Mobile Robot System Realizing Human Following and Autonomous Returning Using Laser Range Finder and Camera

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In recent years, with the development of technology, introduction of autonomous mobile robots to environments close to human life is expected. Examples are shopping cart robots automatically returning to the shopping cart shed after shopping, and guide robots directing the way back to the starting position from the current position in unknown environment. In this paper, we propose a mobile robot system that has functions of autonomous person following and starting position returning. The robot realizes these functions by analyzing information obtained with a camera and a laser range finder. We verified the validity of the system using a wheel mobile robot in indoor environment.

Keywords: Mobile robot, LRF, Camera

1. Introduction

In this paper, we propose a mobile robot system that has functions of human following and returning to the starting location autonomously while avoiding obstacles.

In recent years, introduction of autonomous mobile robots to environments close to us is expected. Examples include shopping cart robots returning automatically to the shopping cart shed after shopping, and guide robots directing the way from the current location to the starting location in unknown environments. A robot that accomplishes these purposes needs the functions of human following and autonomously returning to the starting position functions. [(1)~(3)].

In this paper, we call the movement of the mobile robot from the starting point to the target point the outward way. And, we call the movement of the mobile robot from the target point to the starting point the return way.

We previously proposed a mobile robot system that has functions of autonomous person following and starting position returning [(4)]. In the above paper, the mobile robot follows the human by manual operation. However, we desire that the mobile robot follows the human by autonomous operation because manual operation requires additional work [(5)~(7)].

Therefore, in this paper, we propose a mobile robot system that generates a map with acquisition of range data while following the human on the outward way, and then the mobile robot returns to the starting position autonomously by generated map while avoiding obstacles on the return way.

2. Outline

In this paper, we verify the validity of the system using the mobile robot equipped with the Laser Range Finder (LRF) and the camera (Fig.1). The mobile robot can acquire 2-D range data of 180 degrees forward by the LRF (Fig.2). The mobile robot also acquires the image in the front direction by the camera (Fig.3).

The operating environment of the mobile robot is flat and static environment, and the mobile robot moves on 2-D space. Figure 4 shows the outline of the mobile robot movement. The mobile robot detects and follows the human by using the LRF and the camera when mov-

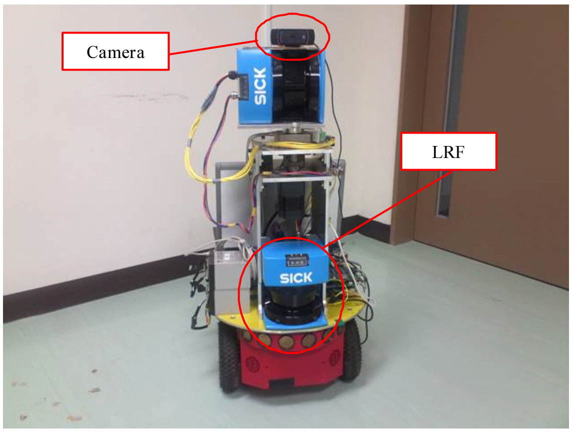

Fig. 1. LRF-equipped mobile robot.

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Fig. 2. Laser range finder.

Fig. 3. Camera.

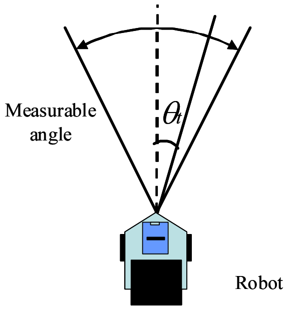


Fig. 5. Mersurement range.

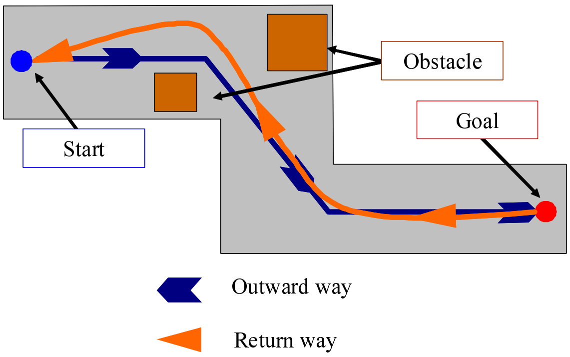
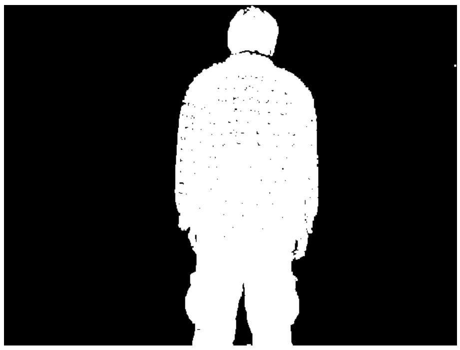


Fig. 4. Outline of robot movement.

(a) Acquired image.



(b) Extracted person region.

Fig. 6. Background subtraction.

ing on the outward way. At the same time, the mobile robot generates a map with range data measured by the LRF. The mobile robot generates a potential field from the generated map by an artificial potential method. And then the mobile robot moves on the return way along gradient directions of generated potential field. At the same time, the mobile robot avoids obstacles not recorded in the map by reconstruction of potential field.

3. Motion on outward way

The mobile robot performs the human following and map generating on the outward way. There are various methods of autonomously human following or manual operation in the method that the mobile robot follows a human. In this paper, the mobile robot follows the human by using functions of human detecting and following. Figure 5 shows measuring range of the camera and the LRF. Human following is done by detecting the human at the angle of θ in front of the mobile robot. The map generation is done by integrating the range data.

3.1 Processing before human following The mobile robot acquires color information on the human who is to be followed by the mobile robot with the camera before the human following begins. We use the background difference method to the acquisition of color information. The difference between background image without human and image where the human exists (Fig.6(a)) is taken. Then the area where the human exists in the acquired image is extracted (Fig.6(b)) and color information in the extracted area is obtained.

In addition, the color histogram is made by using pixel value of the area of the human who is the target of pursuit. To be robust to the change in brightness, the pixel value of the target is converted into HSV. Then the color histogram of hue h and saturation s is made (Fig.7).

3.2 Detection and removal of moving objects

First, the moving object is detected to decide the angle to acquire color information.

Moving objects are detected by comparing measured range data acquired with LRF [8]. Figure 8 shows the outline of moving objects detection when the mobile robot moves straight in the corridor and a human walks ahead of the mobile robot. In our method, the robot measures legs of a human because LRF is installed 30cm above the ground on the mobile robot.

Figure (Fig.8(a)) and (b) show the range data obtained at time t and $(t-1)$), respectively, where corridor walls and a moving object are detected. Then, we find

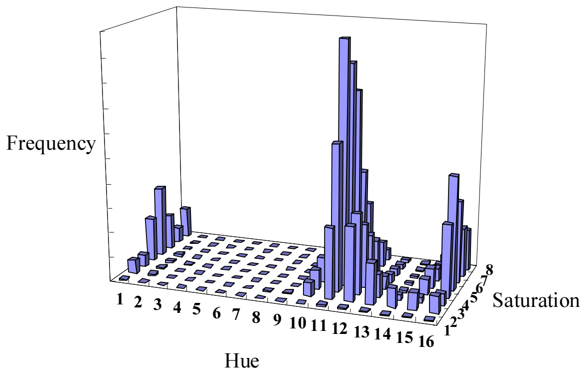
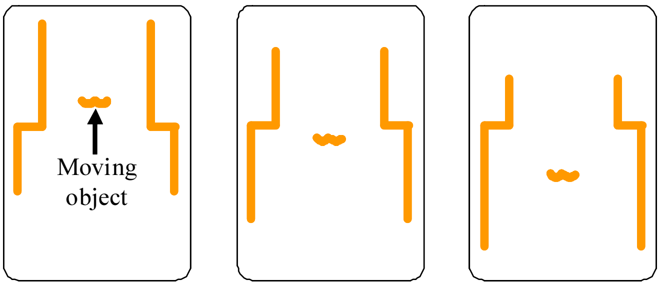
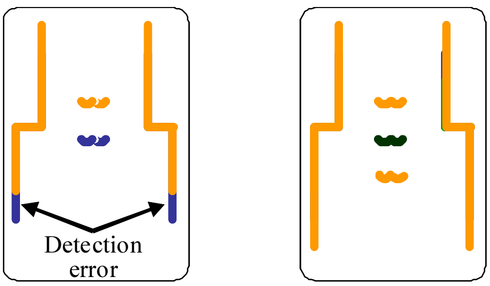


Fig. 7. Color histogram.



(a) Range data(t). (b) Range data(t-1). (c) Range data(t-2).



(d) Moving object in (b) [(b)-(a)]. (e) Moving object in (b) [(b)-(a)-(c)].

Fig. 8. Detection of moving object.

the data among the latter which do not exist in the former. These data are shown in Fig.8(d) in blue. These data are, however, the mixture of those of the moving object and the corridor walls because the area of the measurement by the robot changes with its movement. To remove the above detection errors, we find the data among these data which do not exist in the range data obtained at time $(t-2)$ shown in Fig.8(c). By this processing, we can finally remain only the moving object from the range data. Figure 8(e) shows the result of the above processing where the moving object is shown in green.

3.3 Similarity calculation by color information While the mobile robot follows the human, color information is acquired with the camera for each angle where the moving object is detected. Then the color histogram is made and the degree of similarity with the color histogram made by 3.1 is calculated.

Bhattacharyya coefficient is used for the evaluation of the degree of similarity between histograms. Equation (1) shows Bhattacharyya coefficient R. $H_t(h,s)$ is the frequency of each bin of the color histogram of the human that is acquired before the mobile robot starts human following. $H_i(h,s,\theta)$ is the frequency of each bins of the color histogram acquired in image for angular θ direction where moving object is detected while the mobile robot following the human. h_b is the number of bin of hue h, and s_b is the number of bins of saturation s.

The value of $R(\theta)$ is the degree of similarity for each angle where moving objects is detected.

$$R(\theta) = \sum_{s=1}^{s_b}\sum_{h=1}^{h_b}\sqrt{H_t(h,s)H_i(h,s,\theta)} \cdots\cdots\cdots \quad (1)$$

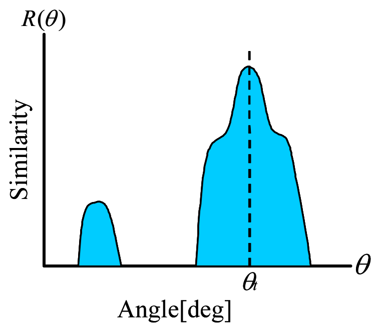


Fig. 9. Similarity distribution in human following.

3.4 Human following The degree of similarity for each angle where a moving object is expected to exit is calculated by the processing in 3.3.

In figure 9, the right area that is the biggest one is judged to be a direction of the angle where the human exists. The dotted line shows the position of the center of gravity of the angle. Then the robot moves to the direction of the angle θ_t.

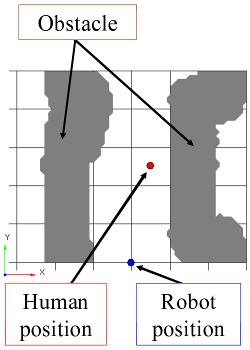
3.5 Map generation In this paper, the mobile robot generates the map of ambient environment while it moves on the outward way. The LRF is used in the ambient environment measuring for map generation. The LRF measures the ambient environment during the mobile robot movement and the ambient environment map is generated by integrating each measurement data.

Measurement data integration needs a accurate self-location estimation of the mobile robot. In this study, the estimation is made by dead reckoning. However, dead reckoning has a problem of slipping error accumulation. So, the mobile robot decreases error of self-location estimation by aligning each measurement data by ICP algorithm [13].

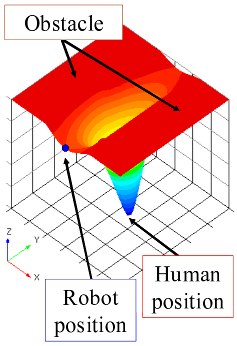
Moving objects do not necessarily exist in the same place. Therefore, it is necessary to remove moving objects from the map. The mobile robot detects moving objects by 3.2.

4. Motion on return way

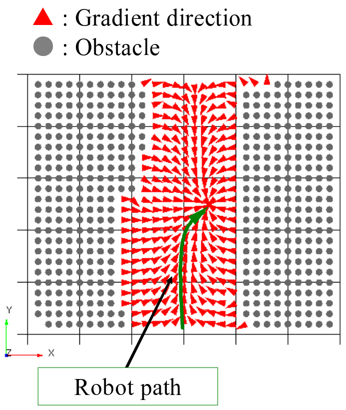
The mobile robot moves on the return way by the Laplace potential method. The robot generates the potential field at the starting point in the generated map



(a) Environment.

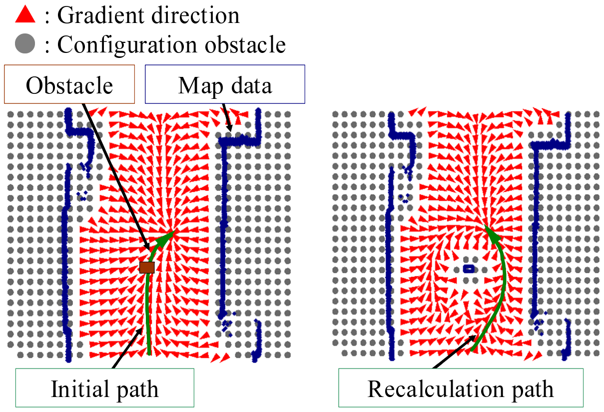


(b) Potential field.



(c) Gradient direction.

Fig. 10. Laplace potential field.



(a) Initial path. (b) Recalculation path.

Fig. 11. Reconstruction of potential field.

on the outward way. Then the robot moves on the return way along a gradient direction of the generated potential field.

An artificial potential method in used for path generation from the mobile robot to the detected human (9) (10). Potential method is a method that generates a potential field in the space, and the mobile robot moves along gradient direction of the generated potential field. In this paper, the mobile robot uses the Laplace potential method for potential field generation (11). This method generates potential field without quasi stationary point by applying the fact that the solution of the Laplace differential equation does not have a local minimum value. Figure 10 shows a potential field generated by the Laplace potential method for environment shown figure 10(a). In figure 10(b), the z-axis indicates a potential value. Figure 10(c) shows gradient direction in potential field shown in figure 10(b). A red arrow shows the gradient direction of potential field and a gray point is an obstacle. In figure 10(c), the robot moves a long the path shown by green arrow by adjusting gradient direction of potential field in present the position to its own front direction.

In this paper, the space where the robot moves is a configuration space, and a potential field is generated in configuration space (12). Configuration space is a space that describes the robot as a point without size(representative point) Configuration obstacle is an obstacle enlarged by the robot size. In configuration space, judgment of contact of the robot and obstacle is easily realized by checking whether the robot point touches the perimeter of the configuration obstacle. In this paper, the shape of the robot is assume to be for simplicity, although the read shape is more complicated.

The robot generates a potential field on the outward way using range data measured by the LRF. When the robot detects a human, the robot determines the position of a human who is the nearest to the robot as a target position and regenerates a potential field. Then the robot moves along the gradient direction of the generated potential field. The robot follows a human by repeating the abovementioned process.

For the robot to avoid obstacles not recorded in the map, the LRF measures an ambient environment while the robot moves on the return way and the robot reconstructs a potential field. Figure 11 shows reconstruction of a potential field. A red arrow indicates a gradient direction of the potential field and gray points show configuration obstacles, blue points show map data, and green arrows show the path for the mobile robot to move. It the robot detects an obstacle which did not exist on the outward way, the obstacle is added to the map data made on the outward way (Fig.11(a)). Then the robot reconstructs a potential field to avoid obstacles (Fig.11(b)). By this method, even if the obstacle not recorded in the map on the outward way exists in the robot path, the robot can move safely on the return way.

5. Experiment

5.1 Experiment device We used the mobile robot "Pioneer3" of MobileRobots, Inc. The mobile robot has 2 drive wheels and 1 caster. The mobile robot's highest speed is 200mm/sec The robot turns with the velocity differential of a right and left wheel.

The robot used the LRF model LMS200-30106 by SICK as a sensor. The LRF and the camera are mounted at a height of 30cm and 80cm above the floor, respectively. The sensing range of the LRF is 180 degree in one plane and it has the resolution of 0.5 degrees.

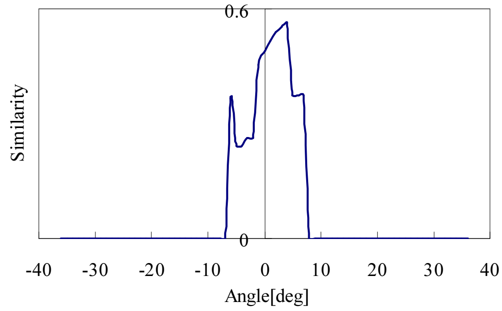
As the specs on computers, CPU is Intel Core 2Duo

(a) Outward way.

(b) Return way.

Fig. 12. Environment.

(a) Acquired image.



(b) Similarity distribution.

Fig. 13. Result of human following.

T9300 2.5GHz, and memory is 3.5GB.

5.2 Experiment environment We conducted experiment that the mobile robot follows a human to the target point and then returns to the starting point. Experiment environment is a corridor with a flat floor. Figure 12(a) shows the experiment environment on the outward way and Fig.12(b) shows the experiment environment on the return way. The obstacle that had not existed on the outward way existed on the return way, as shown in figure 12(b).

5.3 Experimental result On the outward way, the mobile robot followed the human with the LRF and the camera. Figure 13(a) shows an image acquired with the camera while the robot followed the human. Figure 13(b) shows the similarity distribution acquired at that time. The horizontal axis in Fig.13(b) indicates the view angle from the robot (the positive and negative values correspond to the right and left angle, respectively). In figure 13(b), it is shown that the distribution of a high degree of similarity appears in the vicinity of the angle where the human exists Therefore, the robot can detect the angle where the human exists.

The robot moved on the return way by using the map which had been generated on the outward way. And on the return way, the obstacle that did not exist on the outward way existed as shown in Fig.12(b). Figure 14 shows the trajectory of the robot on the outward way and the return way. The triangle shows the starting point and the quadrangle shows the goal point. Red points are range data on outward way, and blue points are range data on the return way. Yellow points shows the robot trajectory on the outward way and green points shows the robot path on the return way. It can be confirmed that the robot avoids obstacles not recorded in a map, as shown in Fig.14.

These results show that the mobile robot can detect and follow the human by the proposed technique in the experimental environment and can return to the starting point while avoiding obstacles not recorded in the map.

6. Conclusion

In this paper, in 2-D static environment, we construct the mobile robot system that has functions of human following and returning to the starting location autonomously while avoiding obstacles. Human following is realized by human detection with the LRF and the camera. Then map generation with few alignment errors is achieved by the ICP algorithm. The robot returns the starting point by path generation by the Laplace potential method with generated map and a path of avoiding obstacle can be generated by reconstructing a potential field.

As a future work, we have to implement location estimation of target human by using particle filter or Kalman filter because the robot loses the target by occlusion and the robot cannot distinguish the target when there appears another human being of the clothes of the same color as the target. Another work is to find the shortest path on the return way, because the human does not always lead the robot in the shortest path on the outward way.

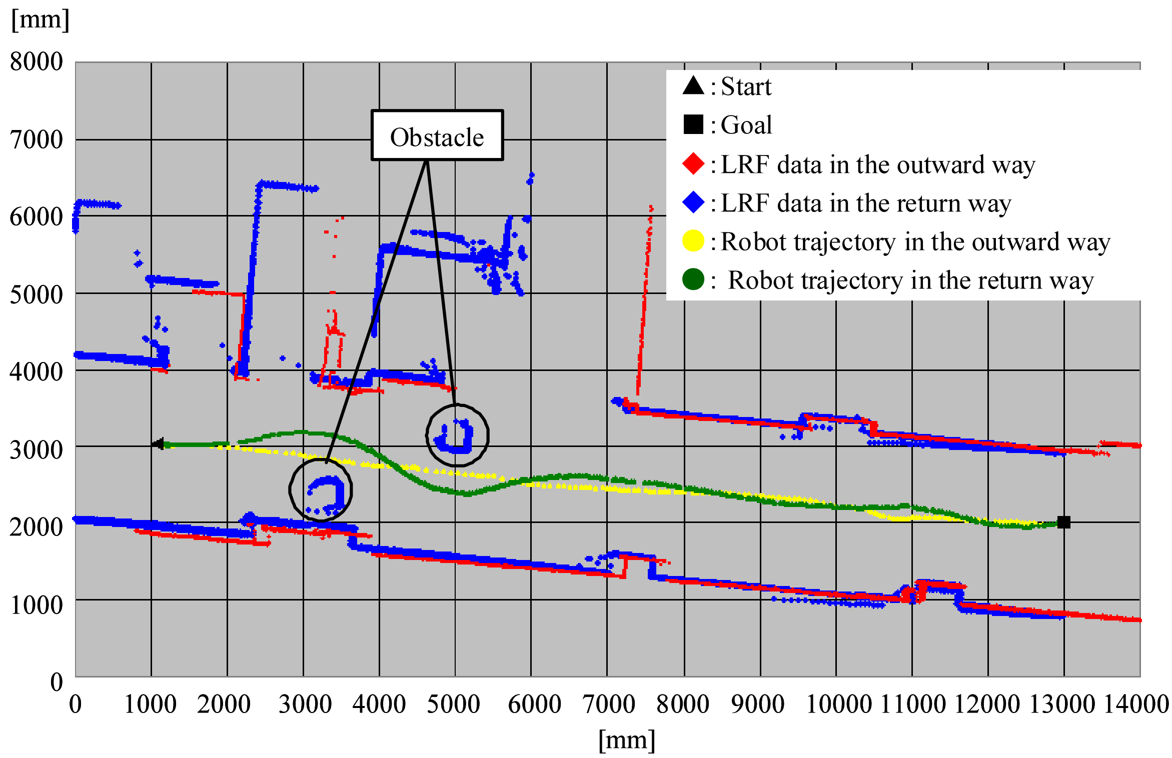


Fig. 14. Generated 2-D map and trajectory of mobile robot on the return way.

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