An Experimental Study of the Use of Multiple Humanoid Robots as a Social Communication Medium

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Abstract. This paper reports on an experimental investigation into the use of humanoid robots as a communication medium. Many social robots have been developed and tried for use in urban environments, but due to their limited perception, their degree of interactivity is still far poorer than that of humans. In this study, our approach used the robots as a non-interactive medium. We propose using robots as a passive-social medium, in which multiple robots converse with each other.

1 Introduction

Over the past several years, many social robots that work in daily environments have been developed such as assistive robots for elderly people (Heerink et al., 2008; Scopelliti et al., 2005; Dario et al., 2001). Researchers have gone further by exploring communicative tasks that mainly involve interaction with people, such as a shopping assistant (Gross et al., 2008), collecting information in a city (Weiss et al., 2008), and delivering snacks at an office (Lee et al., 2009). Robots used for such research can typically make sophisticated human-like expressions. Through their human-like bodies and gestures, such robots are suited to communicate with humans to the extent that humans in these situations sometimes unconsciously behave as if they were communicating with peers. Such abilities could allow robots to perform tasks in human society involving communication such as guiding people along a route (Sakamoto et al., 2005).

On the other hand, the interaction capability of robots is still under development and they have limited sensing capability. These shortcomings are particularly noticeable when we introduce robots into our daily lives. Although the appearance of a humanoid robot often makes people believe that it is capable of human-like communication, it cannot currently engage in such sophisticated communication. The pursuit of more capable sensing and recognition remains at the forefront of robotics research. The results of such research should eventually be integrated into robots so that they can behave as ideal interaction partners that are capable of human-like communication. Pioneering research work in human-robot interaction (HRI) has revealed what robots can accomplish, such as museum guidance (Siegwart et al.,

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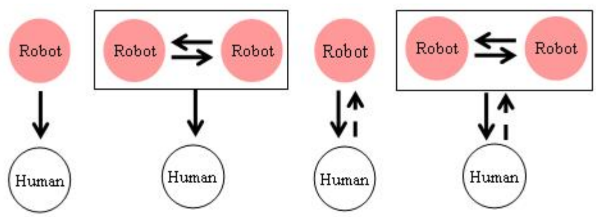
2003; Shiomi et al., 2006), perspective-taking (Trafton et al., 2006), operation support (Breazeal et al., 2005), behaving as a well-mannered servant, and support for language study (Kanda et al., 2004). However, a robot's ability to inform humans is still quite limited.

On the other hand, recent research in HCI (human-computer interaction) has highlighted the importance of robots as a new interface medium. Reaves and Nass researched the role of computers as a new interface medium in the manner of previous media, such as television and radio, and they proved that humans act toward computer interfaces (even a simple text-based interface) as if they were communicating with other humans (Reeves and Nass, 1996). Cassell et al. demonstrated the importance of anthropomorphic expressions, such as arms and heads on embodied agents, for effective communication with humans (Cassell et al., 1999). Cory and Cynthia compared a robot and a computer-graphic agent and found that the robot was suitable for communication about real-world objects (Kidd et al., 2004).

Users are under no obligation to take part in the conversation. In other words, borrowing terms from Clark's linguistic literature (Clark, 1996), the user is placed in a bystander position (free from responsibility for the conversation), where robots are speaking and listening as participants (responsible for it). This characteristic makes it similar to previous media: people do not have to respond to what the medium (the person in the medium) says, or to return a greeting when the medium greets, or feel uncomfortable about leaving in front of the medium.



(a) passive (b) passive-social (c) interactive (d) interactive-social

Fig. 1. Robot(s) as medium

Fig. 1 shows the difference of this type of medium compared to other forms of human-robot interaction. At times robots have been used for merely presenting information to people, which we named a passive medium. This is the same as a news program on TV where one announcer reads the news. On the other hand, many researchers have been struggling to realize robots that act as an interactive medium, which intends to accept requests from people as well as present information to people. The robot-conversation-type medium, on which we focus in this paper, is named a passive-social medium. It does not accept requests from people, that is as same as the passive medium; however, it does present more information than the passive medium, through its social ability: expression of conversation. It is rather similar to a news program on TV where announcers discuss comments spoken by others.

We are exploring an alternate approach to maximizing the information that a robot system can offer to people, focusing on attracting ordinary people's interest to the information. This new strategy is based on letting users observe a conversation between robots. For example, Kanda et al. proved that users understand a robot's speech more easily and more actively respond to it after observing a conversation between two robots (Kanda et al., 2002). We named this kind of medium the "passive-social medium." Figure 1 illustrates the difference between this medium and other forms of human-robot interaction.

In this paper, we focus on the robot-conversation-type medium, a passive-social medium (Fig. 1, b). In this case, the robots do not accept requests from people, similar to a passive medium, but this case still attracts people's interest to information more than does a passive medium through its social ability, i.e. the expression of conversation. We believe that a "passive-social medium" is a more natural way to offer information to people than a simple passive medium. This is similar to a news program on television where announcers discuss comments told by others. Figure 1, d shows what we call an interactive-social medium, but such a medium has a weakness in its interactivity, just as in the case of a conventional interactive robot medium.

2 Multi-robot Communication System

For Passive-Social medium, we developed a system consisted of a sensor and humanoid robot(s).A scenario-controlling system, described below, controlled the robots' behavior. The robots' behavior was written in a simple scripting language that is easy to prepare.

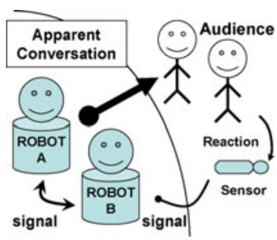


Fig. 2. Schematic of multi-robot communication

2.1 Design Policy

This system implements social expression capabilities and interactivity that perform reliably in a real environment. The social expression capability is based on a system we had developed that allows precise control of conversation timing and easy development. Regarding the interactivity, we limited it to be very simple but robust. The system immediately responds when a person comes close to the robot(s) by making the robot bow to the person. This limited-realistic interactivity is accomplished with a laser range-finder placed in front of the robot. We did not use any other sensors such as audible or visible, because outputs from such sensors are uncertain in a real environment. Thus, what we refer to as "limited-realistic interactivity" is very different from that in some interactive robots, such as Robovie (Kanda et al., 2004) where people may enjoy the unpredictability of unstable sensing capability. We decided on this implementation because unstable interactivity does not work when the purpose is to inform people. Users would be frustrated if they could not retrieve the information they needed.

2.2 Humanoid Robot

We used the humanoid robot Robovie for this system. “Robovie” is an interactive humanoid robot characterized by its human-like physical expressions and its various sensors. We used humanoid robots because a human-like body is useful in naturally catching people’s attention. The human-like body consists of a body, a head, a pair of eyes, and two arms. When combined, these parts can generate the complex body movements required for communication. Its height is 120 cm and its diameter is 40 cm. The robot has two 4x2 degrees of freedom in its arms, 3 degrees of freedom in its head, and a mobile platform. It can synthesize and produce a voice through a speaker.

2.3 Sensor

To sense a human approaching a robot, we used a laser range-finder or sound level meter.

The laser range-finder that we used is the LMS200 made by SICK. This sensor can scan 180° degrees horizontally, and it measures this range within a 5-m distance with a minimum resolution limit of 0.25° and 10 mm.The output is used to make the robots "look at" or turn their heads toward the human passing by them.

The sound-level meter continually receives the volume data [dB] from it.

2.4 Scenario-Controlling System

The system is based on our scripting language for multiple robots, with a new function for changing the scenario that the robots act out when a human presence is detected. The scripting language has adequate capabilities for describing multiple robot communication and is simple enough for a developer to easily use it to control the robots’ behavior.

In this system, a set of robots interprets script files and executes scripts written in this language. One robot becomes the master. The master robot receives signals from the sensor, decides which scenario to execute, and informs its partner robot about it.

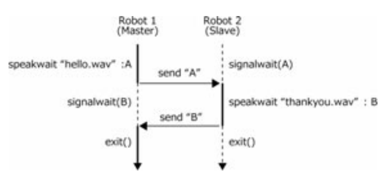


Fig. 3. Example of signal exchanges

Figure 3 shows an example of the scripting language. In Fig. 3, after Robot1 finishes playing the voice file “Hello.wav,” it sends signal “A” to Robot2. At that time, Robot2 is waiting for signal “A.” After receiving signal “A,” Robot2 plays the “thankyou.wav” file and sends signal “B.” When Robot1 receives it, this scenario is finished.

Figure 4 shows how the system works in the interactive condition. If Robot1 (master robot) notices there is a person nearby, it decides which scenario to execute and sends the corresponding signal to its partner. When there is no human around, the robots play the idling scenario.

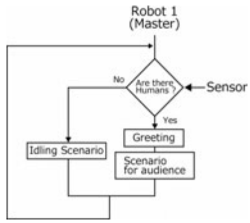


Fig. 4. Example of restrictive reaction

In this way, we constructed a system that is capable of interpreting its environment and executing scenarios accordingly.

3 Experiments

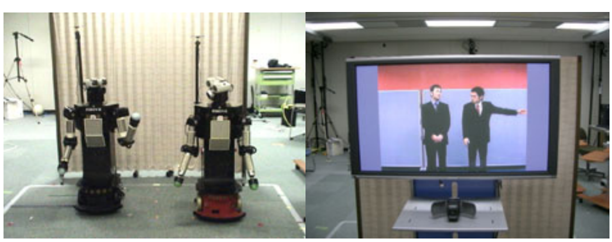
We conducted an experiment to investigate the utility of robots as a passive-social medium in this application by comparing it with television in a field experiment at a train station for eight days to investigate the effects of a passive-social medium.

3.1 Experiment Comparing it with Television

- **Method.** Each subject watched a performance by either robots (Fig. 5, a) or humans (Fig. 5, b) in front of them (Fig. 6):

Robot condition. Two robots performed in front of the subject. Please refer to the movie in the proceedings CD for a scene of the robot performance.

Human condition. Two amateurs, who have practiced performance for three years, performed on a TV screen in front of the subject.



(a) Robot condition (b) Human condition

Fig. 5. Conditions

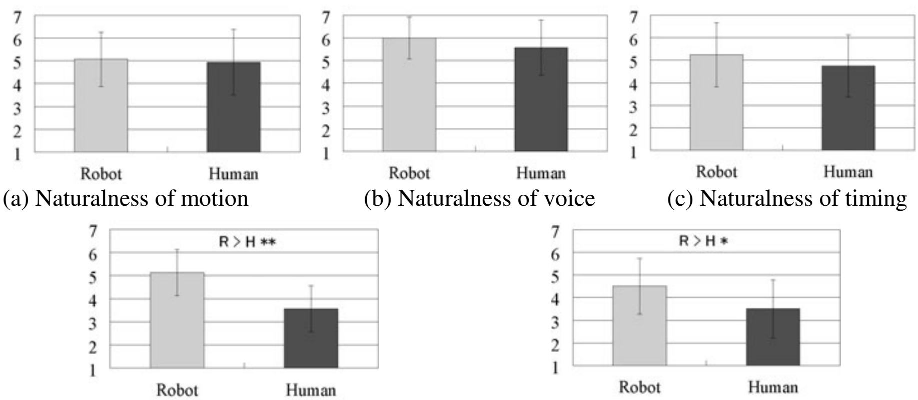
- **Measurement.** Once the experiment was finished, we distributed questionnaires to the subjects who rated the performances on a 1-to-7 scale for each question where

7 is the most positive. There were five questions: naturalness of motion, naturalness of voice, naturalness of timing, presence, and overall impression.

- **Result**

Naturalness of motion, voice, and timing. Figure 6 a-c shows a comparison of questionnaire results for the naturalness scores. From the results of a one-way between-groups design ANOVA (analysis of variance), there was no significant difference between the robot performance and the human performance in the average scores for naturalness.

Presence and overall impression. A one-way between-groups design ANOVA did show a significant difference between the robot performance and the human performance in the average scores when we consider presence and overall impression (Presence: $F(1,31) = 18.49$, $p<.01$; Overall impression: $F(1,31) = 5.71$, $p<.05$). That is, the performance by two robots had higher scores for presence and overall impressions than the performance by humans shown in the video. (Figure d,e)



(a) Naturalness of motion (b) Naturalness of voice (c) Naturalness of timing

(d) Presence (e) Overall impression

Fig. 6. Result of experiment comparing it with television

3.2 Experiment in the Real Environment

- **Method**

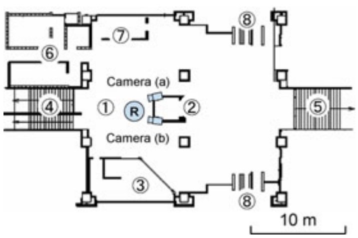
Gakken Nara-Tomigaoka Station was opened in March 2006 as the terminal station of the Keihanna New Line, belonging to the Kintetsu Railway. The Keihanna New Line connects residential districts with the center of Osaka (Fig. 7 b). Station users are mainly commuters and students. There are usually four trains per hour, but in the morning and evening rush hours there are seven trains per hour. Figure 8 shows the experiment's environment. Most users go down the stairs from the platform after they exit a train. We set the robot(s) in front of the left stairway (Fig. 8). The robot(s) announced information toward users mainly coming from the left stairway.

We observed how the users reacted to the behaviors of the robot(s). For this observation, we set cameras on the ceiling nearby (Fig. 8, cameras (a) (b)).

All station users who passed by the robot(s) were assumed to be participants. Their behavior was observed by video. We requested that users who stopped to watch the robot(s) answer a voluntary questionnaire. We obtained permission to record video

(a) Robots as medium in station (b) View of Station

Fig. 7. Scenes of the experiment



1 : Experimental field
2 : Elevator
3 : Shop
4 : Left stairway
5 : Right stairway
6 : Toilets
7 : Vending machines
8 : Ticket gates

Fig. 8. Station map

from the responsible authorities of the station, and a notice was displayed in the station about the video recording.

- **Mesurement**

We requested station users who stopped to watch the robot(s) to answer a questionnaire. We obtained answers from 163 station users. The questionnaire had three questions as follows in which they rated items on a scale of 1 to 7, where 7 is the most positive:

  - Feeling of being addressed by the robot
  - Interest in the content of the information the robot(s) is announcing
  - Enjoyment

- **Conditions**

Passive condition (P condition). In this condition, one humanoid robot was installed (Fig. 7(a)). The robot had a sensor in front of it, although the sensor was not used. The robot randomly played the five scenarios announcing station and travel information continuously.

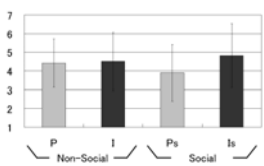
Interactive condition (I condition). One humanoid robot was installed as in the P condition, but the robot had limited-realistic interactivity. That is, it had a sensor (laser range-finder) in front of it and changed the scenario according to the position of the human. Concretely, if there was no person near the robot, the robot played the idling scenario. When the sensor detected a person within a semicircle of 3.5 meters, the robot stopped playing the idling scenario, looked at the person, bowed and said “Hello.” After that, while one or more persons were within the range of 3.5 meters, the robot randomly played the five scenarios announcing station and travel information.

Passive-social condition (Ps condition). Two humanoid robots were installed (Fig. 7(a)). The robots had a sensor in front of them, but the sensor was not used. The robots randomly played the five scenarios announcing station and travel information by communicating with each other.

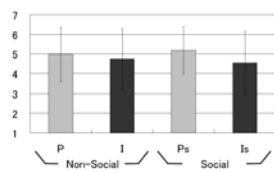
Interactive-social condition (Is condition). Two humanoid robots were installed as in the Ps condition. The robots had limited-realistic interactivity: the robots had an operating sensor in front of them and changed the scenario according to the position of the human. Concretely, if there was no person near the robots, the robots played the idling scenario. (In this scenario, robots chat with each other.) When the sensor detected a person within a 3.5m-radius semicircle, the robots stopped playing the idling scenario, looked in the direction of the person, bowed and said "Hello." After that, as long as one or more persons was within a range of 3.5 meters, the robots randomly played the scenarios announcing station and travel information by communicating with each other.

- **Summary of Results**

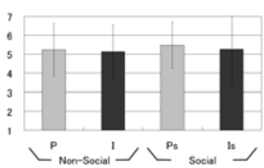
The results indicated that limited-realistic interactivity of the robot gives people the feeling of being addressed by the robot(s). On the other hand, it makes people lose interest in the information. From this result, we believe that using "interactive" as a medium does not necessarily provide a good result in its current form, since such performance has limited realistic use in a real environment. However, the non-social conditions had a lower chance of making people stop at the robot. These findings indicate that the passive-social medium is promising because the system has a better chance of getting people to stop and become interested in the information announced by the robot. (Fig9 a-d)



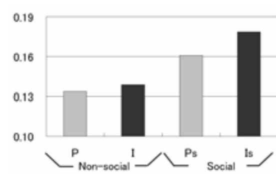
(a) Feeling of being addressed by the robot



(b) Interest in information robot(s) announcing



(c) Enjoyment



(d) Rate of "Stopping to watch"

Fig. 9. Results of experiment in the real environment

4 Conclusion

Although we have used robots as a passive-social medium, we have not truly investigated the effects of robots as a passive-social medium in comparison with other forms. In both trials, robots got people's attention so that they crowded around to see the robots. One of the difficulties has been that when people have a strong interest in robots, it is difficult to identify the effects of the passive-social medium because people appreciate any encounter with a robot due to its novelty.

The experimental results revealed that a two-robot condition (passive-social and interactive-social conditions) was better than a one-robot condition in terms of getting people to stop at the robots. Once people stopped, these conditions did not make any difference. Instead, a lack of interactivity (passive-social and passive conditions) had the advantage of attracting people's interest in the contents of the utterances. Thus, the passive-social condition proved to be the best for this purpose among the conditions tested in the experiment.

Although the experiment revealed the positive aspect of a passive-social medium on the "interest" aspect, it is not clear how naturally the passive-social medium offers information compared with other types of medium. The experimental results revealed effects when people glanced at the robot to decide whether to stop; however, the results did not reveal effects after stopping at the robots. The difficulty is in experimental control. In this experiment, we controlled the contents of the information that the robots said. Two robots (passive-social condition) could enable construction of a bigger variety of scenarios than is possible with a single robot. For example, one robot might ask a question to another, after which the other would make a response. Use of such a staged effect, however, could cause differences not only due to the conditions (passive-social vs. passive) but also due to the different contents of the utterances. Thus, we did not implement such techniques in this experiment. Probably adding such a feature would make robots more enjoyable and make interaction with people more natural. Demonstrating such effects will be one of our future studies.

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