Clarification of the people the robot is talking to using projection

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Abstract: When a mobile robot provides various services in daily life spaces, it is important for the robot to speak naturally to people. However, non-humanoid robots have difficulty using nonverbal information such as gestures and body orientation like humans do, and especially in environments with multiple people, it is difficult to know who is speaking to whom, causing problems such as ignoring the other person or making the surrounding people feel lost or awkward. Here, this paper proposes a method for a robot that does not have a human-like body to present the area where the robot interacts using projection, and a method for clarifying who is speaking to whom. In the experiment, when the robot speaks to some people in an environment with multiple people and guides them, we verified whether the information is accurately conveyed to the people who speak to the robot, compared to the conventional method in which the robot turns toward the other person. As a result, all participants were correctly guided by the proposed method, whereas some participants were incorrectly guided by the method using the robot's orientation. The questionnaire evaluation confirmed that the proposed method has a good tendency in terms of comfort.

Keywords: Augmented reality, Guide robot, Human-robot interaction, Interaction area, Projection robot

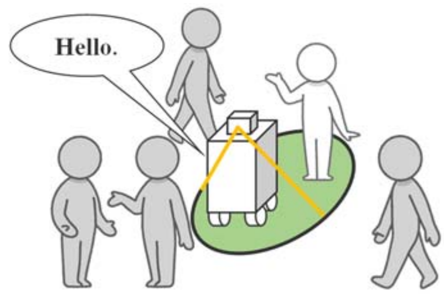
1. INTRODUCTION

Mobile robots are expected to provide many kinds of services in daily living spaces. For example, the tasks of mobile robots include guiding at museums [1], providing information in shopping malls [2], and guiding at airports [3]. When mobile robots offer services to people, one crucial function is to approach and talk to people naturally. In recent years, research has been conducted on methods for mobile robots to initiate interactions with people [4].

When people approach and talk to others, they use verbal information such as voice and nonverbal information such as eye contact, body orientation, and gestures. Such nonverbal communication plays an essential role in interaction by naturally conveying the speaker's emotions, the timing of utterances, and the interaction partner. Learning from this human behavior, the behavior of mobile robots has been studied when they talk to people [5]. For example, studies have focused on the direction and distance to people [6], the direction of the robot's body and gaze [7], the gestures of human-like robots [8], and the appearance of robots and comparison of the modalities they use [9]. However, non-humanoid robots have the problem of not being able to communicate in a manner that mimics human methods. In such cases, the non-humanoid robot has a problem in that the person it intends to talk to is unclear, so the robot's speech is not conveyed to the person (Fig. 1(a)). Other people around the person may not know whether they are being told to, which may lead to uncomfortable impressions such as hesitation, anxiety, and awkwardness.

To solve this problem, we propose a method in which a non-humanoid robot initiates interaction with a person by using a projector (Fig. 1(b)). The advantages of using projection for robots include (1) sharing information with many people around them and (2) displaying information at arbitrary locations. Focusing on the advantages of such projection, research has been conducted on mobile robots

(a) Surrounding people are confused as to who the robot is interacting with



(b) Proposed method uses projection to make it easier to understand who the robot is talking to

Fig.1 Problems when non-humanoid robots talk to

equipped with projectors [10]. Lee [11] presented the robot's future path to the people around it by projecting arrows from the mobile robot. Matsumaru et al. [12] and Wengfeld et al. [13] used projection to communicate the robot's behavioral intentions to the people around it. Tamai et al. [14] used a combination of a mobile robot and projection to guide a person around the robot. Maeyama et al. [15] proposed an interface for interaction by manipulating projected content with the feet. In contrast, we use projection to clarify who the robot is trying to interact with. Focusing on the fact that projection can share information with many people around it and display information at arbitrary locations, we propose a method for non-humanoid robots to initiate natural conversations with people.

2. PROPOSED METHOD

2.1 Problem definition

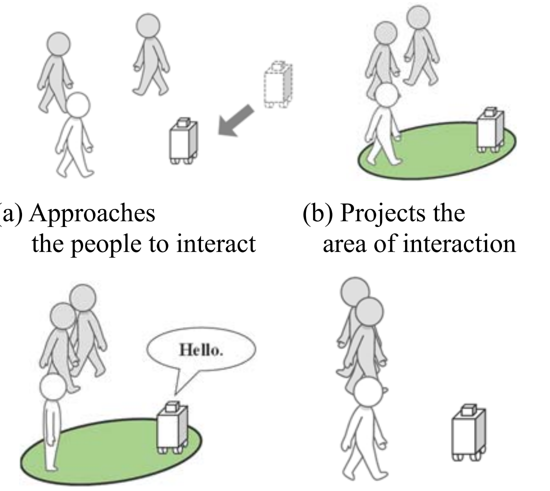
When robots are trying to communicate with people, it is necessary to clarify with whom they are trying to interact. Fig. 2 shows an example of a robot trying to give instructions to people in line. In such a situation, it is difficult for a group of people in line to understand whether the robot, which does not have a human-like body, is talking to them or talking to other people. Such ambiguous robot instructions may cause discomfort, such as hesitation and awkwardness, because the people are unclear whether the robot talks to them and do not know whether they should perform the requested action. In this section, we propose a method for non-humanoid robots to accurately communicate with the people they are talking to without using physical gestures or facial orientation.

2.2 Presentation of the range of robot interaction using projection

We propose a method for robots to present the range of their current interaction in the real world using projection. Specifically, the robot projects a shape on the ground that covers the robot and the people the robot interacts with. Fig. 3 shows a non-humanoid mobile robot approaching people and using projection to show the robot's region before speaking to them. We expect that the people in the region will intuitively understand whether or not the robot is currently interacting with them.Similarly, people outside the region are expected to understand that the robot does not try to interact with them. The required action becomes clearer by explicitly presenting the people that the robot is talking to, and discomfort can be reduced.

We illustrate our proposed method in a situation where the robot approaches the person to talk. In conventional methods, the robot talks after approaching the people at an appropriate distance. Since it is not clear to nearby people whether the robot is speaking to them or not, they may ignore the robot's speech, and the robot may not initiate interactions successfully. To cope with the problem, we propose to project the interaction range just before the robot talks to them. Once the robot approaches the social distance (Fig. 3(a)), the robot projects an area that fully surrounds the people and the robot (Fig. 3(b)). After projecting the range of interaction, the robot talks (Fig. 3(c)). The robot continues to project during the interaction, making it clear to whom the speech is addressed and to whom it is not addressed. After the conversation is over, the projection of the interaction range can be ended (Fig. 3(d)) to convey the end of the interaction with the robot, further facilitating communication. The advantage of this method is that it

Fig.2 Possible problems



(a) Approaches the people to interact
(b) Projects the area of interaction
(c) Talks to the people
(d) Turns off projection and ends interaction

Fig.3 Proposed method. The non-human mobile robot approaches people and uses projection to make it easier to understand the person with whom the robot interacts before speaking to them.

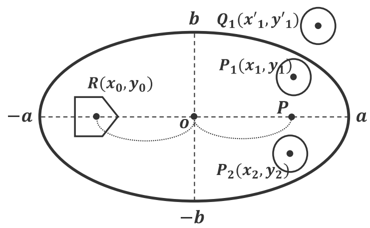


Fig.4 Shape of projected interaction range

specifies the range of interactions in the same way when talking to multiple specific people.

2.3 Area projected on the ground during interaction

The proposed method projects a filled ellipse on the ground to indicate the region of the robot's interaction. The ellipse covering the area containing the robot and the people it talks to is determined as follows. Fig. 4 shows an example where the robot at position R (x_0, y_0), two target people at P_1 (x_1, y_1) and P_2 (x_2, y_2), and one non-target person at Q_1 (x'_1, y'_1). Let P be the center position of the people to be interacted with, the line passing through RP be the x-axis, and the midpoint of both be the origin O. An ellipse with a center at O, and a major axis at RP in equation (1) is projected:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}\leq 1, \quad (1)$$

where a and b are chosen to satisfy equations (2) and (3), n and m are the number of interaction targets and non-interaction targets, respectively, and $n = 2$ and $m = 1$ in Fig. 4.

$$\frac{{x_k}^2}{a^2}+\frac{{y_k}^2}{b^2}\leq 1, \qquad k = 0, 1, 2, \dots, n \quad (2)$$

$$\frac{{x'_k}^2}{a^2}+\frac{{y'_k}^2}{b^2}> 1, \qquad k = 1, 2, \dots, m \quad (3)$$

The ellipse is drawn so that the robot and the person with whom the robot interacts are inside the ellipse and the other people are outside. When there are many people around the robot, it may not be possible to draw an ellipse that exactly satisfies (2) and (3). We believe that this problem can be solved by projecting a more flexible shape, but this is our future work.

3. EXPERIMENTS

To confirm the effectiveness of the proposed method in Section 2, we evaluated it in a task in which the robot asks people in line to move. Currently, stores and facilities may limit the number of people who can enter, considering the impact of infectious diseases. In such a situation, the robot instructed the people in a line to move, in order, to the required number of people. Fig. 5 shows the mobile robot used in this experiment. This non-humanoid robot instructed part of people in a line to move by voice, and we evaluated the understandability of the robot's instructions. In this preliminary experiment, we used a projector fixed in the environment to confirm the effect of using projection when the robot initiates communication with people.

3.1 Conditions

We compared the projection condition, in which the people the robot is talking to are presented using projection, with the orientation condition, in which the people the robot is talking to are presented using body orientation. Under each condition, we examined the case where the robot asks one person to move and the case where the robot asks two people to move. Fig. 6 summarizes the experimental conditions. The robot asked one or two persons to move in a situation where three persons were in a row. We also compared the clarity of the instructions in situations where the robot instructs one person (conditions A and C) or two people (conditions B and D) at the front of the line to move.

Of the three persons receiving instructions from the robot, the center person is the experiment participant, and the other two are the experimenters who always follow the robot's instructions correctly. Depending on the experimental conditions, the central experimental participant may or may not be the target of the robot's interaction.

Fig.5 Cart robot used in the experiment

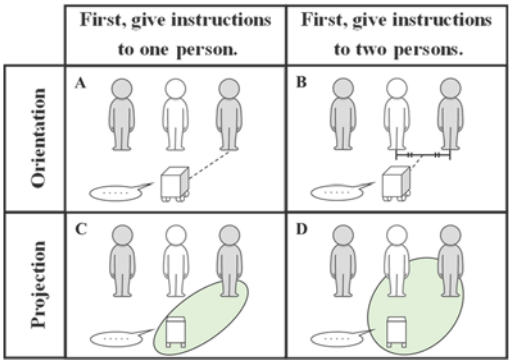


Fig.6 Experimental conditions

In the orientation condition (A and B), when the robot told to one person, it faced the direction of that person; when it told to two people, it faced the direction of their midpoint. In the projection condition (C and D), the robot presented the people it was talking to based on the method using projection proposed in section 2. The robot remained facing forward and did not change its orientation. The ellipses shown in Fig. 6 were projected to surround the target people and the robot. So in the orientation condition, the participant in the center of the experiment would have difficulty judging whether the robot was giving instructions to one or two participants and understanding the robot's instructions. On the other hand, in the projection condition, the participants in the experiment are expected to accurately recognize the person to whom the robot talks and understand the instructions without hesitation.

3.3 Environment

Fig. 7 shows the experimental environment. The robot (T-frog Project i-Cart mini) was placed facing the line of experimental participants, and a projector (ASUS ZenBeam S2) was installed at the height of 2.6 m to project the area in front of the robot. Since the robot's position was fixed in this experiment, the projector was placed at a slightly higher placement in the environment to project a wider area with the projector. The robot was connected to a speaker (SONY SRS-X55) and gave voice instructions to the experimental participant. The experimental participant stood 1.0 m from the robot and received voice instructions from the robot.

3.4 Measurements

We observed the behavior of the experimental participants and recorded the actions they took in response to the robot's instructions.

Participants completed a questionnaire after each experiment. They rated on a seven-point scale whether they found it easy to understand the people to whom the robot was talking (Q1) and whether they were comfortable with the guidance provided by the robot (Q2).

3.5 Participants

Six participants (two women and four men, whose average age was 21.8) participated in our experiment. All procedures used in this research were approved by the Ethical Committee of Hiroshima City University. Written, informed consent was obtained from all the participants in our study.

3.6 Procedure

First, participants were given an overview of the experimental procedures and agreed to participate in the experiment. Participants were told that the robot would use projection or orientation to give instructions and were told that the instructions would be "Please proceed to the left toward us." Practice participants were also briefed on the frontal orientation of the robot. Before starting the experiment, the three people were aligned at a distance of 1 m so that the participant was always in the center. In all conditions, people lined up in the same order before the robot instructed them.

At the beginning of the experiment, the robot said, "Are all participants present?" The robot then gave voice guidance according to the condition to the first person or two, saying, "Please turn to the left." Next, similar instructions were given to the rest of the people in front of the robot, and finally, all three people in line moved. After all the people had moved, the experimenter signaled the people to return to their original positions, and the participants completed the questionnaire. Fig. 8 shows the robot's behavior under each condition. The robot asked one or two persons on the left in the figure to move. The upper A and B conditions used the orientation of the robot, while the lower C and D conditions used the projection to indicate the range of interaction. The conditions A to D were presented in a pseudo-randomized order.

4. RESULTS

Table 1 shows the behavior of the experimental participants in response to the robot's instructions. In the projection condition, all participants understood who the robot told to and correctly followed the guidance. In the orientation condition, the robot did not convey instructions to the intended interaction target, and some participants behaved differently from the robot's guidance.

Participants sometimes showed signs of confusion even when they acted as instructed by the robot. Fig. 9 shows the results of the questionnaire survey. Regarding the ease of understanding the people the robot told to

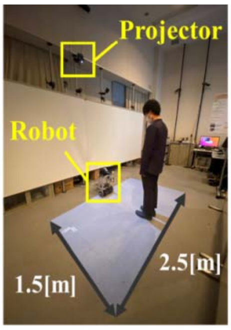
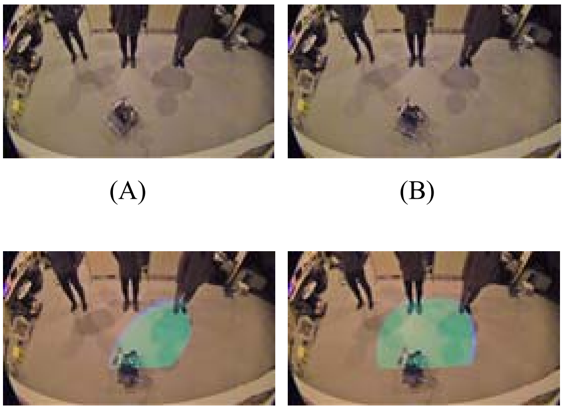


Fig.7 Experimental environment



(A) (B)

(C) (D)

Fig.8 Behavior under each condition

Table 1 Number of times the experimental participant correctly understood the robot's instructions.

	Orientation		Projection	
	A	B	C	D
Correct	5	4	6	6
Incorrect	1	2	0	0

(Q1), many participants tended to respond that the projection condition (C, D) was easier to understand than orientation condition (A, B) (Fig. 9 (a)). Regarding the comfort level of the robot's guidance (Q2), many participants also tended to indicate that they were more comfortable in the projection condition than the orientation condition (Fig. 9 (b)).

In the orientation condition, participants commented that it was difficult to understand the robot's instructions. Participants commented, "It was not clear when I should follow the instructions." "I was not sure if I was included in the instructions." "I was confused"

On the other hand, in the projection condition, participants commented that it was easy to understand whom the robot was addressing and that the message was reliably conveyed. Participants commented, "It was easy to understand to whom I was talking." "It was easy to know when I was talking to you." "The message was conveyed clearly."

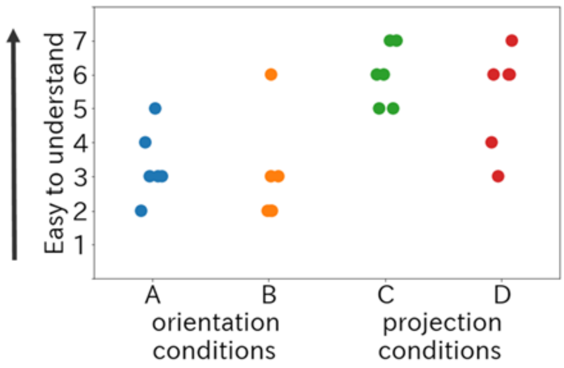
5. DISCUSSION AND CONCLUSION

The contribution of this paper is to propose a method of presenting the range of interactions using projection for non-humanoid robots. When a robot initiates interactions with people, it is important to let them know that the robot is talking to them. The proposed method can easily indicate them by creating a projection on the ground that encompasses both the people and the robot.

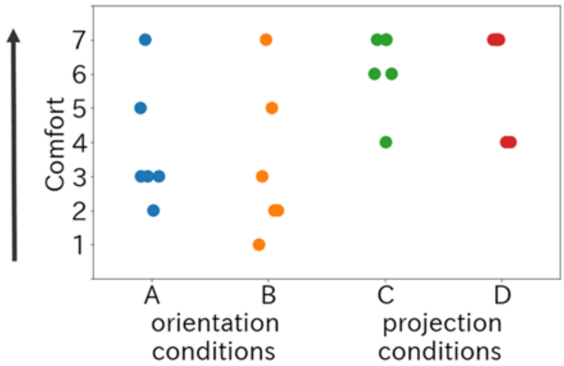
We conducted a preliminary experiment in which a robot guided people, and verified the understandability of the person to whom the robot told. Compared to the method in which the robot shows who it is talking to by the body orientation, the proposed method using projection tended to make it easier to understand when the robot is guiding some people among several people. The proposed method also tended to perform better in terms of comfortability. Based on these results, it is possible that the method based on the robot's orientation is not suitable when the robot wants to accurately communicate instructions to the target person because it is difficult to convey who that person is. Especially in the case of a dense group of people, as in this experiment, the distinction between the participants became ambiguous, making it difficult for the participants to distinguish to whom the robot was talking. It is expected that humanoid robots can use face orientation and gestures to shows who it is talking to in a comprehensible manner. However, the proposed method is effective for non-humanoid robots.

One interesting comment from the experiment participants was that the projection not only made it easier to understand who was speaking to them but also made it easier to understand when they were speaking. Humanoid robots can initiate natural conversations by using gestures such as face orientation and eye contact to show them when to start talking. On the other hand, for non-humanoid robots, using projection to convey the range of interaction may also be effective in communicating the timing.

The limitation of this paper is the limited number of participants in the experiment, which only confirmed the potential of the proposed method. Additionally, the projector was fixed to the environment, and the robot did not move. Therefore, in the next step, we would like to consider how to combine robot movement and projection optimally. We would like to evaluate the proposed method in complex environments where obstacles and pedestrians are present.



(a) Ease of understanding the people the robot told



(b) Comfort with the guidance provided by the robot

Fig.9 Questionnaire results

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