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Path Planning for Autonomous Mobile Robots Considering Walking Rules Generated by Road Surface Guidance Signs

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Abstract: This paper proposes a recognition method for road surface guidance signs that provide pedestrians with easy-to-understand directions and, based on the recognition results, a method for autonomous mobile robots to predict pedestrian movements and generate routes safely and efficiently. The robot recognizes road surface guidance signs using image processing. The direction indicated by a road surface guidance sign is detected by line detection and arrow detection. The direction of the sign and the direction of pedestrian movement recognized by 2DLiDAR are used to calculate the degree of match that indicates the degree to which pedestrians are currently following the sign. The potential method is used for path planning. By extending the repulsive force in the direction indicated by the sign and using the calculated agreement as a weight, the robot can safely avoid pedestrians who are likely to follow the sign.

Keywords: Pedestrian movement forecasting, pedestrian avoidance, mobile robot navigation

1. INTRODUCTION

Service robots generally have the opportunity to pass through areas where people are moving at cross-purposes. In this case, the robot must predict and avoid complex pedestrian paths while planning routes safely and efficiently.

To accomplish this task, robot navigation methods have been proposed for traveling in congested environments using pedestrian flow [1-3].

However, these studies show that when pedestrians suddenly change direction, their behavior deviates from the previously recognized pedestrian flow, making it difficult to plan appropriate routes.

Therefore, this paper focuses on road surface guidance signs. In recent years, many signs with arrows on the road surface have been adopted as a method of presenting destinations to pedestrians in an easy-to-understand manner (Fig. 1). In this paper, we propose a method for safe and efficient route planning by predicting the movements of pedestrians who are likely to follow the signs in an environment where pedestrians are passing by.

(Shinagawa Station, Tokyo, Japan)
Fig. 1 Examples of road surface guidance signs

† Yusuke Oda is the presenter of this paper.

2. RECOGNITION METHODS FOR ROAD SURFACE GUIDANCE SIGNS

2.1 Pre-processing and line detection methods

In this study, road surface guidance signs are assumed to be lines with multiple arrows on them, and the direction and lines of these arrows are recognized by image recognition.

First, the input image is converted to HSV model, and a mask image is generated within the range corresponding to the color of each sign. Next, noise is removed by performing an opening and closing operation, and only the sign is extracted from the image.

For line detection, sign edges are detected from the mask image using the Canny method, and the edge lines are expanded to prevent line breaks. The probabilistic Hough transform is used to detect straight lines from the expanded edges. Since the lines are rectangular, the parameters of the function that performs the Hough transform are appropriately set to the minimum value that is recognized as a straight line to prevent the recognition of short edges.

2.2 Arrow detection

For arrow detection, the image processing method proposed by Youn *et al.* [4] is used as a reference. Specifically, the corners of the arrows are detected in the mask image using Shi-Tomasi's corner detection [5], and template matching is performed with the template image (Fig. 2) in eight directions around the detected points, representing the arrow tips. Since the distance and angle between the camera and the sign differ from the template image depending on the positional relationship between the robot and the sign, the template images were resized and affine transformed to select templates whose correlation coefficients exceeded a threshold value, and the arrow direction was determined based on the direction of the template with the greatest correlation among them. The direction of the arrow was determined based on the orientation of the template with the largest correlation.

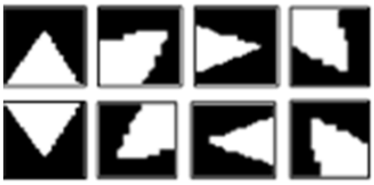


Fig. 2 Template images in eight directions

2.3 Recognition experiment

A preliminary experiment was conducted using the image processes in previous sections. Fig. 3 shows the experimental setup. With this positional relationship, the sign was rotated clockwise 45 degrees at a time around its center of gravity, photographed, and image processing was performed. Table 1 shows the maximum correlation coefficient and the direction of the arrow in the template matching. As an example of the image processing results in this experiment, Fig. 4 shows the line and arrow tips surrounded by rectangles at 0[deg] and 90[deg]. The correlation coefficients for all eight directions in Table 1 are approximately 0.9, which is high, and the direction of the arrow is correctly identified, indicating that the sign is guiding the pedestrian in various directions. Therefore, it is thought that it is possible to recognize which direction the sign is trying to guide the pedestrian from various angles.

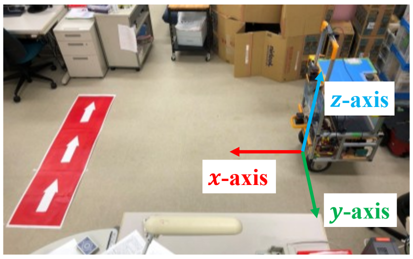
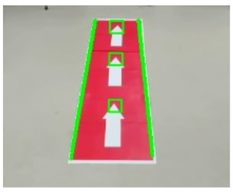


Fig. 3 Experimental setup

Table 1 Arrow detection result

angle[deg]	0	45	90	135	180	225	270	315
correlation coefficient	0.92	0.95	0.91	0.91	0.93	0.90	0.91	0.89
detection direction	⇧	⬀	⇨	⬂	⇩	⬃	⇦	⬁



(a) Sign detection(0[deg])

(b)Sign detection(90[deg])

Fig. 4 Image processing results example

3. ESTIMATING THE DEGREE OF CONSISTENCY BETWEEN THE ANGLE INDICATED BY THE SIGN AND THE DIRECTION OF PEDESTRIAN MOVEMENT

In this study, the degree to which the pedestrian follows the road surface guidance signs is determined by an index called the degree of consistency. The degree of consistency can be calculated using the angle difference between the road surface guidance sign and the pedestrian with respect to the robot, as shown in Eq. (1). The relationship between the angle of the road surface guidance sign and the angle of the pedestrian is shown in Fig. 5. From Fig. 5, the angle difference is obtained by Eq. (2). The pedestrian's angle is measured by Eq. (3) using the pedestrian's velocity vector detected by 2DLiDAR.

The degree of consistency is n, the arbitrary constant is t, the angular difference between the pedestrian's angle and the angle of the road surface guidance sign is θ_{diff}, the pedestrian's angle is θ_{ped}, the pedestrian's velocity vectors in the x and y directions are v_x and v_y respectively, and the angle of the road surface guidance sign is θ_{sign}.

$$n = \begin{cases} |t\cos(\theta_{diff})| & (-\pi/2 < \theta_{diff} < \pi/2) \\ 0 & (\theta_{diff} \leq -\pi/2, \theta_{diff} \geq \pi/2) \end{cases} \quad (1)$$

$$\theta_{diff} = \theta_{ped} - \theta_{sign} \quad (2)$$

$$\theta_{ped} = \arctan\left(\frac{v_y}{v_x}\right) \quad (3)$$

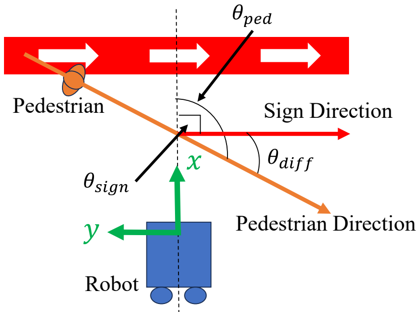


Fig. 5 Relationship between the angle of signs and the angle of pedestrians

4. ROBOT NAVIGATION CONSIDERING THE ROAD SURFACE GUIDANCE SIGN

In this research, in order for the robot to safely avoid pedestrians who are likely to follow the road surface guidance signs, it is necessary to generate a large avoidance path in the direction where the pedestrians are likely to come from. Therefore, we create a potential equation (Eq. (4)) that takes into account the direction of the road surface guidance signs, referring to the free-space model of the artificial potential equation proposed by Nishino *et al* [6]. In the designed potential field, the direction of the road surface guidance sign is the center, and the fan shape is determined by the angles α and β. In this study, the central angle of the fan shape composed of α and β is set to 45°. When multiple road surface guidance signs are recognized, the potential values of each are added together (Eq. (5)). M_{sign} is a function of θ and represents the repulsive potential value in the road surface guidance signs direction generated for pedestrians, θ is the various angles in pedestrian-centered coordinates. a and k are constants obtained experimentally in previous studies , θ_{sign} is the angle of the road surface guidance signs, M_{total} is the value of the summed potentials, $sign_{num}$ is the number of recognized road surface guidance signs, and w_{sign} is the value of the degree of consistency n obtained in Section 3. The range r of the repulsion potential is assumed to be proportional to the pedestrian's movement speed v, which, with the experimentally determined constant l, becomes Eq. (6).

The artificial potential formula is used to generate an avoidance path for the robot to avoid pedestrians that would be coming toward it according to the road surface guidance signs in advance, and to allow the robot to travel safely.

$$M_{sign}(\theta) = \frac{ae^{-r}}{k|\theta - \theta_{sign}| + 1} \left(\alpha < \theta_{sign} < \beta\right) \quad (4)$$

$$M_{total} = \sum_{i=0}^{sign_{num}-1} w_{i_{sign}} \cdot M_{i_{sign}} \quad (5)$$

$$r = lv \quad (6)$$

In addition to the potential field considering the direction of the road surface guidance sign, a circular potential field proposed by the previous study [6] was added to generate repulsion in all directions. Fig. 6 shows the potential field during robot navigation using the artificial potential method. In Fig. 6, because pedestrians are assumed to walk according to the signs on the ground, we can see that the proposed method increases the potential for signs to be in the direction of the pedestrians. Therefore, the robot can actively avoid the pedestrians' path.

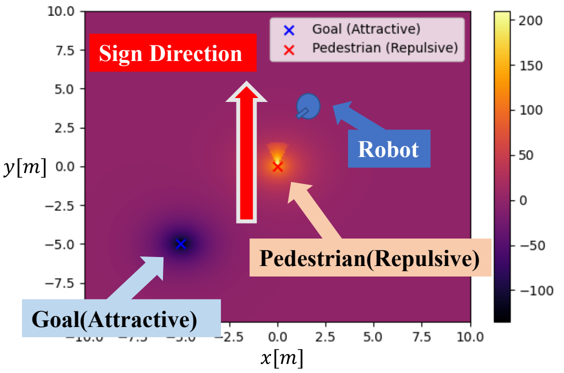


Fig. 6 Robot navigation using potential fields

5. EXPERIMENTS

5.1 Specification of our prototype mobile robot

The robot used in this study is shown in Fig. 7. The robot has two drive wheels and one caster, and is equipped with a 2DLiDAR and a camera mounted in front of the robot. 2DLiDAR measures 180° in front of the robot, and the camera captures images of the floor in front of the robot.

Fig. 7 Our prototype robot

5.2 Experimental setup

The environment assumed in this study is a free space with a road surface guidance sign. The pedestrian is assumed to follow the road surface guidance signs, and if the angle of the road surface guidance signs changes during the walk, the pedestrian changes its course in the same direction. The robot's target point is set at 10[m] in front of the robot, and the robot runs to the target point avoiding the pedestrian who suddenly changes course. The starting and destination points of the pedestrian and the robot are shown in Fig. 8.

In this study, we experiment with two patterns: the proposed method and the previous method that generates a circular potential field. After the robot recognizes a road surface guidance sign from a camera image and detects a pedestrian using 2DLiDAR, we confirm that the robot generates an avoidance route considering the pedestrian who is likely to follow the road surface guidance sign. The speed of the robot and pedestrian were set to 0.6[m/s] and 0.8[m/s], respectively.

The values used for comparison in the experiment are the distance $dist$ traveled by the robot to the destination and the minimum distance $P-R_{min}$ between the robot and the pedestrian.

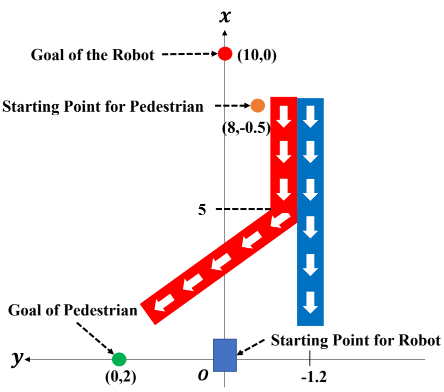


Fig. 8 Experimental setup

5.3 Experimental results

The results of the experiment are shown in Table 2. Figs. 9 and 10 show the relationship between the robot's trajectory and the pedestrian's position in each time series, Fig. 9 using the previous method of generating a circular potential field, and Fig. 10 using the proposed method.

The orange line in the figure represents the trajectory of the robot, which travels in the direction of the x-axis. The black arrows indicate the direction in which the pedestrian is moving.

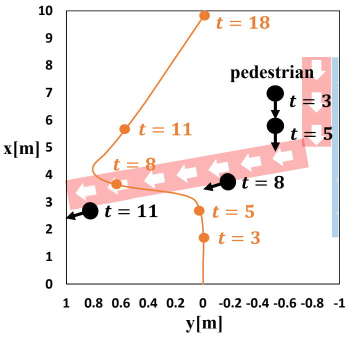


Fig. 9 Moving Trajectory of the Robot and Pedestrian (Previous method)

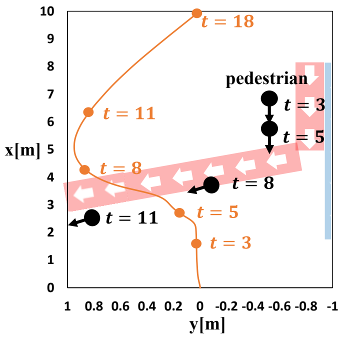


Fig. 10 Moving Trajectory of the Robot and Pedestrian (Proposed method)

Comparing Figs. 9 and 10, at $t = 5$, when the robot did not consider the road surface guidance signs, the robot did not anticipate that a pedestrian was coming toward it and went straight ahead, but when the robot considered the road surface guidance sign, the robot anticipated that a pedestrian was coming and took evasive action. After $t = 5$, when the robot did not consider the road surface guidance signs, the robot suddenly changed its course and made a sharp turn to avoid the pedestrian who was coming toward it. However, when the road surface guidance signs were taken into account, the robot predicted that the pedestrian would change its path, and thus safely avoided the pedestrian that actually changed its path without making a sharp turn.

Table 2 shows that $dist$ is 0.06[m] smaller and $P - R_{min}$ is 0.72[m] larger for the proposed method. This confirms that the robot traveled along an efficient path at a safe distance from pedestrians heading in the direction of the sign.

From the results of two experimental patterns conducted in this study, it was confirmed that the system can generate an avoidance route for a pedestrian who suddenly changes course by recognizing road surface guidance signs and predicting the pedestrian's path.

Table 2 Total distance travelled by robots and distance between pedestrians and robots at closest approach

	$dist$[m]	$R - P_{min}$[m]
Previous Method	10.57	0.42
Proposed Method	10.51	1.14

6. CONCLUSION

In this paper, we propose a method to predict the direction of pedestrian movement by recognizing road surface guidance signs, and to generate safe and efficient routes for an autonomous mobile robot based on the predictions. Using the direction indicated by the recognized road surface guidance signs and pedestrian information from 2DLiDAR, the degree to which pedestrians follow the road surface guidance signs is estimated. Furthermore, we extended the robot navigation method using artificial potentials and proposed a robot navigation method that enables the robot to safely avoid pedestrians who may make sudden changes in their paths. We implemented the proposed method on a robot and confirmed its effectiveness through experiments.

REFERENCES

[1] R. Tsugita, N. Nishino, D. Chugo, S. Yokota, S. Muramatsu, and H. Hashimoto, “Mobile robot path generation in crossing passages using implicit walking rules”, The 18th sice system Integration Division Annual Conf.(SI2017), 2D3-12(2017).

[2] W. Kumahara, G. Masuyama, Y. Tamura, A. Yamashita, and H. Asama, “Navigation System for Mobile Robot Based on Local Path Information and Pedestrian Flow in Dynamic Unknown Environment,” Proc. of the SICE, Vol. 50, No. 1, pp. 58-67, 2014.

[3] Y. Hara, and Y. Haneda, “Running of the autonomous mobile robot by route generation using pedestrian flow ,” Proceedings of the JSME Conf. on Robotics and Mechatronics, Vol. 64-626, pp. 3854-3861, 2017.

[4] Youn, Junhee, Gi-Hong Kim, and Kyusoo Chong, “Automatic Extrac- tion of Direction Information from Road Sign Images Obtained by a Mobile Mapping System,” GWF,2014.

[5] Jianbo Shi and Tomasi, "Good features to track," 1994 Proceedings of IEEE Conf. on Computer Vision and Pattern Recognition, pp. 593-600,1994.

[6] N. Nishino, R. Tsugita, D. Chugo, S. Muramatsu, S. Yokota and H. Hashimoto, "Robot Navigation According to the Characteristics of Pedestrian Flow," Proc. of the 42nd Annual Conf. of the IEEE Industrial Electronics Society, pp.5947-5952, 2016.