Friendship estimation model for social robots to understand human relationships

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Abstract

This paper reports our friendship estimation model for social robots that understand human social relationships. Our interactive robot autonomously interacts with humans with its human-like body properties, and as a result, induces the humans' friendly group behavior in front of it. Based on these features as well as inspired by a survey in psychology research on friendship, we purpose a friendship estimation model for an interactive robot. The capability provided by such a model is probably essential for interactive robots to establish social relationships with humans. The results of an experiment demonstrate that the fundamental part of the estimation model functions effectively.

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, that perform certain tasks in limited applications. Interaction-oriented robots are designed to communicate with humans and 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 be used for entertainment but also provide communication support such as route-guidance and mental support tasks.

Several researchers are endeavoring to realize interaction-oriented robots, such as Aibo and Kismet [1]. Moreover, several research works are exploring the possible applications of interactive robots. Shibata et al. successfully applied a seal-like pet robot, Paro, for the mental care of elderly persons [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 an interaction-oriented robot participate in human daily life, establish social relationships with humans, and contribute to society?" In other words, our purpose is to realize a peer/partner robot that socially communicates with humans to support their daily lives.

We believe that the social ability of robots will be greatly improved by putting these robots into human society. The initial tasks of the robots will be limited and perhaps not so important, since the interaction abilities of the current robots are not as high as human infants' and their social skills are very low. However, we can improve the social skills of robots in society by finding various problems that robots will suffer, which are most likely similar development steps as those of human infants.

Currently, robots are applied to work in our daily lives as interactive robots, and they are gradually growing in their interactive abilities; however, they have not advanced to the stage of social work that requires social communication with more than one person. While previous research works have developed robots' interactive abilities for only one person 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 indicated by the broken-line arrow in Figure 1. We believe that robots' tasks will emerge according to the improvement in robots' abilities, even if current robots are equipped with little skill to accomplish useful tasks in human society.

We are pursuing this approach of making robots gradually work in our daily lives to improve their social abilities as well as to explore the possible tasks of the robots. The first step of the approach was a field trial in an elementary school where interactive robots behaved as peer tutors of a foreign language, English, as reported in [4]. The robot Robovie was equipped with a person-identification function to distinguish children, such as for calling the names of children, and simultaneously interacted with more than one child. As a result, it demonstrated the possibility that interactive robots can motivate children to learn a foreign language through interaction with robots. Meanwhile, we have observed the group behavior among friends around the robot. For instance, a boy and his friend counted how many times the robot called their respective names, and the boy whose name was called more often proudly told his friend that the robot preferred him. If the robot could understand their friendship, it could promote interaction with the boys and interaction between the boys. That is, the ability of friendship estimation would enable robots to mediate the interaction between humans. Moreover, friendship is tightly connected to social relationships (described in the next section in detail). Thus, this friendship estimation is essential for accomplishing more general social relationship estimation, which might provide a future social robot that could help to solve the bullying problem or the problem of isolated children. 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.

Friendship Estimation Model from Observation

Related research on 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, that 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 [5, 6].

A sociometric test has been used to investigate peer relationships and social networks, which lets a human directly answer the name of others whom he/she likes and dislikes. This method has been validated as a reliable assessment of human peer relationships. It categorizes each child's social status into one of such groups: popular, average, neglected and rejected [7, 8]. It has been widely used to determine the relationships in a classroom or a company.

On the other hand, observation-based methods have been developed for understanding peer relations and social status. Children form a group and behave with the group, along with their friendly relationships. Children usually play with peers, while boys tend to play in groups and girls tend to play with only one other girl [9]. Ladd et al. investigated the relationships between observed group behavior and their relationships. They coded videotape of children's play with four behavioral measures: cooperative play, rough play, unoccupied, and teacher-orientation. This revealed that cooperative play was associated with positive nominations while rough play was 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 [6]. Coie et al. investigated the difference between popular and rejected children in terms of their behavior and revealed the relationships between rejected children and their aversive behaviors [10]. We believe these findings support the possibility that social robots can recognize humans' peer relationships and social status by observing their group behavior.

Related research on sensor-based observation of humans' interactions

Our research approach is to recognize human social relationships by observing group behavior in the presence of an interactive robot, which is closely related to the research works that attempt to analyze human interaction from sensors embedded in environments or attached to humans. Recently, several research works have attempted to automatically observe and analyze large-scale human behaviors by using virtual reality, wearable computing, and ubiquitous sensing technologies.

Velde et al. proposed a mixed-reality approach for supporting human activity at conferences [11], which is known as the COMRIS project. Here, a parrot-like physical agent on human shoulders supplies information connected to a backbone information infrastructure. At the same time, this system measures interactions in large groups occurring spontaneously. With recent ubiquitous sensing technology, Sumi et al. developed a ubiquitous sensor environment for capturing and analyzing human physical group interaction by using infrared sensors that are good at sensing directions such as eye gaze [12]. By using the sensing system, Bono et al. analyzed human social behaviors during a poster session in an exhibition, which revealed the role of non-verbal cues for conversation between an exhibiter and visitors as well as the possibility of detecting their preferences for the exhibited posters [13].

On the other hand, several research works have attempted to analyze human behaviors toward interactive robots. For example, Dautenhahn et al. analyzed children's eye gaze and contact time for an interactive robot in the AURORA project [3], which aims to apply interactive robots to helping autistic children acquire social skills. Moreover, a motion capturing system enables us to automatically capture human embodied behavior during human-robot interaction. Kanda et al. measured the spatial and temporal synchrony between humans and an interactive robot to predict humans' subjective impressions of the robot [14].

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 among different individuals. Since the previous research works have proved the correlations between children's group behavior and their relationships [6, 9, 10], 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 an early attempt at *recognition* of peer relationships and social network. Yet it is not through *recognition* (finding all correct information accurately) but through *estimation*

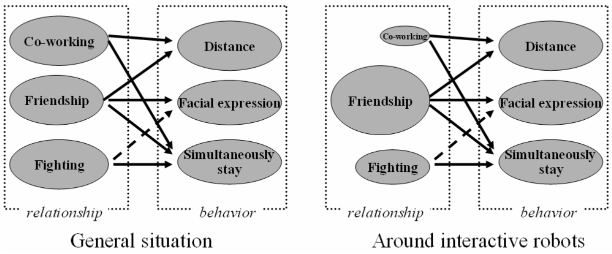

Figure 1: Relations between social relationships and group behavior

Figure 2: Scenes of friend accompanying behavior in front of an interactive humanoid robot

(partially finding correct information with moderate accuracy) that robots can utilize 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 the group behavior is observed to recognize their relationships," which is also 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 psychological research such as the works mentioned above. In general, humans' social relationships affect group behavior, such as accompanying, distance among members, facial expressions during conversation, and so forth. For instance, a human is accompanied by another friendly human but does not willingly approach a disliked human (accompanying and close distance). Sometimes, such dislike relations cause a quarrel or fight (distance will be close, but facial expression will be far from friendly). Meanwhile, official relationships rather than private ones sometimes cause non-spontaneous group behavior. For instance, a teacher may organize co-working activity such as "children collaborate to carry a heavy box." The left figure in Figure 1 describes these examples of the associations between group behaviors and peer relations in general situations.

On the other hand, according to our hypothesis, an 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 2. We are going to verify this hypothesis in this paper later. Thus, we believe we can estimate such friendly relationships by simply observing group behavior. This idea is described in Figure 3-right.

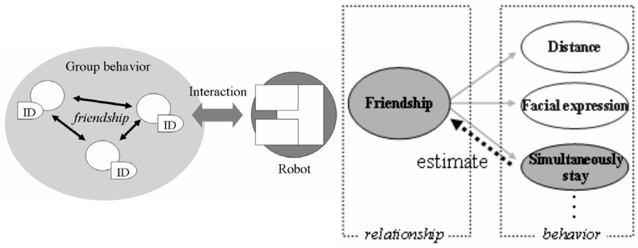

Figure 3: Current estimation model for friendship

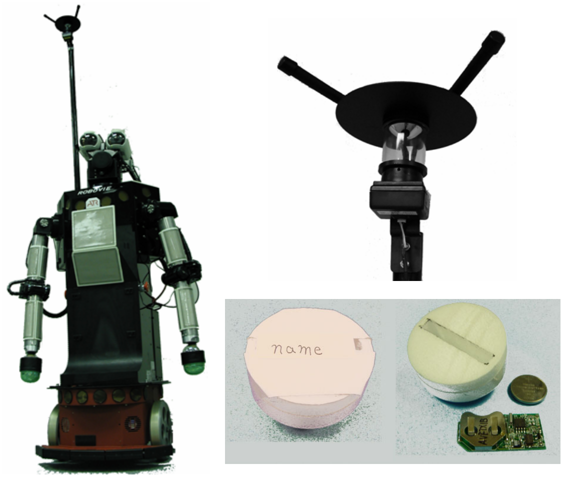

Figure 4: Robovie (left) and Wireless tags

As the beginning step for the estimation, we only utilize "accompanying" behavior that can be recognized by using a wireless tag system.

Algorithm

Figure 3-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 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→B)*) as

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

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

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

where *observe(A)* becomes true only when the robot observes the ID of person A, *if()* becomes 1 when the logical equation inside the parentheses 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.

Robovie: An Interactive Humanoid Robot

Hardware of Interactive Humanoid Robot

Figure 4 shows the humanoid robot "Robovie" [15]. 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.

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 [16]). 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.

Interactive behaviors

"Robovie" features a software mechanism for performing consistent interactive behaviors (detailed mechanism is described in [17]). 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.

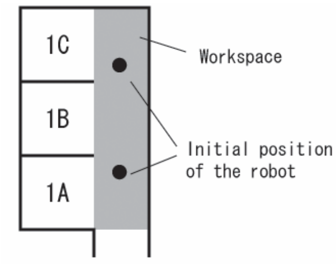

Figure 5: Environment of elementary school

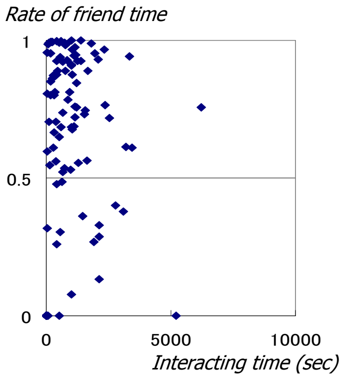

Figure 6: Frequency of friend accompanying behavior

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, 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.

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 effect 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.

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

Table 1: Estimation results with various parameters

coverage / reliability		T_{TH} *(simultaneously interacting time)*					
		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 was estimated, so reliability was not calculated)

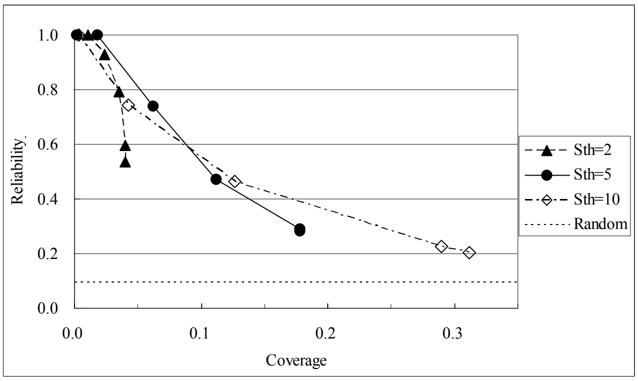

Figure 7: Illustrated estimation results

were placed in a corridor that connects the three classrooms (Figure 5). 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 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.

Results for frequency of friend-accompanying behavior

As we compared the questionnaire on friendships and the interacting time with the robot, we found a higher frequency with which children interacted with the robot in the company of his/her friend (see Figures 6). 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 that "our interactive robot mostly causes friendly accompanying behavior of children around it rather than the other behaviors associated with non-friendly relationships, such as hostile, dislike, co-working". This implies that we can estimate their friendship by even simply observing their accompanying behavior.

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

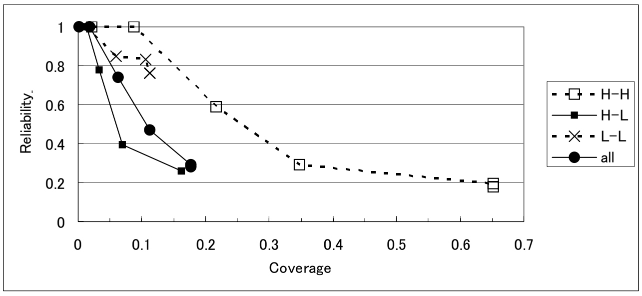

Figure 8: Relationships between friendship estimation and frequency of interaction with robot (at Sth=5)

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. 7 indicate the results of estimation with various parameters (S_{TH} and T_{TH}). In Fig. 7, 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 at 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 on friendship estimation, which are reported in this subsection, have already appeared in our previous paper [18]).

Results for comparison between frequency of interaction with the robot and estimation result

We analyzed the results in detail to determine how we could improve the estimation. Figure 8 shows a comparison between frequency of interaction with the robot and estimation results. We classified the children into two groups as higher frequency half of 109 children (referred to H) and lower-frequency half (L) according to their interacting time with the robot> We then illustrated the estimation performance among H-H (friendship between children within the H group), H-L (friendship between a child in the H group and a child in the L group), and L-L (friendship between children within the L group). The comparison's results revealed that our method better estimated the relationships in the H-H group. In other words, the estimation is more accurate for the relationships between children who often appeared around the robot. In contrast, the upper boundary of the coverage is more limited for the relationships between children who did not often appear around it. (As Figure 6 shows, there is no obvious correlation between frequency of interaction with the robot and the rate of friend-accompanying behavior, thus this does not cause the difference in estimation between the H-H group and others). We believe these findings also support the effectiveness of our estimation model, since it seems that the estimation will become more accurate with an increase in the amount of observed data on inter-human relationships around the robot.

Conclusions

We proposed a friend estimation model for a social robot that interacts with humans and verified the fundamental component of the model by field experiment. In the field experiment, two identical interactive humanoid robots were placed in an elementary school for two weeks, where children freely interacted with the robots during recesses. These interactive humanoid robots identified individual children by using a wireless tag system, which is utilized for recording individual and friend-related interaction time as well as for promoting interaction by such actions as calling their names. The result suggested that mostly children were accompanied with one of more friend (72% of the total interacting time) and that the robot successfully estimated friendly relationships among children who often appeared around the robot while it showed moderate performance for the others (for example, 5% of all relationships with 80% accuracy). We believe that these early findings will encourage further research into the social skills of social robots as well as the sensing technology for autonomous observation about inter-human and human-robot interaction.

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