non-friendship, it would obtain 90.7% correct answers, which means the evaluation is completely useless. Thus, we evaluate 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

Table 1 and Fig. 8 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 1,092 correct friendships among 11,772 relationships, the estimation obtains 9.3% reliability with any coverage). In other words, random indicates the lower boundary of estimation. Each of the other lines in the figure represents the estimation result with 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 mostly performs better estimation of the friendship, and S=10 performs better estimation when coverage is more than 0.15. 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") (these early findings about friendship estimation, which are reported in this subsection, has been already appeared in our previous paper [15]).

5. Conclusion

We proposed a social development approach for an interactive robot that is capable of communicating with humans socially. According to the approach, we have applied an interactive humanoid robot for a language-education task, where we have found a lack of social skill of the robot. As we have found the robot cause a friend-accompanying behavior, the robot causes human social behavior to understand their social relationships. This friend estimation model for social robot was partly verified by the field experiment. In the field experiment, two identical interactive humanoid robots placed in an elementary school for two weeks, where children freely interacted with the robots during recesses. These developed interactive humanoid robots identify individual child by using wireless tag system, which is utilized for recording individual and friend-related interaction time as well as for promoting the interaction by such as calling their names. The result suggested that mostly children were accompanied with one of more friend (72% of the total interacting time), and the robot was successfully estimated friendly relationships partly (for example, 5% of the all relationships with 80% accuracy). We believe that this early findings would encourage further research in social skill of social robots as well as the sensing technology for autonomous observation about inter-human and human-robot interaction.

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