A Larger Audience, Please!
- Encouraging people to listen to a guide robot -

Masahiro Shiomi Takayuki Kanda Hiroshi Ishiguro Norihiro Hagita
ATR Intelligent Robotics and Communication Laboratory
2-2-2 Hikaridai, Keihanna Science City,
Kyoto, Japan
{m-shiomi, kanda, ishiguro, hagita}@atr.jp

***Abstract*—Tour guidance is a common task of social robots. Such a robot must be able to encourage the participation of people who are not directly interacting with it. We are particularly interested in encouraging people to overhear its interaction with others, since it has often been observed that even people who hesitate to interact with a robot are willing to observe its activity. To encourage such participation as *bystanders*, we developed a robot that walks backwards based on observations of human tour guides. Our developed system uses a robust human tracking system that enables a robot to guide people by walking forward/backward and allows us to scrutinize people's behavior after the experiment. We conducted a field experiment to compare the ratios of overhearing in "walking forward" and "walking backward." The experimental results revealed that in fact people do more often overhear the robot's conversation in the "walking backward" condition.**

Keywords-components: Eliciting spontaneous participation, tour-guide robot, social human-robot interaction

I. INTRODUCTION

Tour guidance is one of the most promising robot applications. Many studies in robotics have focused on the navigation of robots with people (e.g., [1-6]), and field trials have often been conducted with guide robots [7-13]. For instance, Siegwart et al. developed navigation robots that operated at an Expo [7], and Thrun et al. developed a tour-guide robot for the Smithsonian Institution [8]. The usefulness of robots in information-providing tasks [13] and advertisement applications [11] has been demonstrated as well. Many robots have capabilities that make them well-suited for tour guidance applications, including mobility, the ability to speak to people, and a novelty that attracts people's attention.

However, these studies did not focus on how to elicit spontaneous participation, which is one fundamental interaction in tour-guide robots. In fact, we found that people often hesitate to participate [12, 14]. Previous studies considered a way for a robot to encourage people's interaction [14-16], but they only considered a robot standing in a specific place. A few studies have investigated robots that proactively approach people [8, 13, 17], but these studies only considered how to invite people to be the addressee of the interaction, i.e., the person who speaks, listens, and acts with the robot. In contrast, we observed that people standing within some distance often overheard the interaction, even though they hesitated to participate (Fig. 1). If the robot's role is to provide information, such *participation as audience* is also useful.

When a tour is led by a human professional, such tour guides are commonly seen walking backward to look at people to more naturally provide explanations. Stimulated by this human behavior, we considered walking backward as one way to elicit spontaneous participation while our robot is leading people. Here, we see the advantages of robots over humans. Humans need to frequently look in the direction they are walking to observe their environment and avoid collisions. In contrast, a robot doesn't have to "look" in the direction of its movements. The term "look" might not be accurate here. A robot observes its environment with other devices; consequently, a robot can use its eye and head devices to express its "looking" direction purely for natural interaction with people.

In this paper, we study how human-robot interaction changes when the robot moves forward or backward. Note that our study and analysis were conducted with a robust and accurate tracking system of walking people [18]. It enables us to control the robot's behavior in a way we defined, e.g., forward/backward accompanying behavior. Moreover, it records pedestrian behavior around the robots while they expressed their accompanying behavior. The analysis produced a working hypothesis that the opportunity of looking at the robot's face, which is offered more by moving-backward, would increase the chance to let pedestrians overhear a robot's guidance utterances.

Figure 1. Overhearing an interaction

This research was supported by the Ministry of Internal Affairs and Communications of Japan.

II. PARTICIPATION ROLE

A. *Theoretical background*

There is literature in the human sciences about modeling participation roles for conversation. Goffman classified people as "*ratified participants*" and "*unratified participants*" during conversations in the *participation framework* model [19]. Clark classified participants as *speaker*, *addressee*, *side-participant*, *bystander*, and *eavesdropper* [20]. Speakers, addressees, and side-participants are defined as ratified participants in conversation. All other listeners are defined as *over-hearers* who are unratified participants. Over-hearers include two types: bystanders and eavesdroppers. In contrast to over-hearers, bystanders are openly present but do not participate in the conversation.

Milgram et al. studied how people mutually influence each other by setting up a situation where a confederate was gazing at a nearby building on a street. They found that the confederate's behavior elicited other people to gaze at the same building. Moreover, the number of pedestrians who looked up at the building increased based on an increase in the number of confederates [21]. Similar findings have been reported in a series of studies in group dynamics known as *casual crowds* [22, 23]. Similar to these findings in the literature, we considered that a situation in which a robot interacted with a person would stimulate the casual participation of others.

B. *Participation role in tour guidance with a robot*

Borrowing terms from [20], we modeled the participation role in guiding interaction (Fig. 2). In guiding situations, since the robot does most of the speaking, its role is the *speaker*. There is usually a person in front of the robot listening to and following it called the *addressee*. In addition, a group of people is often involved. While the leading person behaves as the *addressee*, other ratified participants are accompanied in a group around the *speaker* and *addressee* and are called *side-participants.* All other people encouraged by the *speaker/addressee/side-participants* to join the interaction (i.e., listen to or follow the robot) are called *bystanders.*

The role of *bystanders* is a comfortable vantage point for pedestrians. People might hesitate if they were asked to be *addressees*, since this role is responsible for responding to the robot; in contrast, *bystanders* are not responsible for interacting with the robot. We believe this is a reasonable strategy with which a robot can elicit spontaneous participation from pedestrians as bystanders.

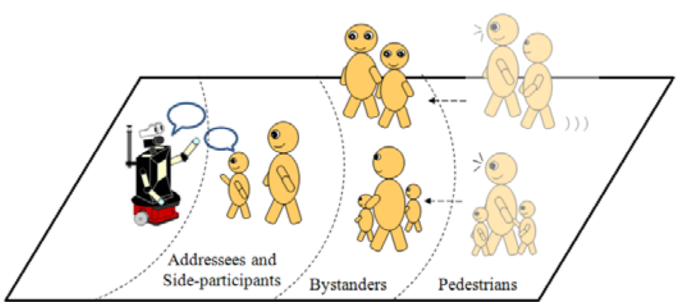

Figure 2. Participation roles in guiding

III. SYSTEM CONFIGURATION

Figure 3 shows an overview of our system that enables a robot to guide people by walking forward/backward. The robot guides an addressee based on the position information of itself and the people in the environment. Moreover, the robot controls its speed, rotation, and behavior based on a positional relationship between itself and the addressee. The system is completely autonomous after starting an interaction with an addressee.

We used environmental sensors for position estimation [24]. Many research works have achieved robust position estimation functions using only the robots' sensors [7-9, 25]; however, for our analysis we also need the position information of the surrounding people, even those distant from the robot. Therefore, we used environmental sensors for position estimation.

A. *Hardware*

1) *Robovie*

"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 upper body is useful for naturally holding the attention of humans [26]. Robovie is 120 cm high, 40 cm wide, and can synthesize and produce a voice through a speaker.

Its lower mobile base is a Pioneer 3-DX (ActiveMedia). Its maximum moving speed was set to 2.5 km/h (700 mm/second), based on the average speed of people walking in a mall, the capability of the mobile base, and safety.

For obstacle detection, we attached a Hokuyo URG-04LX Laser Range Finder (LRF) to the lower mobile base to enable the robot to detect low obstacles that the environmental sensors cannot detect.

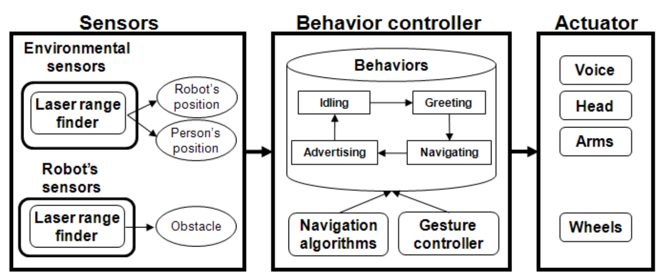

Figure 3. System overview

Figure 4. Shopping arcade and laser range finders

Figure 5. Estimated positions of people

2) Environmental sensors for position estimation

We used SICK LMS-200 laser range finders (LRFs) mounted around the trial area's perimeter at a height of 85 cm to track people's positions (Fig. 4). We used a technique derived from the algorithm presented in a previous work [18], in which individual particle filters were used to track the location of each person in the scan area based on the combined torso-level scan data from all of the laser range finders. This tracking technique provides highly stable and reliable trajectory data. For natural walking speeds, the tracking accuracy of our sensor configuration was measured to be +/- 6 cm.

Figure 5 shows the estimated positions by scanning data from six laser range finders. The sensors were also used for robot localization; the system estimates the robot's position as accurately as the peoples' positions.

B. Behavior Controller

We implemented the following robot task: guiding an addressee to a shop that will open soon in a shopping mall. The task consists of four behaviors: idling, greeting, guiding, and advertising. In the idling behavior, the robot simply waits for a person to address. In the greeting behavior, the robot turns to the target, greets him/her, and shakes hands. In the guiding behavior, the robot asks the target to follow and moves in front of the shop. The robot chats with the person while guiding; the contents are randomly selected from ten kinds, such as "A few days ago, I got caught in a downpour. My heart was racing because I was soaked!" In the advertising behavior, the robot advertises the shop and says "goodbye" to the target after arriving at the shop's front.

We developed two functions to realize the four behaviors: a gesture controller and a navigation algorithm. The details of each function are described as follows.

1) Gesture controller

This function controls the robot's face and arms. In greeting and advertising behaviors, the robot uses gestures for greeting, shaking hands, and pointing to the shop. In the guiding behavior, the robot faces the addressee while guiding, and in this condition the maximum degree of the face direction is 90/-90 from the direction in the front of the body. The robot swings its arms while guiding.

2) Navigation algorithm

For walking forward, the robot guides the addressee by standing to the addressee's side. For this purpose, the robot adjusts its position to be diagonally in front of the addressee at about 50 cm (we defined *Gtf* as this temporary target position for walking forward). It makes this adjustment by controlling its speed and rotation.

For walking backward, the robot guides the addressee by standing in front of the addressee. For this purpose, the robot adjusts its position to about 50 cm in front of the addressee by controlling its speed and rotation (we defined *Gtb* as this temporary target position for walking backward).

The robot reduces its speed by half when the distance between the robot and the addressee exceeds 1.5 m. The robot does not stop until it arrives at the shop or encounters an obstacle within 50 cm in the direction of its movement. This behavior is based on preliminary experimental results showing that addressees stop and wait for the robot when it moves too slowly. Furthermore, the robot looks at the addressee while guiding in both conditions.

To adjust its speed, the robot estimates the distances between itself and each pedestrian using position information from the LRFs. The speed and the moving and face directions of the robot are calculated by the following equations:

$$Speed = \begin{cases} MaxSpeed \cdots (DistA < 1500 \;\; or \;\; DistAG > DistG) \\ MaxSpeed - (DistA - 1500) \times \alpha \cdots (1500 \le DistA \le 2500) \\ MaxSpeed / 2 \cdots (DistA > 2500) \end{cases}$$

$$MovingDirection = \begin{cases} \theta_{RTP} \cdots (-45 \le \theta_{RG} \le 45 \;\; and \;\; abs(\theta_{RTP}) < 90) \\ \theta_{RG} \cdots (otherwise) \end{cases}$$

$$FaceDirection = \begin{cases} 90 \cdots (\theta_{RA} > 90) \\ \theta_{RA} \cdots (-90 \le \theta_{RA} \le 90) \\ -90 \cdots (\theta_{RA} < -90) \end{cases},$$

where DistA is the distance between the robot and the addressee, DistG is the distance between the robot and the shop, Maxspeed is 700 mm/seconds (as described above), θ_{RTP} is the angle between the robot and a temporary target position (*Gtf* or *Gtb*), θ_{RG} is the angle between the robot and the goal, and θ_{RA} is the angle between the direction of the front of the robot's body and the addressees. The major differences between the two cases are the positioning of the robot and the direction of its body while walking.

IV. FIELD EXPERIMENT AT A SHOPPING MALL

We investigated how the robot elicits spontaneous participation while guiding through a field experiment at a shopping mall by comparing the effectiveness of walking forward and walking backward.

A. Method

1) Environment and settings

The field trial was conducted inside a mall located between a train station and an amusement park. The robot was placed in a corridor visited hourly by an average of more than 400 people (during summer vacation in Japan). We conducted experiments during four days, all weekdays.

Figure 6 shows the environment, where we installed six LRFs and four cameras. The experiment space was as equal as the area covered by laser range finders. The robot was autonomous in the experiments except for the start signal sent by an operator in the beginning of first greeting. The robot waits at the start position for a person to greet; when a visitor talks to the robot, the operator simply start the greeting behavior of the robot. After greeting, the robot guides the person to the front of a shop that will open soon and advertises it fully-autonomously. The guiding distance was approximately 10 m. For safety, one staff member remained around the robot during the trials.

The visitors were mainly families, couples, and sightseers, all of whom could freely interact with the robot. The number of visitors fluctuated between day and night, so we divided the experiment into time slots that covered both daytime (lunch, shopping, or the amusement park) and night (dinner, shopping, or the station) to avoid results skewed by different numbers of participants.

The trial was divided into three stages based on the robot's behavior: greeting, guiding, and advertising. Each trial started when a pedestrian talked to the robot in its idling behavior. After finishing these three stages, each trial was completed. The mean duration of a guiding stage was 20 seconds. The mean duration of an advertising stage was also 20 seconds.

We obtained permission to record video and sensor data from the mall authorities. The experimental protocol was reviewed and approved by our institutional review board.

2) Conditions

We adopted two conditions for the experiment and defined each factor as follows:

Forward condition: In the guiding stage, the robot guides people by walking forward. Before guiding, the robot said, "Let me give you some interesting information. Please follow me." As shown in Fig. 7-a, the robot guides people to the shop's front by walking forward.

Backward condition: In the guiding stage, the robot guides people by walking backward. Before guiding, the robot says, "Let me give you some interesting information. Please follow me." As shown in Fig. 7-b, the robot guides people to the shop's front by walking backward.

3) Hypothesis and prediction

We hypothesized that the robot would elicit more spontaneous participation in the backward condition than in the forward condition. Based on this consideration, we made the following prediction:

1. In the backward condition, the number of bystanders will be larger than in the forward condition.

B. Results

1) Visitor Interactions with the Robot

In the forward condition, the robot guided people 19 times. As shown in Fig. 7, almost all addressees stood to the side or obliquely behind the robot while being guided. We can easily understand the behavior of these pedestrians: the robot walks and chats so they naturally follow it to a place where they can listen to it. Therefore, basically to face the addressees, the degree of the robot's face direction was 90 or -90.

On the other hand, almost all addressees stood in front of the robot while being guided in the backward condition. Fig. 8 shows guiding scenes in which people participated in the guidance and followed the robot. The robot starts to guide addressees after greeting and shaking hands; the addressees followed the robot and completely listened to its advertisements (Fig. 8-a). While walking, pedestrians passing through the corridor pay attention to the robot (Figs. 8-b, c). Some stopped around it, indicating that they want to become bystanders and completely listened to the robot's advertisement (Fig. 8-d). The robot guided people 18 times in the backward condition.

Moreover, only in the backward condition, we observed scenes of participant interaction caused by the robot walking backward. Such interactions were not observed in the forward condition. For example, a few addressees beckoned to friends or relatives as they followed the robot. Other addressees left the guidance on the way when pedestrians approached the robot. They seemed to feel embarrassed by following the robot on their own in a face-to-face manner. Bystanders did not leave when an addressee or side-participants faced them during guiding. Bystanders often left when the robot stopped at the shop or finished an explanation about it.

2) Numbers of each role of participants

We defined four categories of participants to investigate the effectiveness of the walking direction. We classified participants into these categories between the start and the end of the guiding part by analyzing recorded videos and estimated position data after the experiments.

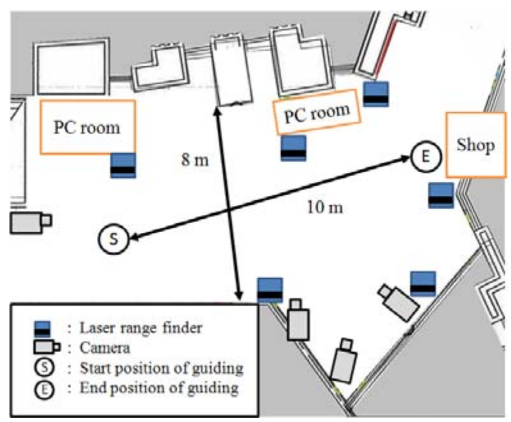

Figure 6. Map of shopping mall

(a) Walking forward (b) Walking backward

Figure 7. Guiding scenes under each condition

(a) (b) (c) (d)

Figure 8. Robot elicits spontaneous participation in its guiding task

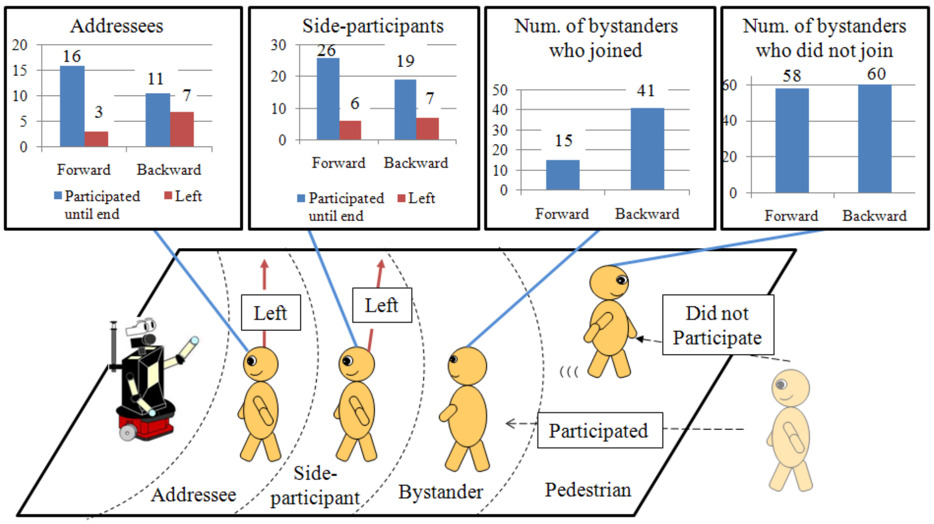

Figure 9. Numbers of each role of participants

Addressees: Visitors who talked to the robot when it was idling.

Side-participants: Visitors who listened to the greeting behavior of the robot with the addressees.

Bystanders: Pedestrians who looked at the robot for more than three seconds while stopping during the guiding stage.

Pedestrians: Visitors who stayed more than 10 seconds in the environment, except people from the above three categories. We did not count visitors sitting on benches as pedestrians.

In a field trial, particularly with such an observational study, it was difficult to interview all of pedestrian and ask whether they listen to the robot. Instead, we tried to establish a simple rule to categorize whether people was likely to listen or not, to be used in the video analysis. As described above, this was accomplished by “three seconds” rule. That is, we classified a person who stopped for more than three seconds with orienting his/her face toward the robot. We decided the three seconds rule from a quick preliminary test. When a robot is speaking, and a person walks to a robot and stop, three seconds of stop was enough for the person to start listening to the robot (e.g. so that the person was able to tell what the robot spoke at the moment).

Next, we describe how we classified the participants. For example, when the robot greets a group of three persons, we counted one addressee (nearest person) and two side-participants. If another group of three persons stopped and looked at the robot for more than three seconds during the guiding stage, we also counted them as bystanders. On the other hand, if one addressee and two side-participants left during the guiding stage, we counted one addressee failure and two side-participant failures. In our definition, side-participants do not become bystanders because we defined visitors who listened to the robot’s greeting behavior with the addressees as side-participants.

In the classification process, first, based on the above rules, a coder coded all 269 participants into four categories by recorded images and the estimated positions of people. In the forward conditions, 19 addressees, 32 side-participants, 15 bystanders, and 58 pedestrians were classified. In the backward conditions, 18 addressees, 26 side-participants, 41 bystanders, and 60 pedestrians were classified. Fig. 9 shows the number of participants assuming each role in each condition.

The first coder also analyzed the guiding success rate with all 95 data sets (all addressees and side-participants) to show the effects of walking direction on addressees and side-participants. A data set was judged successful if his/her behavior was presented from the beginning of the guiding to its end. In the forward condition, 16 addressees and 26 side-participants were classified as “participated until the end.” In the backward conditions, 11 addressees and 19 side-participants were classified as “participated until the end.”

To validate the classification accuracy, a second coder classified a randomly chosen subset of 50 participants. From the two coders’ classifications, Cohen's kappa coefficient [27] was 0.647, indicating that their evaluations were considerably consistent.

The second coder, who also analyzed the guiding success rate, did verification for 18 data sets chosen at random from all 95 (all addressees and side-participants). The kappa statistic between the two coders' measurements was 0.74, indicating that their evaluations were also considerably consistent.

3) Verification of prediction 1

We verified the differences of the bystander numbers between the backward and forward conditions with a Chi-square test that revealed significant differences between the conditions (χ^2 (1) = 7.802, p<.01, φ=.211). This result indicates that the robot's guidance by walking backward encouraged people to listen more than by walking forward. In other words, the result shows that the robot gathered a larger audience by walking backward; prediction 1 was supported.

4) Does walking direction affect addressees?

We believe that the walking direction slightly affected the guiding success rate. In fact, the experimental results show that the ratio of addressee being stayed is higher for the forward condition. We think that the walking forward is common in guidance, so the ratio might be higher than the backward condition. We verified the guiding success rate between the backward and forward conditions with a Chi-square test. The results revealed no significant difference between the conditions for the number of participants (χ^2 (1) = 2.501, p = 0.114, φ=.260). Similarly, there was no significant difference for side-participants, either (χ^2 (1) = 0.551, p=0.458, φ=.097). At the very least, this experimental result did not show a significant difference between the conditions. Note that the Chi-square test result for participants is approaching significance and its effect size is .260, which is above the ignorable level. Thus it is too early to conclude that the direction did not affect the guiding success rate.

V. Modeling Participation Process

A. Analysis of stopped positions of bystanders

Why did walking backward attract more bystanders? Some literature has analyzed how people participate in such interaction. Katagiri *et al*. [28] analyzed participation in relationship to bodily interaction and demonstrated the importance of standing, and Mutlu *et al*. [29] demonstrated the importance of gaze. But both studies addressed interaction where people have already stopped together. To further study how people participate in interaction when they are walking, we analyzed the data from a field experiment to establish a working hypothesis about how people participate in mobile interaction with a robot. Due to our human-tracking system, we were able to measure the data that indicate the stopped positions of bystanders.

Figures 10 and 11 show the stopped positions of bystanders in the forward and backward conditions. Their positions are denoted relative to the robot position, where the x- and y-axes are identical with Fig. 6; the direction from the left to the right is the positive x-axis, and the direction from the bottom to the top is the positive y-axis.

Interestingly, the trend of the stopped positions seems quite different in the forward and backward conditions. In the forward condition, the pedestrians mainly stopped around the side of the robot. In contrast, in the backward condition, the pedestrians stopped not only at its side but also around the front of its body direction.

B. Area of audience and area of passing

The difference of the stopping positions in the two conditions enables us to further speculate on people's behavior to a moving robot. We are interested in finding the *area of audience* (AOA), where pedestrians tend to become members of the audience, and the *area of passing* (AOP), where pedestrians tend to keep passing.

Our analysis suggests that AOA is where the pedestrian can see the robot's face. In Fig. 10 (forward condition), bystanders often stopped at one side of the robot: the direction of its face; the robot's gaze direction was oriented to the addressees who stood at this side of the robot (the direction from the origin to the minus y-axis). A similar trend was observed in the backward condition. In Fig. 11, bystanders often stopped at the direction of the robot's face (the direction from the origin to the minus x-axis). These findings suggest that the direction from which the robot is viewed encourages pedestrians to stop walking and participate in the interaction as bystanders. Therefore, this direction establishes the AOA.

Our analysis also suggests that AOP is where a pedestrian has difficulty stopping. As shown in Figs. 10 and 11, almost all bystanders failed to stop at the direction of the robot's movement (the direction from the origin to plus x-axis). They also did not stop at the area between the robot and addressees. These seem to be areas where pedestrians feel that stopping is inappropriate, even if they wanted to observe the guiding robot and the addressee. If pedestrians want to observe the guiding robot, they will avoid the movement direction of the robot and the addressees. They will also not stand in the area between the robot and addressees. Therefore, we believe these two areas establish the AOP.

From these considerations, we illustrated AOA and AOP in walking forward (Fig. 12) and walking backward (Fig. 13).

C. Confirmation of AOA and AOP with observed data

We confirmed that the experiment data at least support our working hypothesis. As shown in the bottom right of Fig. 14, we defined the AOA area as the overlapping of the view direction and an observable area where other people can view the robot. The observable area's radius is 7.2 m, and the view direction is an isosceles trapezoid. We refer to the "public distance" of proxemics theory [30] to define the sizes of the isosceles trapezoid and the circle.

Similarly, we defined the AOP area as the union of the movement direction of the robot and the addressee and the area between the robot, the addressees, and the side-participants. The area between the robot, the addressees, and the side-participants forms an ellipse that includes them. We also defined the moving direction as an isosceles triangle. We refer to the "social distance" of proxemics theory to define the size of the isosceles triangle.

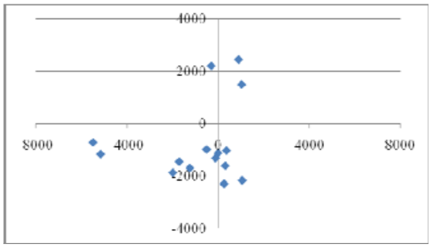

Figure 10. Stop positions of bystanders in forward condition

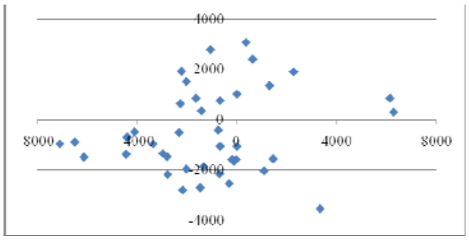

Figure 11. Stop positions of bystanders in backward condition

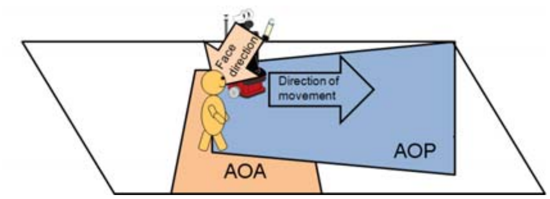

Figure 12. AOA and AOP for walking forward

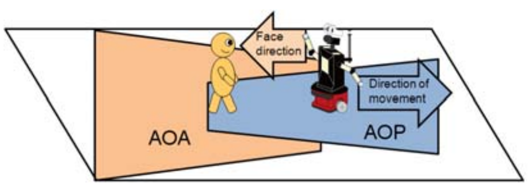

Figure 13. AOA and AOP for backward

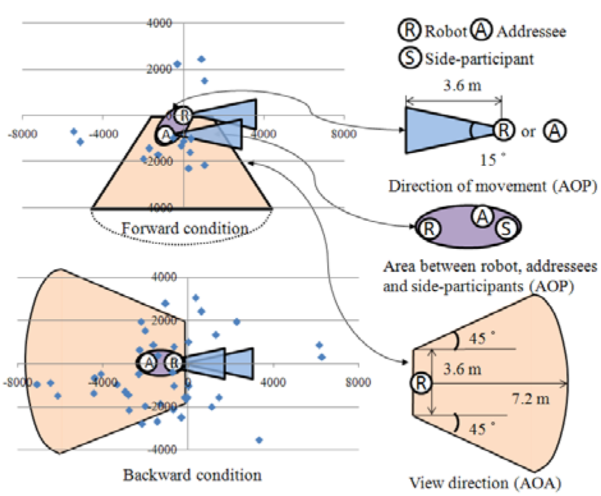

Figure 14. Defined AOA and AOP with stopped positions of bystanders. We calculated the movement direction and the area between robot, addressees, and side-participants from recorded position data.

We measured how the defined AOA and AOP matched the gathered position data. Nine bystanders (60.0%) stopped in the AOA and one (6.7%) stopped in the AOP in the forward condition. In the backward condition, 27 bystanders (65.9%) were included in the AOA and none in the AOP. We believe that the results reasonably fit our working hypothesis about AOA and AOP.

VI. Discussion

1) *Contribution to HRI research*

A main contribution of this work to HRI is that it shows how human-robot interaction changes when the robot moves forward or backward in real environments. The experimental results indicate that when walking backward, the robot's guidance encouraged people to listen more than when walking forward. By analyzing the stopped positions of bystanders, we hypothetically drew two kinds of spaces: AOA and AOP, which affected their stopped positions. The experimental results reveal the validity of the effects of AOA and AOP, whose definitions leave room for a variety of interpretations and whose concepts can be applied to other kinds of tasks.

2) *Why did backward movement attract more pedestrians?*

As shown in the experimental results, backward movements attracted more pedestrians to become bystanders than forward movements. We believe that the AOA direction affects the number of bystanders.

In the forward condition, AOA is established on the side of the robot. Pedestrians who encounter the robot from its opposite side cannot enter the AOA. On the other hand, such pedestrians can enter the AOA in the backward condition because it is established on both sides of the robot.

Moreover, the AOA moved with the robot. In the forward condition, pedestrians who encounter the robot from behind also have difficulty entering the AOA because this area moves forward with the robot. In contrast, such pedestrians easily come into the AOA because they are already in it when they approach the robot. These effects explain why the backward movement encouraged more pedestrians to become bystanders.

3) *Angle of robot's face*

In the experiments, the robot primarily engaged in the interaction with the addressee. Thus, we designed robot's behavior to fit with this context. For example, gaze was allocated in this, so that the robot kept gazing at the addressee. Therefore, there are two differences in the robot: the traveling direction and the angle of the robot's "face" between the forward and backward conditions. Our intention was to differentiate the interaction motion, not the angle of the robot's face toward the addressee. Thus, in the forward condition, the robot and the participant walked side-by-side, and the robot turned its face to the side to maintain eye-contact. We did not allow the robot to look backward while walking forward: it would look odd if a humanoid robot's head was directed backwards. Such odd behavior might provoke strange reactions from people and change the behaviors of pedestrians. In this research, we did not design our experiment to have two-independent motion and face-direction conditions to focus on the effects of the robot's travel direction.

4) Limitation

Since we only conducted tests with a particular robot and in the specific environment of a shopping mall, the generality of the findings is limited. However, such a situation is difficult to avoid in HRI because it is too expensive to use two or more different robots and different environments to generalize findings. We believe that our findings are applicable to other robots with a similar appearance and interaction complexity.

We used the same data to construct the hypothesis and verification of the hypothesis. In the future, we will try to verify the other data set.

VII. CONCLUSION

Our research focused on how a robot elicits spontaneous participation from pedestrians while it guides an addressee. We proposed a model to design behavior inspired by the well-known "participation roles" in conversation structure. We designed a guiding behavior in which the robot walks backward to elicit spontaneous participation. We also developed a robot system that applies this behavior in a real environment.

We conducted a field trial at a shopping mall where the robot was given commercial tasks of guiding and advertising. The robot interacted with a person, guided that person to the front of a shop, and advertised it. The results showed that the robot elicited more spontaneous participation by walking backward than by walking forward. We believe that our findings will lead to the development of robots that act in real environments with commercial tasks; the concepts of AOA and AOP can easily be applied to robots that have wheels and navigation tasks.

ACKNOWLEDGMENTS

We wish to thank the administrative staff at Sumisho Urban Kaihatsu Co., Ltd. for their helpful participation. We also wish to thank Dr. Akimoto, Dr. Miyashita, Mr. Glas, Dr. Satake, and Mr. Kurumizawa for their help.

REFERENCES

[1] E. A. Sisbot, et al., "Navigation in the Presence of Humans," Humanoids 2005, pp. 181-188, 2005.

[2] E. A. Sisbot, et al.," Implementing a Human-Aware Robot System," IEEE International Symposium on Robot and Human Interactive Communication 2006, 2006.

[3] R. Simmons, et al., "Grace: An autonomous robot for the AAAI robot challenge," AI Magazine, vol. 24, no. 2, pp. 51-72, 2003.

[4] R. Gockley, J. Forlizzi, R. Simmons, "Natural Person-Following Behavior for Social Robots," *HRI2007*, pp. 17-24, 2007.

[5] K. Dautenhahn, et al., "How may I serve you?: a robot companion approaching a seated person in a helping context," In Proc. Int. Conf. on Human-robot interaction (HRI2006), pp. 172–179, 2006.

[6] M. L. Walters, et al., "Human Approach Distances to a Mechanical-Looking Robot with Different Robot Voice Styles," IEEE Int. Symposium on Robot and Human Interactive Communication (Ro-Man 2008), pp. 707-712, 2008.

[7] R. Siegwart, et al., "Robox at Expo.02: A Large Scale Installation of Personal Robots," *Robotics and Autonomous Systems*, 42(3), pp. 203-222, 2003.

[8] S. Thrun, et al., "Minerva: A second-generation museum tour-guide robot," *ICRA 1999*, pp. 1999–2005.

[9] W. Burgard, et al., "The interactive museum tour-guide robot," *Proc. of National Conference on Artificial Intelligence,* pp. 11-18, 1998.

[10] M. Shiomi, et al., "Interactive Humanoid Robots for a Science Museum," *HRI2006,* pp. 305-312, 2006.

[11] T. Kanda, et al., "Who will be the customer?: A social robot that anticipates people's behavior from their trajectories," *UbiComp2008*, 2008.

[12] M. Shiomi, et al., "A Semi-autonomous Communication Robot-A Field Trial at a Train Station-," *HRI2008*, pp. 303-310, 2008.

[13] M. Finke, et al., "Hey, I'm over here - How can a robot attract people's attention," IEEE International Workshop on Robot and Human Communication, 2005.

[14] N. Bergstrőm, et al. "Modeling of Natural Human-Robot Encounters, "IEEE/RSJ International Conference on Intelligent Robots and Systems, 2008.

[15] Michalowski, M.P., Sabanovic, S., and Simmons, R., "A Spatial Model of Engagement for a Social Robot," Proceedings of AMC 2006.

[16] K. Hayashi, et al., "Humanoid robots as a passive-social medium-a field experiment at a train station-," *HRI2007*, pp. 137-144, 2007.

[17] S. Satake, T. Kanda, D. F. Glas, M. Imai, H. Ishiguro, and N. Hagita, "How to Approach Humans?-Strategies for Social Robots to Initiate Interaction," *HRI2009,* pp. 109-116, 2009.

[18] D. Glas, et al., "Laser Tracking of Human Body Motion Using Adaptive Shape Modeling," *In Proc. Int. Conf. Intelligent Robots and Systems*, pp. 602-608. 2007.

[19] E. Goffman, "Forms of Talk," University of Pennsylvania Press, 1981.

[20] H. H. Clark, , "Using Language," Cambridge University Press, 1996.

[21] S. Milgram, I. Bickman, and L. Berkowitz, "Note on the drawing power of crowds of different sizes," Journal of Personality and Social Psychology, 13, 79-82, 1969.

[22] H. Blummer, "Collective behavior," In A. M. Lee (Ed.), New outline of the principles of sociology. New York: Barnes & Noble. 1946.

[23] R. W. Brown, "Mass phenomena," In G. Lindzey (Ed.), Handbook of social psychology (Vol. 2, pp. 833-876). Cambridge, MA: Addison-Wesley. 1954.

[24] S. Nishio, et al., "Robotic Platforms Structuring Information on People and Environment," IEEE/RSJ International Conference on Intelligent Robots and Systems, 2008.

[25] A. Scheidig, et al., "Generating Persons Movement Trajectories on a Mobile Robot," IEEE International Symposium on Robot and Human Interactive Communication, 2006.

[26] T Kanda.., Ishiguro, H., Imai, M., and Ono, T., "Development and Evaluation of Interactive Humanoid Robots," Proceedings of the IEEE, Vol. 92, No. 11, pp. 1839-1850, 2004.

[27] J. Carletta.: "Assessing agreement on classification tasks: the kappa statistic," Computational Linguistics, Vol. 22(2), 249- 254, 1996

[28] Y. Katagiri,., M. Bono, , and N. Suzuki, "Conversational Inverse Information for Context-based Retrieval of Personal Experiences," Proceedings of the International Workshop on Conversational Informatics, pp. 1-6, 2005.

[29] B. Mutlu et al "Footing In Human-Robot Conversations: How Robots Might Shape Participant Roles Using Gaze Cues," *(HRI2009)*, pp. 61-68, 2009.

[30] E. T. Hall, "The Hidden Dimension," Anchor Books, 1990.