Guidance of a person by combining moving and scaling projections from a mobile robot

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ABSTRACT

Conventional mobile guide robots have a problem as they cannot control the positions of people around the robot, and thus the path of the robot is blocked when people gather near the robot. To guide gathered people to move away from the robot, the robot had to give explicit instructions by voice or display, such as “please clear the way” or “please move that way.” Such repeated instructions from robots are not comfortable for humans. This study proposes new guiding behaviours for a projector-equipped mobile robot that naturally leads a person away from the robot without explicit instructions. The proposed method guides a person through a combination of projection movements and scaling based on a person’s tendency to move to a position where the projection can be easily viewed. An experiment with 15 participants showed quantitatively that the proposed guiding behaviours could lead people away from the robot without explicit instructions based on human behavioural measurements.

1. Introduction

Among the mobile robots that provide services by interacting with people in our daily lives, guiding people is one of the most important tasks. So far, much research has been done on guide robots, such as in museums [1,2], in science museums [3], and at airports [4]. Guide robots that effectively use facial expressions [5] and multiple modalities to communicate with people [6] have been proposed.

Conventional mobile guide robots have a problem that they cannot control people’s positions around the robot. Since the people to be guided tend to follow or gather around the robot, they often block the path of the robot [7]. It has been reported that the gathering of people around a robot can cause problems for the people around them [8]. In a previous research on guidance using robots, it is common to repeatedly instruct a person from a robot by integrating voices and gestures such as “Please move that way.” and “Please make way.” It is disturbing when such explicit instructions are repeated, and the people around us also feel it is noisy.

In contrast, we often implicitly guide others with our behaviours and gestures. Recently, research on such natural guidance by robots has been proposed. In the task of evacuation guidance by robots, Jiang et al. [9] showed that the movement of a robot-affected evacuees’ behaviour implicitly and improved the efficiency of evacuation. Tang et al. [10] proposed a robot control method that efficiently guides people in evacuation using a panic propagation model and the social force model. Okada and Ando [11] 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. Based on the idea of an implicit rule about a person’s relative position [12], Akita et al. [13] proposed a robot that moves to an appropriate relative position according to the status of surrounding people to appreciate a painting.

In this study, we propose an implicit guiding behaviour using projection from a mobile robot. So far, many studies on mobile robots using projectors have been proposed. Lee [14] proposed the concept of a mobile robot with a projector to present the necessary information to people in the environment and conducted an experiment to guide people by projecting an arrow. Shiotani et al. [15] proposed a method of controlling movement and projection based on constraints that consider the distance to surrounding people and the quality of the projected image. Matsumaru [16] projected information on the future moving speed and direction of a mobile robot so that people around the robot could understand the robot’s future behaviour. Saegusa [17] proposed a walking rehabilitation system using a mobile robot which projected the foot landing position. Tatsumoto et al. [18] proposed a navigation method to continue projection while the robot was avoiding people and obstacles. In these studies, essential functions for projecting human-friendly projections from mobile robots have been proposed; however,
they did not deal with guiding people away from the robot.

The effectiveness of guiding people with mobile robots has been shown in past research, and in this study, we use projectors on the robots to guide people more naturally. In contrast to the voice guidance, which gives direct instruction to the person to move, the proposed method uses the person's natural reaction when the projected image is controlled. Since the guidance method encourages people to move spontaneously, we expect people not to feel as if they are being instructed. We have proposed a method for implicitly guiding people through the projection of explanations from a projector on a mobile robot [19]. However, there was no quantitative analysis of the behaviour of the guided person. In our previous work, focusing on that people tend to move to a position where they can easily read the projected explanation, we proposed a method of guiding a person back and forth towards the projection image by scaling the size of the projected image [20]. In our past work, the person could only be guided in one particular direction.

In this paper, we extend the method given in [20] by combining [19] and propose a method to guide people in a different diagonal direction. The proposed method can also guide a person farther away from the robot. We quantitatively compare the relative distance and direction between the guided person and the robot using a human behaviour measurement system to show the effectiveness of the proposed method.

2. Guiding people away from guide robots through a combination of moving and scaling of projections

2.1. Problem definition

The purpose of guide robots is to guide a person to a destination along a given route and explain the exhibitions on the route. During the guidance, the task of the robot is to guide the person closer to a given route without explicitly instructing the person to move. A typical situation in which the proposed method can be applied is as follows. When the person to be guided is around the exhibit, the robot makes a plan to guide the person to the next exhibit along the route. For the robot to smoothly lead and guide the person, the robot must move to a position slightly ahead of the person on the guide route in advance. If the person is on the robot's movement path, the robot will guide the person based on the proposed guide behaviours by controlling the projected image to secure the moving path and move safely. Towards this goal, this paper proposes a method to guide a person by moving and scaling the projection image when the robot guides the human along the corridor.

2.2. Guiding people by moving projections

Since conventional guide robots cannot control the position of surrounding people well, when people gather near the robot, robots have difficulty in moving and even self-localization based on measurements [7]. Also, it has been reported that too many people around the robot may cause annoyance to the surrounding people [8]. To guide the people away from the robot, instead of repeating the explicit instruction using voice, we focus on the effect of robot movement and projection on people's movement around the robot. By rotating the projector on the robot, the projection position can be controlled independently of the robot's movement. Figure 1(a) shows a mobile robot guiding a person while projecting an explanation.

The guided people tend to move naturally to the position where the projection is easy to see. Using this tendency, Tamai et al. [19] proposed a method to guide a person to the right and left direction by moving an projected image on a wall (Figure 1(b)). However, their method guides a person only in the right and left direction towards the projection plane.

2.3. Guiding people by scaling projections

To guide a person appropriately according to the situation, it is sometimes necessary to guide a person's back and forth direction towards the projected image. We focus on the fact that there is an appropriate distance at which we feel the projected content is easy to see when viewing the projected information. When the projected image is large, we perceive it to be easier to see from a larger distance, and when the projected image is small, we perceive it to be easier to see from a closer distance. Therefore, by gradually scaling the size of the projected image, it can be expected that people will naturally move to a position where they can easily see the projected image (Figure 1(c)).

Using this tendency, we believe it is possible to guide a person's position back and forth towards the projected image and guide the person away from the robot. However, even if the projection images are scaled, it can only guide a person in one direction, back and forth direction, towards the projection plane.

2.4. Guiding people by both moving and scaling projections

Based on the methods in Sections 2.2 and 2.3, the projection robots can guide a person away from the robot in a specific direction by moving or scaling the projection. To guide a person in other oblique directions, the robot can perform both moving and scaling the projection images (Figure 1(d)). This guiding behaviour allows the robot to select a direction of guidance according to the situation. In addition, this
3. Experimental environment

In this section, we explain the experimental environment. Figure 2 shows the configuration of the proposed guide robot system. The robot measures its surroundings using a LiDAR then identifying its position relative to a map of the environment obtained in advance (Localization). Then the robot moves autonomously along a predetermined path (Path Following). Based on the estimated position and the projection position, the robot manipulates the pan-tilt actuator to direct the projector to the projection position (Pan-Tilt Control). Finally, the robot performs image processing to project the projected content at the specified size without distortion (Distortion Correction).

3.1. Human tracking system

We installed three LiDARs (HOKUYO AUTOMATIC UTM-30LX) to measure the position of a pedestrian surrounding the experiment environment. To stably measure the position of the pedestrian’s centre of gravity, we put the sensors at 120 cm, which is about the height of a person’s shoulder and is higher than the height of the robot. We assumed that there was only one pedestrian in the measurement area.

The measurement consists of two steps: pedestrian detection and tracking. In the detection step, it extracts the pedestrian candidates by the background subtraction and clustering. Then it detects an entity that fits a person’s size and computes the centre of gravity. In the tracking step, it applies a particle filter to estimate the trajectory of the pedestrian. The tracking system computed the smoothed position at a rate of 20 times per second.

3.2. Projection robot

Figure 3 shows the mobile robot used in the experiment. A pan-tilt actuator (TRACKLabs BiclopsPT)
is mounted on a mobile robot (T-frog Project Robot Frame i-Cart mini), and a robot head is placed on the pan-tilt actuator. The robot has the function of turning the face in vertical and lateral directions. A LiDAR (UTM-30LX) is mounted at a position 46 cm from the ground and localizes its position by matching the observation with the grid map of the environment acquired in advance based on a particle filter [21]. The robot can move autonomously along a specified path. In the experiments in the next section, the robot travelled the same predetermined path in all conditions.

Concerning the moving speed of the robot, in previous studies, the speed is set to a slightly slower than our average walking speed (about 1.1 m/s). In Pacchierotti et al., the speed of the robot is set to 0.6 m/s [22]. The speed in [22] is when the robot moves down a corridor and passes a person. A slower speed would be appropriate in a human guidance situation, so we set the robot’s speed to 0.5 m/s.

3.3. Projection position control and image processing

Projections are used to describe the exhibits just below the exhibits placed on the wall (Figure 4). The centre position of the projected image was 120 cm in height on the wall surface. The direction of the projector is determined from the location of the exhibit given in advance on the map and the estimated position of the robot. Then the pan-tilt actuator is controlled so that the image is projected to the calculated position. We applied the deformation to the projected image and realized the projection without distortion based on the relation between the posture of the robot and the projection plane.

The projected image size depends on both the size of the image size and the distance between the robot and the projection plane. In this experiment, to concentrate on the effect of the projected image size, we made image corrections so that the projected image size does not change when the distance between the robot and the projected image changes.

4. Experiments

To examine the effect of the combination of movement and scaling of the projected images, we measured the movements of the guided participants when the robot performed four types of proposed guiding behaviours proposed in Section 2. We compared and verified the differences in their movements when the robots performed different guiding behaviours.

4.1. Hypotheses

In condition A, the robot projects right next to the robot without scaling. In contrast, the robot moves the projected position away from the robot in condition B, and the robot reduces the size of the projected image in condition C. Therefore, compared with condition A, the guided person can be expected to move away from the robot in conditions B and C. Based on these considerations, we made the following hypotheses:

**Hypothesis 1**: When a person is following a projection robot, if the projected image is moved away from the robot, the person moves closer to the projection and away from the robot.

**Hypothesis 2**: When a person is following a projection robot, if the size of the projected image is reduced, the person moves closer to the projection and away from the robot. If the robot moves and shrinks the projected image at the same time, the guided person is expected to move farther away from the robot. Therefore, we made the following hypothesis:

**Hypothesis 3**: When a person is following a projection robot, if the projected image is moved away from the robot and shrunk simultaneously, the person moves farther away from the robot.
4.2. Participants

Fifteen participants (4 females and 11 males, whose average age was 22.9, SD was 1.15) 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.

4.3. Environment

Figure 5 shows the environment in which the guidance experiment was conducted. The experiments were conducted in an indoor 2.5 m wide corridor environment. The guide robot moved leftward from the position in Figure 5 (1) and performed one of the guiding behaviours from the position (2), and the robot finally reaches (3), which is common in all conditions. Two photographs were displayed on the wall to the right of the robot's direction of movement. From position (3), the robot projected the description to a height of 1.2 m below either one of the photographs, as shown in Figure 5.

4.4. Conditions

This study had a within-participant experiment design. Each participant experienced all four conditions. Table 1 shows the experimental conditions. In conditions A and C, the robot projected an explanation under photograph P1 from position (3) to the wall. In conditions B and D, the robot projected under photograph P2 from position (3) in the oblique direction to the projection plane. In conditions C and D, the robot reduced the size of the projection image to 50% of its original size. Figure 6 shows typical scenes in which the robot performs guiding behaviours B and C. In guiding behaviour B, the person did not follow the robot and stayed behind (Figure 6(a)), and in guiding behaviour C, the person approached the wall due to the reduction of the projected image (Figure 6(b)).

The projected image size when the guidance started was 64 cm in width and 39 cm in height. The size of the reduced projected image for conditions C and D is half the size of each side, 32 cm in width and 19.5 cm in height. In conditions B and D, the distance from the robot to the projected image changed during the guiding process, but the size of the projected image was kept the same as in conditions A and C, respectively. Figure 7 shows a standard size and a reduced size projection image. The 50% reduction makes the projected image smaller, but we can see most of the contents.

4.5. Measurements and statistical analysis

We measured the distance between the robot and the guided person using the human tracking system. After the robot completed its guiding behaviour and stopped at the position in Figure 5 (3), we measured the position of the participants when they signalled that they had seen enough.

To verify the direction of the guided person’s movement, we computed the $x$- and $y$-directions of the distance between the robot and the guided person after

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Table 1. Experimental conditions.

| Conditions | Photograph explained | Moving projection | Scaling projection |
|------------|----------------------|-------------------|--------------------|
| A          | P1                   |                   |                    |
| B          | P2                   | ✓                 |                    |
| C          | P1                   | ✓                 | ✓                  |
| D          | P2                   | ✓                 | ✓                  |
guiding behaviours. As shown in Figure 5, the $x$-axis direction is along the corridor and the right direction is positive. In conditions B and D, the robot moves the projection in the positive direction of the $x$-axis. The $y$-axis direction is perpendicular to the projected surface, and the direction approaching the projected surface is positive.

The purpose of this experiment is to compare the differences in distances between each condition to clarify Hypothesis 1, 2, and 3. Therefore, we performed a pairwise comparison between each condition. After detecting whether there is a difference in the average distance with one-way ANOVA, a pairwise comparison with Bonferroni’s correction was performed when a significant difference was found among conditions. A confidence limit of $p = 0.05$ was used.

### 4.6. Procedures

First, participants were given an overview of the experimental procedures and agreed to participate in the experiment. Before the experiment, participants were given a brief description of the outline of the experimental procedure and agreed to participate in the experiment. Participants were instructed that the robot would guide and explain one of the photographs and that we would then ask to fill out a questionnaire about the photographs.

To get used to being guided by the projection robot, the participants observed that the robot moved alone and projected a photograph’s description. Participants were explained that the robot moves and scales the projected image. Then participants were instructed to “Please let the robot guide you,” and experienced four types of guidance as shown in Table 1. The guiding behaviours were presented in a pseudo-randomized order.

When the participants were guided, they were asked to move to the designated initial position (Figure 5 (1)), then the experimenter gave the participants a start signal and then started the robot guidance. First, the robot projected an explanatory message, “I will start guiding you” immediately after the start of guidance. Then, the robot went straight along the corridor and carried out one of the guiding behaviours from point (2) in Figure 5. When it reached the exhibition, the robot stopped and continued projection (Figure 5 (3)). We used different exhibits and descriptions for each guiding behaviour. Participants returned to the starting position when they felt that they had seen the exhibition sufficiently.

### 5. Results

#### 5.1. Overview of the movement of people away from robots

We measured the positions of participants after the robot performed four guiding behaviours using the human tracker system. Figure 8 shows the positions of the robot and the participants after the guiding behaviours. The top and bottom edges of Figure 8 are the walls of the corridor, and the two pictures described by the robot are at the top of the figure. The robot and the participants moved from the right side of the figure to the left. In all conditions, the robot stopped at the crosshairs in the lower-left corner.

The final positions of the participants in each condition are shown in the figure. In guiding behaviour A, all subjects followed the robot. The distance to the robot did not change greatly through guiding behaviour. In guiding behaviour B, the robot moved the projection from right next to the robot, which caused the participants to move closer to the projection and away from the robot. In guiding behaviour C, the participants tended to move closer to the projection plane and away from the robot as the robot reduced the size of the projection. In the guiding behaviour D, the participants tended to move obliquely and farther away from the robot as the robot moved and reduced the projection image simultaneously.

#### 5.2. Comparison of distance and direction of movement away from the robot

The first row of Table 2 shows the average distance between the robot and the participants at the end of the guiding behaviour. In condition D, the guided person tended to move farthest away from the robot. We conducted a one-factor within-subject ANOVA for the distance. We identified a significant difference among the conditions ($F(1, 14) = 196.226; p < .001$). Multiple comparisons with the Bonferroni correction revealed significant differences: $A < B (p < .001), A < C (p = .011), A < D (p < .001), B > C (p < .001), B < D (p = .038)$, and $C < D (p < .001)$. 

![Figure 8. The locations where participants were guided to after each guiding behaviour. In condition B, they are guided to the right along the corridor, and in condition C upward to approach the projection plane. In condition D, they are guided to the upper right by both the effects.](image-url)
Since the distance between the robot and the person at the end of the guiding behaviour is $A < B$, Hypothesis 1 is supported. Similarly, the distance of $A < C$ supports Hypothesis 2. Since the distances are $B < D$ and $C < D$, Hypothesis 3 is supported.

The distance between the robot and the person in the $x$-direction is shown in the second row of Table 2. Larger average distances were observed in conditions B and D compared to condition A. The results show that in conditions B and D, the participants tended to move farther away from the robot in the direction along the corridor as the projection moved. We conducted a one-factor within-subject ANOVA for the distance in the $x$-direction. We identified a significant difference among the conditions ($F(1,14) = 314.260; p < .001$). Multiple comparisons with the Bonferroni correction revealed significant differences: $A < B$ ($p < .001$), $A < D$ ($p < .001$), $B > C$ ($p < .001$), and $C < D$ ($p < .001$). No significant difference was observed between $A, C$ ($p = .13$) and $B, D$ ($p = 1.000$).

The distance in the $y$-direction is shown in the third row of Table 2. Larger average distances were observed in conditions C and D compared to condition A. As for the distance in the $y$-direction, a larger average distance was observed in conditions C and D compared to condition A. The results show that in conditions C and D, the participants tended to move farther away from the robot in the direction towards the projection screen as the projection size reduced. We conducted a one-factor within-subject ANOVA for the distance in the $y$-direction. We identified a significant difference among the conditions ($F(1,14) = 13.253; p < .001$). Multiple comparisons with the Bonferroni correction revealed significant differences: $A < C$ ($p < .001$), $A < D$ ($p = .010$), and $B < C$ ($p = .011$). No significant difference was observed between $A, B$ ($p = .215$), $B, D$ ($p = .087$), and $C, D$ ($p = 1.000$). These results show that the movement in both the directions was larger in condition D than in condition A.

6. Discussion

The contribution of this paper is that we have proposed a method of guiding a person away from the robot by using a projection-based guiding robot that scales and moves the explanation image projected on the wall. When the robot uses the projection to explain exhibits, taking advantage of the fact that a guided person naturally tends to move to a location where they can see the projection more easily, we proposed a method to guide people away from the robot without the robot giving explicit instructions. This is the first study that quantifies a guided person's distance and direction away from a robot when the robot moved and reduced its projection at the same time.

Concerning the relative distance between the robot and human, we quantified the results of [19], as $A < B$ was confirmed (the first row of Table 2). The result of $A < C$ shows that the reduction of the projection can guide a person in the direction towards the projection. The result of $C < D$ shows that the proposed method can guide a person farther away from the robot by moving and reducing the projection at the same time. However, the increase from B to D was relatively small. This may be because the distance is smaller than the sum of the relative distances in B and C because the person is guided diagonally by the simultaneous induction in the $x$-direction by movement and the $y$-direction by reduction.

In this experiment, by moving and scaling the projection simultaneously, we showed that a person could be guided in an oblique direction, which has not been shown by previous methods. However, in this experiment we only showed that they move in one particular oblique direction on average. Our next step is to guide people in various different directions by controlling the projection. We believe it is possible to guide them in a specific angular direction by combining the right amount of movement and scaling. Verification of the accuracy of the direction of guidance is our future work.

In the distribution of final positions (Figure 8), we succeeded in guiding them to the right by moving the projection, while there was a relatively larger variance in the guiding by scaling the projection. It may be due to the fact that the viewing position of the different size projections depends on the person. In this paper, by reducing the size by 50% from the initial size, we showed the principle of the proposed method. In the future, we believe it is important for a guiding robot to evaluate the effects of scaling during a guided tour and to behave according to the guided person.

### Table 2. Mean and standard deviation of distance between the robot and the participants after the guiding behaviour.

| Conditions | A (M(SD)) | B (M(SD)) | C (M(SD)) | D (M(SD)) | One-Way ANOVA | Pairwise Comparison |
|------------|-----------|-----------|-----------|-----------|----------------|-------------------|
| Relative  | 997 (1977) | 1205 (2130) | 2130 (F(1,14) = 196.226; $p < .001$) | × × × × × | A-B p-Value | A-C p-Value | A-D p-Value | B-C p-Value | B-D p-Value | C-D p-Value |
| X-direction | 835 (1857) | 745 (1899) | 1899 (F(1,14) = 314.260; $p < .001$) | × × × × | p < .001 | p < .011 | p < .001 | p < .001 | p = .038 | p < .001 |
| Y-direction | 470 (607) | 895 (866) | 866 (F(1,14) = 13.253; $p < .001$) | × × × × | p < .001 | p < .13 | p < .001 | p < .001 | p = 1.000 | p < .001 |

Notes. Results of the ANOVA for three distances, as well as pairwise comparisons, are reported.
Concerning the distance between the guide robot and the person being guided, the required distance will depend on the robot's size and environment. When a small robot is guiding in a 2-meter corridor in the current experimental environment, it may be necessary to be 1 m away in the front-back direction and 1 m away in the left-right direction, depending on the situation. When the person to be guided is around the exhibit, the robot makes a plan to guide the person to the next exhibit along the route. For the robot to smoothly lead and guide the person, the robot must move to a position about 1 meter ahead of the person on the guide route in advance. If the person is on the robot's movement path, the robot will guide the person closer to the wall to secure a 1-meter-wide path for the robot to move safely. The robot then either moves 1 meter ahead of the person or leads the person back 1 meter. In this situation, the robot needs to leave a distance of 1 meter in the direction along the corridor and in the direction towards the wall, respectively. From the results of this experiment, we can see that in condition D, the robot is able to successfully move away from the human at a sufficient relative distance.

At the end of the guidance, the participants stopped slightly before the exhibit (Figure 8). The reason could be because the participants were walking slightly behind the robot. The place where the participants stopped could be the place where the participants were walking when the projected image stopped moving. Another reason could be that the light beam from the projector affected their behaviour. In the future, we would like to investigate the factors that affect human behaviour in more detail.

In this experimental set-up, the robot maintained a constant distance from the wall, so the effect of the robot's behaviour on the human was relatively small. When the robot approaches or leaves the wall, the person may be affected by the robot's movement. The person being guided is likely to be affected by both the robot's movement and the change in the projected image. To investigate the guide method that takes into account both influences is our next work.

We confirmed the effectiveness of the proposed method for one person. Guiding multiple people is an important task for a mobile robot. Several methods have been proposed for guiding multiple people using robots [23], such as guiding multiple people as one group by drawing their attention or guiding people by focusing on the person who is the leader [24]. We believe that the proposed method can be combined with these methods and extended to multi-person guidance methods.

7. Conclusion

To solve the problem of people gathering too much on the robot when guiding a person using a mobile robot, we proposed methods of guiding a person without giving explicit instructions using a projector on the robot. In the new guiding method, the robot moves and scales the projected image at the same time. We quantitatively showed that the proposed method guided a person farther away and guided the person oblique direction compared to the conventional method using the human tracking system. This allows the robot to create free space, then the robot can perform preparatory movements and preceding movements for the next guidance.

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