A Method for Guiding a Person Combining Robot Movement and Projection*

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***Abstract*— This paper proposes a new method to guide a person along with a route when a mobile robot explains an exhibition. In previous work, there were problems that people overtake the robot and go out of the guide route, and that people move to positions that interferes with the movement of the robot. In response to these problems, a conventional solution is to frequently instruct people to move by using voice, displays, etc., and it was not a comfortable for people who are guided. In this paper, we focus on a mobile robot with a projection function and propose a method of controlling human positions without explicit instructions by combining movement and projection of a robot. We introduce three basic guiding behaviors combining projection and movement, each controlling a person and a robot into different positional relationship according to the situation of guiding. Experiments of basic guiding behaviors showed that both the existence of the robot and the position of the projected image are combined to affect the movement of the guided person. The result indicates that by selecting appropriate guide behavior according to the situation of guiding, the robot can guide a person effectively while controlling the position of the person.**

I. INTRODUCTION

In recent years, many mobile robots have been developed, and robots are being used not only in factories but also in daily living environments. With advances in robot navigation technology that moving around us, guidance has been drawing attention as an important task of mobile robots. For example, robots that provide explanations and guidance of exhibits at museums [1][2] have been proposed, and demonstration experiments of guidance at Haneda airport [3] and Smithsonian museum [4] have been conducted. Mobile robots are expected to be along with us and guide us smoothly at various places.

When we guide some kind facilities to guests along a route, while guiding them to the destination, explanations are given on items and exhibits on the way. For those who guide, it is necessary to make the guests follow and draw attention to the exhibits. In many studies so far, it has been shown that mobile robots have the ability to make people follow. However, there were problems that people overtook the robot and went out of the guide route, and that people moved to positions that interferes with the movement of the robot.

To cope with these problems, in conventional methods it is common for the robot to explicitly instruct the people to move using voice such as "Please do not go there" or "Please wait a while". However, the guide by such explicit instructions gives us unpleasant impression when instructions are issued many times. In order to make the guide by the robot comfortable, a technique for naturally controlling positions of guided people according to the situation of guiding.

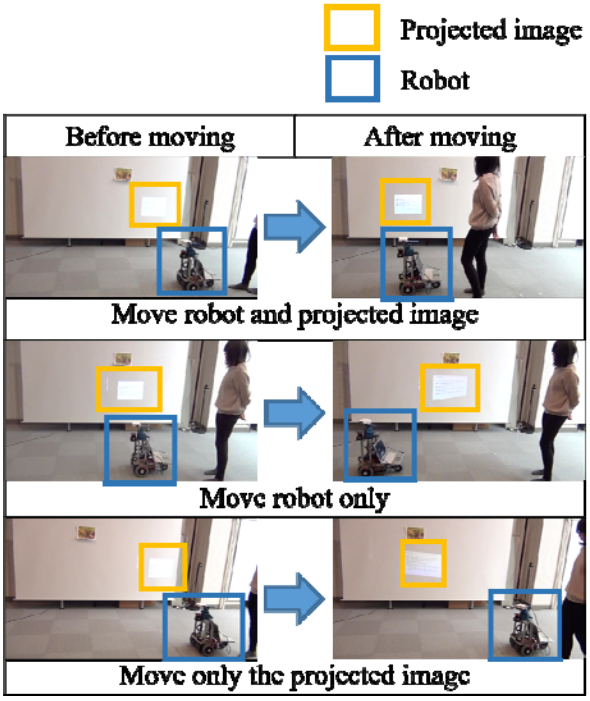

Figure 1. A projection robot that guides a person. By combining movement and projection behavior, the robot can induce different movements of the person.

In recent years, mobile robots having information projection capability have been proposed [5] [6] and commercialized [7]. Mobile projection robots can present information in an easy-to-understand manner, such as projecting arrows to explain the direction and projecting advertisements on the wall. As an essential function of mobile projection robots, human behavior can be influenced not only by the movement of robots but also by the projection. For example, we tend to move closer when an explanation is projected, and we tend not to cross the space between the robot and the projected contents. By taking advantage of such influences on the behavior of people given by these projections, it is possible to realize comfortable guidance in which people are naturally guided without explicit instruction.

In this paper, we propose a method of guiding a person by a combination of two kinds of behaviors of mobile projection robots: movement and projection. To guide while explaining exhibits to a person, we define three basic guiding behaviors combining movement and projection. With this combination

* This work was supported by Hiroshima City University Grant for Research Preparation.

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of guiding behaviors, we propose a method of guiding a person without instructing movement explicitly using voice or gesture.

II. Related Work

A. Guide Robots

As a pioneering work on robots to guide people, Tachi and Komoriya [8] proposed a guide dog robot for the visually impaired. Burgard et al. [1] and Thrun et al. [2] realized the robot which guides the museum for the first time. Kim et al. [9] propose a guide robot with a decision making process that selects appropriate movement according to the situation. Faber et al. [10] proposed a humanoid guide robot that interacts with guests using multimodal communication. Research on these guide robots made use of the tendency that people are interested in and follow guide robots. The problem is that the guide robots cannot control the position of the surrounding people and sometimes people tend to gather too close to the robot [11].

In the field of evacuation guidance task, several studies have been reported to implicitly guide people without giving explicit instruction by utilizing the existence and movement of robots affecting human behavior. Okada and Ando [12] simulated the movement of the crowd based on a vector field model and proposed a method for arranging the inducers so that evacuation becomes efficient. Jiang et al. [13] proposed a method to guide people implicitly in the evacuation by the movement of the robot. Tang et al. [14] proposed a robot control method that efficiently guides people in evacuation using a panic propagation model and the social force model. These studies utilize the fact that the movement of people is implicitly affected by the existence and movement of inducers and robots.

In this paper, in contrast to these work, we focus on a new kind of guide method by using a mobile projection robot and investigate guiding behaviors that combine movement and projection of the projection robot.

B. Projection Robots

Control methods of projection robots have been reported. Shiotani et al. [5] proposed a navigation method based on constraint functions, considering the distance to people, projection quality, and other factors. The proposed algorithm generated a path that moves without going too close to people while performing a clear projection. Donner et al. [15] proposed a robot to guide museums using projection function for the interactive and entertaining presentation of information. Tatsumoto et al. [6] proposed a navigation method to continue projection while the robot was avoiding people and obstacles based on environmental information structuring that placed markers at projectable positions in the environment. These studies proposed navigation methods during projection as an essential function of projection robots.

Mobile robots that present their behavior to the surrounding people using projection have been proposed. Matsumaru et al. [16] presented preliminary notice information on the future behavior of the robot using projection. Watanabe et al. [17] projected the future travel path on the road surface by projection during autonomous navigation of personal mobility. These studies proposed to convey the movement of the robot to the surrounding people by projection for comfortably coexisting the robot's behavior without worrying about it.

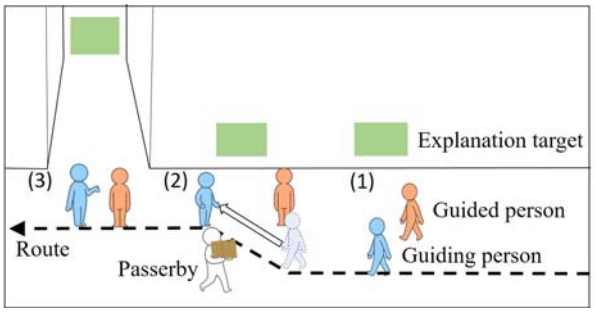


Figure 2. Guidance consists of a combination of several types of movements and explanations. For example, (1) explanation while traveling together. (2) the guiding person moves first. (3) explanation of an exhibit away from the route.

These work does not deal with the influence on movement of a person by projection behavior. In this paper, we investigate the changes in movement of a person by combining movement and projection, and propose to control positions of a person.

III. Guide Based on a Combination of Movement and Projection

A. Essential Behavior for Guiding a Person

When introducing people who visit the exhibition or company for the first time, we will guide people to the destination along the prescribed route while explaining the exhibits and facilities. In this paper, we focus on such guiding tasks (Fig. 2). For a person who guides people, it is necessary to be careful that guided people do not go to unintended places.

For example, the guiding person needs to control the position of the guided person when stopping at the exhibition or explaining it while traveling together (Fig. 2 (1)), when temporarily moving to avoid other pedestrians while keeping the guided person at the present place (Fig. 2 (2)), and when explaining exhibits away from the route while letting the guided people stay on the route (Fig. 2 (3)).

From the viewpoint of people's behavior related to guiding, in order to guide people, the following three behaviors are essential.

1. Make the people to be guided follow without leaving.
2. Make the people to be guided stay.
3. Do not let people get out of the route.

A guiding person carries out a guide of a person by selecting appropriate behavior from these three behaviors, at the time of leading, avoiding collision, and explaining far exhibits.

B. Guide a Person by Robots without Explicit Instruction

In many studies of guide robots, people tend to approach and follow the mobile guide robots. On the other hand, a phenomenon has also been reported that people tend to gather too close to the robot [11]. It is a problem that robots cannot sufficiently control the surrounding people. When the robot

guides a person, it is a problem when a person closes the way the robot goes, or a person moves first and goes to a person different from the route. Also, to avoid collision to other pedestrians, sometimes only the guiding person often needs to temporarily move. In such a case, to control the movement of people, it is common to give an instruction such as "Please do not go there" or "Please wait a while". However, receiving such instructions repeatedly is not generally comfortable for us.

On the other hand, in the area of evacuation guidance, many studies were conducted to implicitly guide people without explicit instruction [12] [13] [14]. It has been shown that the presence or movement of a robot can affect the movement of people without explicit instructions.

In the area of guiding, we believe that by combining the movement and projection of the projection robot positions of people can be controlled with fewer explicit instruction. In order to clearly see the projected information, a person tends to move to a position where the projected image is easy to see. Focusing on this property, by combining the two functions of robot movement and projection, it is a promising approach to guide a person implicitly with fewer explicit instructions of movement.

C. Guide a Person by Robots by Combining Movement and Projection

In order to realize the three basic guiding behaviors in III-A, we propose three basic guiding behaviors by combining movement and projection of a robot.

For performing three basic guiding behaviors, we define a combination of movement of the robot and movement of the projected image as follows (Fig. 3):

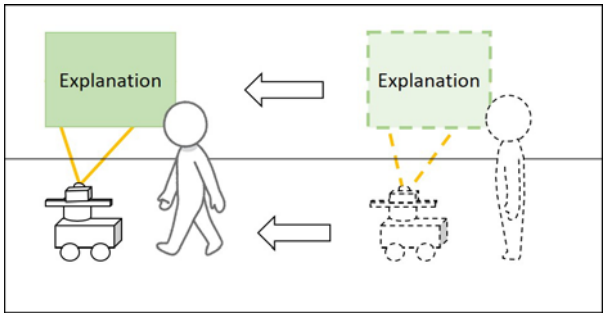
1. Move both the robot and the projected image.
2. Move only the robot and stop the projected image.
3. Stop the robot and move only the projected image.

Regarding behavior 1, when guided by the robot, the person is expected to follow the robot without explicit movement instruction. It is reported that people follow a robot without explicit movement instruction in guidance tasks. Therefore, in basic behavior 1, the person and the robot are expected to move together.

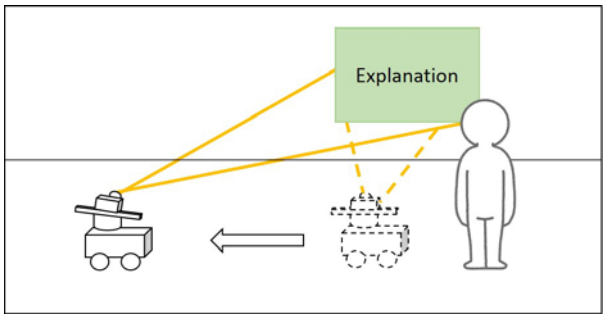
Regarding behavior 2, there is a tendency for a person to pay attention to explanation in projection images. While the robot is moving, by rotating the projector so that the projected image is stationary, the person receiving the guidance is expected to stay and watch the projected contents. Therefore, in basic behavior 2, the person is expected to stay, whereas the robot moves.

Regarding behavior3, to explain far exhibits that are not in the guide route, the robot rotates the projector and moves the projected position while staying at the current place. The person may want to go close to the projected image but is expected to stay because the robot is in front of the person. Therefore, basic behavior 3, the person is expected to stay, whereas the projection image moves.

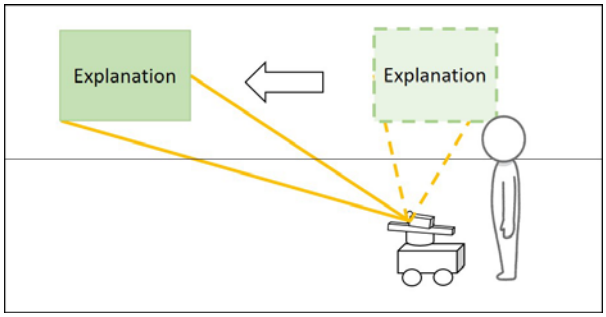
In this paper, we propose a guidance method using three behaviors that combine movement and projection of a robot.



a) Move both the robot and the projected image to make the people follow without leaving.



b) Move only the robot and stop the projected image to make the people stay.



c) Stop the robot and move only the projected image not let people get out of the route.

Figure 3. Basic guiding behaviors for a projection robot.

IV. EXPERIMENTS

In order to verify the movement of the person during the proposed guidance behavior, guide experiments using a projection robot were conducted.

A. Participants

In total 12 subjects participated in the experiment (1 male and 11 female, aged 21-22 years). All procedures used in this research were approved by the Ethical Committee of Hiroshima City University.

B. Environments

The experiment was carried out in a corridor of about three meters in width as shown in Fig. 4. On the right side of the passage in the robot traveling direction, screens are placed on the wall. Pictures of four kinds of animals are affixed to the

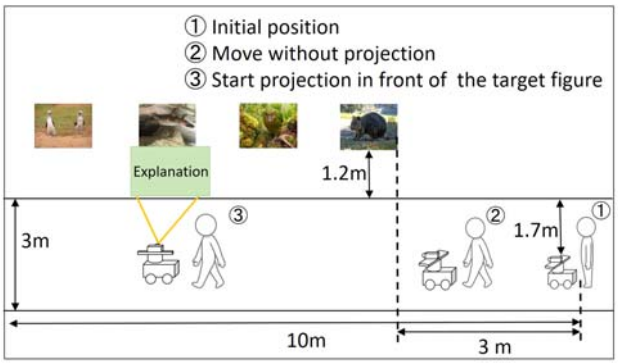


Figure 4. Environments

screen at a height of 1.2 m from the floor as exhibits for the robot to explain to the subjects. The projector projects explanations under the pictures (Fig. 5). Fig. 6 shows the robot used in the experiment, which is equipped with a pan-tilt actuator on a small mobile robot and is configured to control the projecting direction of the projector. The robot has a range sensor (Hokuyo Electric UTM-30LX) which measures the distance to surrounding objects and estimates its position by comparing with a map of the environment acquired in advance. The robot moves autonomously along a predetermined guide route. Two range sensor are installed on the wall to measure the position of the subjects.

C. Evaluation

Behavior of subjects was measured by range sensors in the environment. The movement of the subjects when the robot moved or projected was evaluated.

In order to confirm whether the subjects viewed the projected image, the subjects answered a quiz of selecting one of three choices for each guidance experiment of one condition. Then the subjects freely described the impression of the robot's behavior.

D. Conditions

The guide behaviors performed by the robot during the experiment are shown in Table I, which shows the combination of the movement of the robot and the projected image. The conditions A, B, and C correspond to basic guiding behaviors 1, 2, and 3 in III-C. The movement of the subjects was investigated under a total of four conditions including the additional condition D of displaying explanation contents on a display on the robot.

E. Procedure

After subjects received an explanation of the contents of the experiment, the subjects saw the movement and projection of the robot in advance to get used to the robot. The subjects were explained that the robot would project an explanation of one of the four pictures on the wall from the projector on the robot. The subjects were explained that the experiment was done four times and that each time an experiment was finished they would be asked to fill in the questionnaire.

Then the subjects were asked to see the explanation by the robot. They were not instructed to follow the robot. Firstly the robot moved straight a distance of about three to nine meters

TABLE I. EXPERIMENTAL CONDITIONS

condition	*Movement of the robot*	*Movement of the projected image*
A	✓	✓
B	✓	×
C	×	✓
D	✓	(Shown in the display)

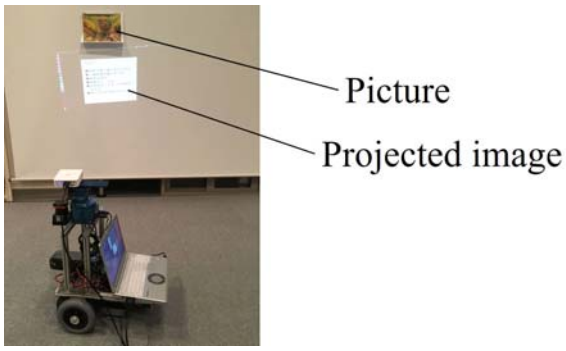


Figure 5. State of projection. The robot projects an explanation below the picture.

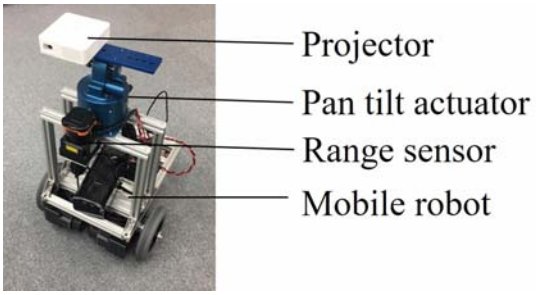


Figure 6. Projection robot used in the experiment. The projector is controlled independently of the movement of the robot using a pan-tilt actuator.

Figure 7. An example of the picture on the wall and the projected description

to the front of the target picture without projection. The speed of the robot was set to 0.6 m/s. The robot always kept a distance of about 1.7 meters from the screen. After the robot arrived in front of the explanation picture, the robot stopped and began to project an explanation under the picture. The

projected content was a still image which explains the animal's name and habitat with several lines of text (Figs. 5 and 7).

Subjects received a guide under four conditions in Table I, and after each guide was finished they filled the questionnaire. The order of the experimental conditions other than the condition 4 was counter-balanced. The experiment under condition 4 was done last.

V. Results

When the robot started guiding from the initial position without projection, all subjects followed the robot. The robot continued to move along the corridor and conducted guidance behaviors under the four conditions shown in Table I. Figs. 8 - 11 show the behavior of subjects under each condition. As a criterion to judge the behavior of the subject as follow-up and staying, the movement of one or two steps and the movement in the direction orthogonal to the direction of the corridor were regarded as staying.

Figs. 8 and 9 indicate the behavior of subjects under conditions A and B. Regarding condition A, when both the robot and the projected image moved, 11 people followed the robot and 1 did not follow the robot. Many subjects showed behaviors following the robot to receive guidance (Fig. 8).

Regarding condition B, the projected image stopped and only the robot moved. Two people followed the robot, 10 people did not follow up. Many subjects did not follow the movement of the robot and saw the projected explanation (Fig. 9).

Regarding condition C, the robot stopped and only the projected image moved. Fig. 10 shows the subject's behavior. Six people passed the robot, approached the projection surface, six people stopped at the side of the robot. Behavior changed differently depending on the subjects.

Regarding condition D, the explanation was not projected but shown on the display on the robot. All 12 people followed the robot (Fig. 11).

VI. Discussion

In the case where both the robot and the projected image moved (behavior 1), most people followed the robot. This is the same result as the guide experiment using a conventional mobile robot without projection function, indicating that mobile robots have the effect of making the person follow. The reason why one of the subjects did not follow may be that it was able to read the contents of the projected image without following the robot and that there was no subsequent guidance in the experiment.

In the case where only the robot moved with the projected image fixed (basic guiding behavior 2), most people stayed at the place of the projected image and did not follow the robot. This indicates that the subjects have focused on the projected explanation. Unlike conventional guide robots, even when the robot moves, most subjects do not follow up and stayed close to the projected image. This result showed that combining the movement of the robot and the projection has the effect of guiding the person.

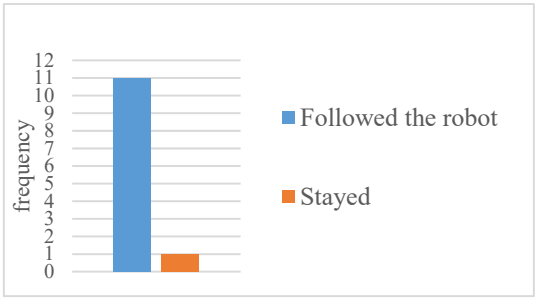


Figure 8. Behavior of participants in guide behavior 1 (condition A). Most participants followed the robot.

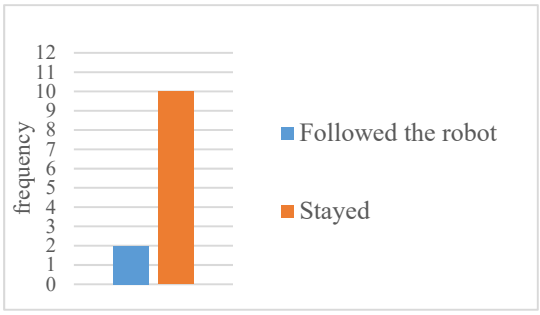


Figure 9. Behavior of participants in guide behavior 2 (condition B). In this case most participants did not follow the robot.

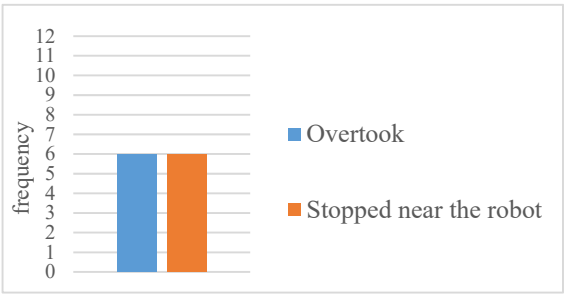


Figure 10. Behavior of participants in guide behavior 3 (condition C). Half of the participants stopped near the robot.

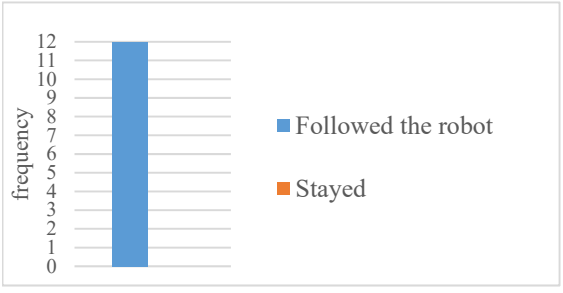


Figure 11. Behavior of participants in display condition (condition D). All participants followed the robot.

In the case where the robot stopped and only the projected image moved, two kinds of behaviors were observed: the subjects staying on the side of the robot and the subjects following the projected image. In the free description in the questionnaire answer of the subjects who stayed on the side of the robot, it was noted that the projected content could be seen from the standing place and it was a little hard to move because the robot was in front. This description suggests that if guidance using only the projection without the robot is carried out, it is more likely to follow the projected image like the result in the basic behavior 2. This result also suggests that these subjects did not move due to the existence of the robot. In contrast, in the free description of the subjects who followed the projected image, it was noted that it was difficult to read the description of the projected image from the side of the robot. If a sufficiently visible explanation is projected from the position aligned with the robot, there is a possibility that the subjects did not follow the projected image.

These results indicate that the existence of the robot and the position of the projected image are combined to influence the behavior of the guided person. For example, one subject had stopped by the robot under condition 3, whereas the subject did not follow the robot under condition 2. This means that whether or not to follow the robot depending on the movement of the projected image.

In this preliminary experiment, the behavior of the subject was classified into two in terms of whether it follows the robot. It will be possible to model behavior of the guided person in response to the guidance robot's behavior in more detail by analyzing the movement trajectory and clarifying the difference between the responses in more detail.

VII. Conclusion

In this paper, we proposed a new method to guide a person naturally when a mobile robot explains an exhibition. By using a robot with a projector on a pan-tilt actuator, we make use of the fact that the behavior of a person is influenced by both movement and projection behavior of the robot. For conventional mobile guide robots, it was difficult to control the position of the people to be guided. For those who overtake the robot and those who blocked the route of the robot, the robot was required to give instructions such as "please come here" or "Please leave the way" by voice or other means. To overcome such frequent instruction, we propose three basic guiding behavior for a projection robot that combines movement and projection behavior. By selecting appropriate guide behavior, guides of various situation can be realized.

Experiments involving 12 subjects confirmed the behavior of subjects when conducting three types of basic guiding behaviors. For basic behaviors 1 and 2, almost all subjects performed the expected movements, not only follow the robot but also showed behaviors that stayed in place even when the robot leaves. These results indicate that the existence of the robot and the position of the projected image are combined to influence the behavior of the guided person. On the other hand, regarding the basic behavior 3, half of the subjects remained in place by being affected by the presence of the robot. However, the other half of the subjects moved to near the projected image without staying on the route. It seems that projected explanation in a distant place cannot be seen from the side of the robot. It is our future work to verify the effect when projecting a readable explanation from the position of the robot.

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