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Communication Robots in Real Environments

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1. Introduction

The development of robots is entering a new stage, where the focus is on interaction with people in their daily environments. We are interested in developing a communication robot that operates in everyday conditions and supports peoples' daily life through interactions with body movements and speech. The concept of the communication robot is now rapidly emerging and developing, with communication robots in the not-too-distant future likely to act as peers providing mental, communication, and physical support. Such interactive tasks are important for enabling robots to take part in human society.

Many robots have already been applied to various fields in real environments. We discuss the details of related works in the next section. Here, there are mainly two kinds of fields: closed and open. The difference between a closed and an open environment lies in the people who are interacting. In a closed environment, such as an elementary school or an office, robots interact with a limited group of people. On the contrary, we chose to work in an open environment because we expect that many people, in a wide-range of ages, will interact with robots. In line with this prospect, we have been developing a science museum guide robot that we believe to be a promising application.

There is a double benefit in choosing a science museum as the experiment field. On the one hand, visitors have the opportunity to interact with the robots and experience the advanced technologies by which they are made, which is the fundamental purpose of a science museum. Thus, we can smoothly deploy our research in a real environment.

On the other hand, in a science museum we are naturally targeting people who are interested in science and are unlikely to miss the chance to interact with our robots; thus this field is one of the best choices for collecting feedback and examining the interaction between people and the communication robot in various tasks. The need for extensive and accurate feedback goes back to our belief that interaction with humans through tasks is one of the communication robot's essential roles. This feedback is vital for developing the ability of the robots to act appropriately in a daily living environment.

In this chapter, we introduce recent research efforts in communication robots in real environments and describe an experiment in which a system using many ubiquitous sensors and humanoid robots -- Robovies -- guide the visitors at a science museum. In this setting, the Robovies interacted with the visitors and showed them around to exhibits according to information from ubiquitous sensors, such as the visitors' positions and movement histories.

Location	Purpose	People		Function		Interaction
		Wide age range	Many people	Navigation	Person identification	Human-like
Home	Entertainment [Fujita 1998]	✓	−	−	−	−
Hospital	Mental care [Shibata 2004]	✓	−	−	−	−
School	Language education [Kanda et al. 2004]	−	✓	−	✓	✓
Lobby	Interaction [Gockley et al. 2005]	✓	✓	−	✓	−
Office	Guiding [Asoh et al. 1997]	−	−	✓	✓	−
Museum	Guidance & navigation [Burgard et al. 1998] [Siegwart et al. 2003]	✓	✓	✓	✓	−
	Interaction & guidance [This paper]	✓	✓	✓	✓	✓

Table 1. Various field experiments with interactive robots

2. Related Works

Table 1 shows a comparison between our work and previous works based on the concept of the communication robot. Aibo [Fujita, 1998] and Paro [Shibata, 2004] had animal-like appearances – respectively, a dog and a seal. These robots provide entertainment or mental care to people through a human-pet style of interaction. Both studies indicated the effectiveness of interaction between people and pet-like robots.

In an elementary school, Robovie [Kanda et al. 2004] was used to assist with the language education of elementary school students. This research detailed the importance of using personal information in an interaction and the effectiveness of human-like interaction from a communication robot in a real environment. On the contrary, this research mainly focused on the interaction between people and a robot with a human-like body. In addition, Robovie only interacted with a limited group of people. As a result, it is not clear how a robot should operate in large-scale real environments where a wide variety of people visit.

Valerie [Gockley et al. 2005] is a robotic-receptionist. This research indicated the effectiveness of the robot's personality through long-term interaction with people. Valerie used functions of emotion expression and storytelling to represent her personality. In addition, Valerie interacted with many people using personal information such as name (from a magnetic card) in a large-scale environment. Valerie cannot, however, move around and has only simple interfaces such as a keyboard; therefore, this research did not address problems associated with navigation and human-like interaction.

Jijo-2 [Asoh et al. 1997], RHINO [Burgard et al. 1998], and RoboX [Siegwart et al. 2003] are traditional mobile robots, the developers of which designed robust navigation functions for real environments. In particular, RoboX and RHINO guided thousands of people in large-scale environments. Although these works represent the effectiveness of robust navigation functions in interactions between people and robots, their interaction functions are quite different from human-like interactions. In addition, these researchers mainly focused on the robustness of their systems, thus none of these reports evaluated the effectiveness of human-like interaction in large-scale real environments.

From surveying the related research, we consider it important to investigate the effectiveness of human-like interaction as well as to develop robust functions. Therefore, we designed our robots to interact with people using human-like bodies and personal information obtained via ubiquitous sensors.

3. System Configurations

3.1 The Osaka Science Museum
1) General settings:
Seventy-five exhibits were installed on the fourth floor of the Osaka Science Museum, and visitors could freely explore these exhibits. Figure 1 shows a map of the fourth floor of the museum. Generally, visitors walk in the counterclockwise direction from the entrance to the exit. The width and length of the Osaka Science Museum are 84[m] and 42[m], respectively.

2) Our experimental settings:
We installed the humanoid robots, RFID tag readers, infrared cameras and video cameras in the fourth floor of the Osaka Science Museum for an experiment. Visitors could freely interact with our robots similar to the other exhibits. Typically, in our experiment, visitors progress through the following steps:

• If a visitor decides to register as part of our project, personal data such as name, birthday, and age (under 20 or not) is gathered at the reception desk (Fig. 1, point A). The visitor receives a tag at the reception desk. The system binds those data to the ID of the tag and automatically produces a synthetic voice for the visitor's name.

• The visitors could freely experience the exhibits in the Osaka Science Museum as well as interact with our robots. Four robots were placed at positions B, C, and D on the fourth floor, as shown in Fig. 1. When leaving the exhibit, visitors returned their tags at the exit point (Fig. 1, point E).

3.2 Humanoid Robots
1) Robovie:
Figure 2 shows "Robovie," an interactive humanoid robot characterized by its human-like physical expressions and its various sensors. The reason we used humanoid robots is that a human-like body is useful to naturally control the attention of humans [Imai et al. 2001]. The human-like body consists of a head, a pair of eyes, and two arms. When combined, these parts can generate the complex body movements required for communication. We decided on a robot height of 120 cm to decrease the risk of scaring children. The diameter was 40 cm. The robot has two 4*2 DOFs (degrees of freedom) in its arms, 3 DOFs in its head, and a mobile platform. It can synthesize and produce a voice via a speaker. We also attached an RFID tag reader to Robovie [Kanda et al. 2004] that enables it to identify the individuals around it. Two of the four robots used in this experiment were Robovies.
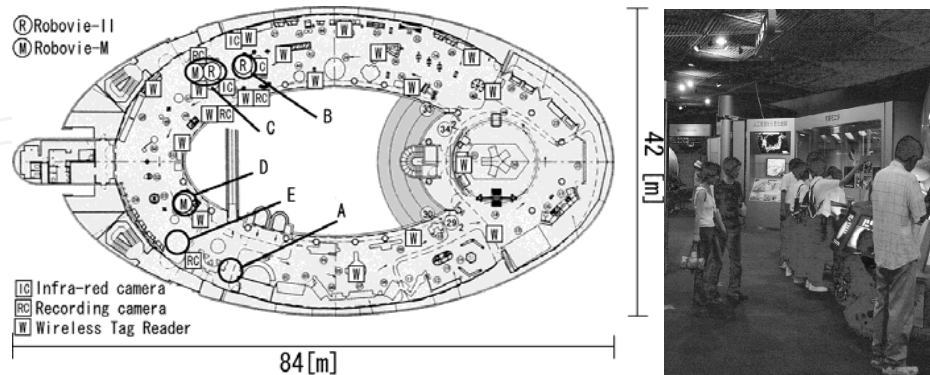
Figure 1. Map of the fourth floor of the Osaka Science Museum

2) Robovie-M:

Figure 3 shows a "Robovie-M" humanoid robot characterized by its human-like physical expressions. We decided on a height of 29 cm for this robot. Robovie-M has 22 DOFs and can perform two-legged locomotion, bow its head, and do a handstand. We used a personal computer and a pair of speakers to enable it to speak, since it was not originally equipped for this function. The two other robots in this experiment were Robovie-Ms.

Figure 2. Robovie   Figure 3. Robovie-M

3.3 Ubiquitous sensors in an environment:

On the fourth floor of the Osaka Science Museum, we installed 20 RFID tag readers (Spider-IIIA, RF-CODE), which included the two equipped on the Robovies, three infrared sensors, and four video cameras. All sensor data were sent to a central server's database via an Ethernet network.

In the following sections, we describe each type of sensor used.

1) RFID tag readers:

We used an active type of RFID tag. This technology enables easy identification of individuals, since detection is unaffected by the occurrence of occlusions, the detection area is wide, and the distance between the tag reader and the RFID tag can be roughly estimated. Such benefits are advantageous for large environments.

However, drawbacks of this approach include low accuracy over long distances and the inability to detect exact positions. We compensated for these shortcomings by installing many RFID tag readers in the environment.

To achieve approximate distance estimation, we set the RFID tag readers to have eight levels of sensitivity. Detection areas, however, are affected by the position of the RFID tag readers and reflections due to walls. Therefore, we measured each detection area prior to the experiment. We then attached the tag readers in positions two meters above the floor, and to successfully detect the tags we had to set the reader sensitivity level to at least five.
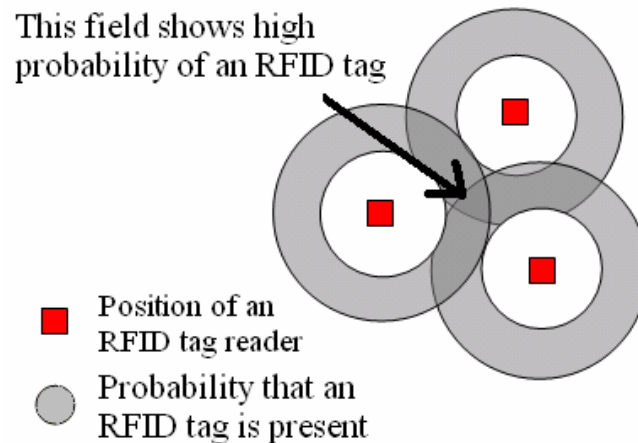

Figure 4. Detection fields of RFID tag

Figure 1 shows an example of how we positioned the tag readers. We placed them around particular exhibits, so that the system could detect whether visitors approached them. Moreover, since a tag reader's detection field has a torus shape, the system can estimate the tag position by superposing the circles calculated from the reader outputs (Fig. 4).

2) Infrared cameras:

We placed an infrared LED on top of a Robovie and attached infrared cameras to the ceiling to determine the robot's correct position. The system produces binary images from the infrared cameras and detects bright areas. It calculates absolute coordinates with a reference to the weighted center of the detection area and sends them to the database.

Infrared camera positions are shown in Fig. 1. The distance between the floor and ceiling is about 4 m. The width and height of images from an infrared camera are 320 and 240 pixels, respectively. One pixel represents about 1 cm^2 of area.

3) Video cameras:

The video camera positions are also shown in Fig. 1. The output images of each video camera are recorded onto a PC and used to analyze the data generated during the experiment.

4. Robot Behaviour

4.1 Locomotive robot

We used a Robovie as a locomotive robot that moved around in parts of the environment, interacted with visitors, and guided them to exhibits. Such behaviour can be divided into four types, the details of which are explained as follows.

1) Interaction with humans: Childlike interaction

The robot can engage in such childlike behaviour as handshaking, hugging, and playing the game of "rock, paper, scissors." Moreover, it has reactive behaviours such as avoidance and gazing at the touched part of its body, as well as patient behaviour such as solitary playing and moving back and forth. Figure 5 shows interaction scenes between the robot and visitors.

(a) A child touching the robot   (b) The robot hugging children

Figure 5. Scenes of interaction between visitors and the robot

2) Interaction with humans: Using information from RFID tags

The robots can detect RFID tag signals around themselves by using their RFID tag reader, which allows them to obtain personal data on visitors from their RFID tag IDs. Each robot can greet visitors by name, wish them a happy birthday, and so on. In addition, the system records the time that visitors spend on the fourth floor of the Osaka Science Museum. The robots can behave according to that duration of visit.

3) Guiding people to exhibits: Human guidance

The robot can guide people to four kinds of exhibits by randomly determining the target. Foe example, when bringing visitors to the telescope, the robot says, "I am taking you to an exhibit, please follow me!", and approaches the telescope. It suggests that the person look through it and then talks about its inventor.

4) Guiding people to exhibits: Using information from RFID tags

The RFID tags' data are also used for interaction. We used the amount of time that visitors spent near an exhibit to judge whether visitors tried it. For example, when an RFID-tagged visitor has stayed around the "magnetic power" exhibit longer than a predefined time, the system assumes that the visitor has already tried it. Thus, the robot says, "Yamada-san, thank you for trying 'magnetic power.' What did you think of it?" If the system assumes that the visitor has not tried it, the robot will ask, "Yamada-san, you didn't try 'magnetic power.' It's really fun, so why don't you give it a try?"

4.2 Robots that talk with each other

Two stationary robots (Robovie and Robovie-M) can casually talk about the exhibits as humans do with accurate timing because they are synchronized with each other through an Ethernet network. When taking, Robovie controlled the timing of Robovie-M's motion and speech. The topic itself is determined by data from RFID tags. By knowing a visitor's previous course of movement through the museum, the robots can try to interest the visitor in an exhibit he or she overlooked by starting a conversation about that exhibit. Figure 6 shows scenes of robots talking to each other.

(a) Two robots talking   (b) Two robots talking to visitors
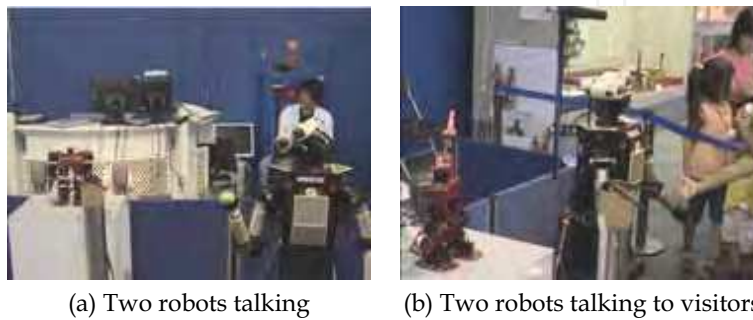
Figure 6. Scenes of robots talking to each other

4.3 A robot bidding farewell

This robot is positioned near the exit and, after requesting data from their RFID tags, says goodbye to the departing visitors. We used Robovie-M for this robot. It also reorients visitors on the tour who are lost by examining the visitor's movement history and time spent on the fourth floor of the Osaka Science Museum, which was recorded by the system. If visitors walk clockwise, they will immediately see this robot at the beginning and will be pointed in the right direction by the robot. Figure 7 shows a scene with this robot.

Figure 7. The robot bidding farewell

5. Results of Exhibition Experiment

We performed experiments to investigate the impressions made by robots on visitors to the fourth floor of the Osaka Science Museum during a two-month period. By the end of the two-month period, the number of visitors had reached 91,107, the number of subjects who

wore RFID tags was 11,927, and the number of returned questionnaires was 2,891 (details are not discussed here). Details of questionnaires' results are described by Nomura et al [Nomura et al, 2005]. The results of the two-month experiment indicate that most visitors were satisfied with their interaction with our robots. In this section, we describe the observed interaction between visitors and our robots at the exhibition and how the ubiquitous sensors contributed to the entire system in the real environment.

5.1 Observations of interaction between visitors and the robots
1) Locomotive robot
- Often there were many adults and children crowded around the robot. In crowded situations, a few children simultaneously interacted with the robot.
- Similar to Robovie's free-play interaction in a laboratory [Ishiguro et al. 2001], children shook hands, played the paper-rock-scissors game, hugged, and so forth. Sometimes they imitated the robot's body movements, such as the robot's exercising.
- When the robot started to move to a different place (in front of an exhibit), some children followed the robot to the destination.
- After the robot explained a telescope exhibit, one child went to use the telescope. When she came back to the robot, another child used the telescope.
- Its name-calling behaviour attracted many visitors. They tried to show the RFID tags embedded in the nameplates to the robot. Often, when one visitor did this, several other visitors began showing the robots their nameplates, too, as if they were competing to have their names called.

We demonstrated that robots could provide visitors with the opportunity to play with and study science through exhibits they might have otherwise missed. In particular, this reminds us of the importance of making a robot move around, a capability that attracts people to interact with it. Moreover, as shown in the scene where children followed the locomotive robot, it drew their attention to the exhibit, although the exhibit (a telescope) was relatively unexciting. (The museum features many attractive exhibits for visitors to move and operate to gain an understanding of science, such as a pulley and a lever.)

2) Robots that talk to each other
- There were two types of typical visitor behaviours. One was simply listening to the robots' talk. For example, after listening to them, the visitors talked about the exhibit that was explained to them, and sometimes visited the exhibit.
- The other behaviour is to expect to have their name called. In this case, the visitors paid rather less attention to the robots' talk but instead showed their names to the robots, which is similar to the actions observed around the locomotive robot. Often, a visitor would leave the area in front of the robot just after his/her name was called.

One implication is that displaying a conversation between robots can attract people and convey information to them, even though the interactivity is very low. Such examples are also shown in other works [Hayashi et al. 2005] [Hayashi et al. 2007].

3) Robot bidding farewell
- There were two types of typical visitor behaviours. One was simply watching the robot's behaviour.
- The other was, again, to expect to have their name called. In this case, the visitors often showed their names to the robots.

Significantly, the effectiveness of the name-calling behaviour was again demonstrated, as seen in the children's behaviour when returning their RFID tags.

5.2 Contribution of the ubiquitous sensors
1) RFID tags and tag readers
As shown in the scenes of interaction with the robots, the application of RFID technology largely promoted the human-robot interaction, particularly with regard to the name-calling behaviour. However, the information obtained from the distributed RFID tag readers made a relatively small contribution to the system. Robots talked to the visitors about their exhibit-visiting experience, such as "You did not see the telescope exhibit, did you? It is very interesting. Please try it," based on the information from the RFID reader network, but it seemed to be less attractive and impressive to the visitors. This was also pointed out in our previous work [Koide et al. 2004]. Perhaps, robots are too novel for visitors, so they highly value the mere experience of interacting with the robots while paying less attention to the detailed services that they offer.

2) Other ubiquitous sensors
Regarding the ubiquitous sensors other than the RFID tags, their role was limited. The infrared camera supplied the exact position of the robot, which was very helpful in the crowded environment. We believe that there will be much useful information from ubiquitous sensors available for human-robot interaction, which should be incorporated in our future work. For example, Nabe et al. reported that the distance between a robot and a person was influenced by age [Nabe et al. 2006].

6. Conclusion

We have developed an interactive robot system that combines autonomous robots and ubiquitous sensors. The system guided visitors through a science museum with human-like interaction, such as calling their names in a free-play behaviour and explaining exhibits with voice and gestures. In a two-month exhibition, 91,107 people visited the Osaka Science Museum, 11,927 of whom wore RFID tags to participate in the field trial. The results from questionnaires revealed that almost all of the visitors evaluated these robots highly.

7. Acknowledgments

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Humanoid Robots, Human-like Machines

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In this book the variety of humanoid robotic research can be obtained. This book is divided in four parts: Hardware Development: Components and Systems, Biped Motion: Walking, Running and Self-orientation, Sensing the Environment: Acquisition, Data Processing and Control and Mind Organisation: Learning and Interaction. The first part of the book deals with remarkable hardware developments, whereby complete humanoid robotic systems are as well described as partial solutions. In the second part diverse results around the biped motion of humanoid robots are presented. The autonomous, efficient and adaptive two-legged walking is one of the main challenge in humanoid robotics. The two-legged walking will enable humanoid robots to enter our environment without rearrangement. Developments in the field of visual sensors, data acquisition, processing and control are to be observed in third part of the book. In the fourth part some "mind building" and communication technologies are presented.

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