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Development of Outdoor Mobile Robot for Human Following Navigation

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Abstract: This paper deals with the development of a mobile robot for human following navigation in outdoor urban environment. Laser scanner and omni-directional camera were installed on the mobile platform for detecting people including a target person. The scan and image data from both sensors was fused into the information for tracking multiple moving objects, i.e. people. System configuration has been designed for effective collaboration between components operating in real-time. In order to follow the target, a motion control method based on the relative distance and velocity between the target and the robot itself. The proposed method was demonstrated through experiments of human following navigation with the developed robot in the outdoor environment of university campus.

Keywords: Human Following, Motion Control, Outdoor Mobile Robot.

1 INTRODUCTION

Over the classical contribution of robots to industry, recent technology is advancing for the future role in human daily life. Also in the case of mobile robot, over the last several decades AGV (Automatic Guided Vehicle) has been its typical application for object transportation in factory automation. However, researches to find applications of the advanced technology recently have been carried out for the innovation of mobile system in human daily life. It has been known that the capability to recognize daily environment and interact with human is fundamentally required for such robot to exist with people and perform service tasks.

So the researches related to human recognition have been actively performed. Most of them use camera sensor to detect human feature [1]. It can provide abundant data in its image but requires complicated algorithms and computing power for processing to extract important information in real time. Besides, stereo camera system is needed for the case to use range information. By using Omni-directional camera with a hyperbolic mirror, a special image of 360-degree field of view in the horizontal plane can be provided. Laser scanner is another alternative sensor to detect the state around the robot, which provides range data of horizontal plane with the time-of-flight information of the laser ray reflected by the rotating mirror. It has been utilized in various applications to mobile navigation such as human detection, map building, positioning, and so on [2].

The objective of this paper is to develop a mobile robot that can follow a target person moving in outdoor environment. For that, a laser scanner and an omni-directional camera have been employed as the primary and the secondary sensor to detect people around the robot, respectively. The information of both sensors and the odometer data of the robot were fused in real time by the filtering algorithm installed in the control system. The system and the proposed method were confirmed through experiments of human following navigation.

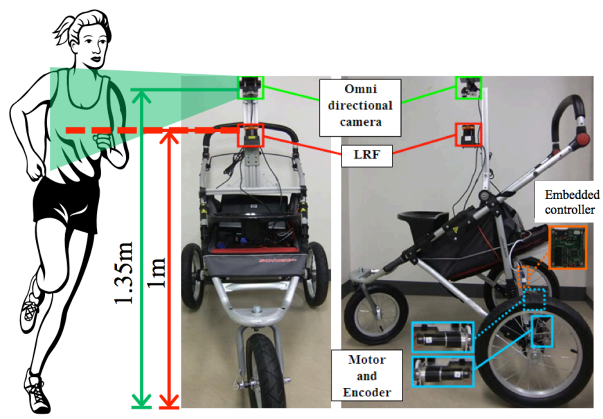


Fig. 1. Mobile robot system

2 DEVELOPMENT OF OUTDOOR MOBILE ROBOT

2.1 Mobile robot system

The mobile robot developed in this research is shown in Fig. 1. Its two active rear wheels rotate independently by two motors and a passive caster was used for the front wheel. An embedded controller is used for the motion control of the robot. The maximum velocity of the robot was designed as 4 [m/s] with the combination of reduction gear and wheel size. The encoders of rear wheels provide the position information with the manner of odometer.

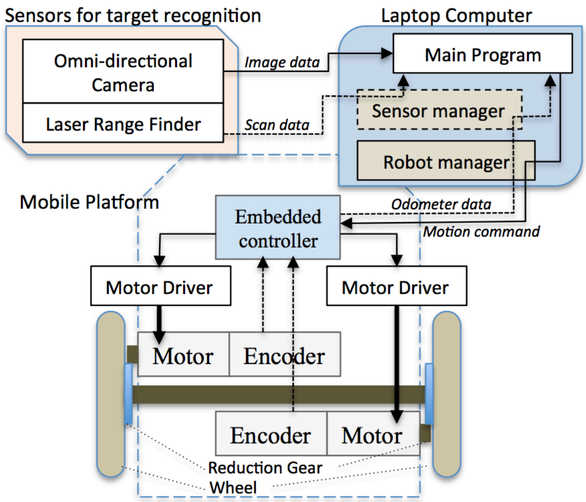


Fig. 2. System block diagram of the mobile robot

2.2 System configuration

The block diagram to show the configuration of the hardware system is given in Fig. 2, which mainly consists of three parts, mobile platform, sensors for target recognition, and laptop computer. The embedded controller in mobile platform is connected to the robot manager of laptop computer. Thus the motion command and odometer data are exchanged with each other. Two sensors, omni directional camera and laser scanner (Laser Range Finder), are installed on the top of the robot with the height of about 1.35 [m] and 1 [m], respectively. Their image and scan data is transferred to the main program in the computer. The capturing frequencies are 30 [fps] for image and 40 [Hz] for scan data, respectively. The sampling time of the odometer data is set to 5 [ms] in the robot. For the management of the large amount of high speed data, sensor manager with ring buffer is employed in the computer. It transfers scan and odometer data as synchronized information. The image data is transferred directly to the user program because of its huge amount. All of them are synchronized and fused with filtering algorithm in the computer.

2.3 Target recognition

In previous research [3, 4], a method to track people with laser scanner and omni directional image. Figure 3 shows the resultant omni directional image in which the laser range data is displayed with red points. This research modified it to recognize the target person. The state of people detected by the robot at time k is defined as

$$x_i(k) = (\ x_i(k) \quad y_i(k) \quad \dot{x}_i(k) \quad \dot{y}_i(k) \quad h_i(k)\ )^T, \quad (1)$$

where the subscript i denotes the number of people. $h_i(k)$ denotes the color state of i-th human, which is extracted from the part of the image.

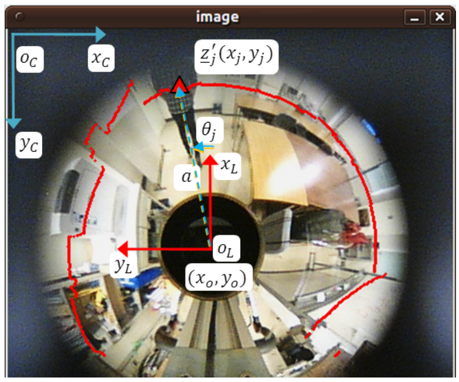


Fig. 3. Omni-directional image with scan data

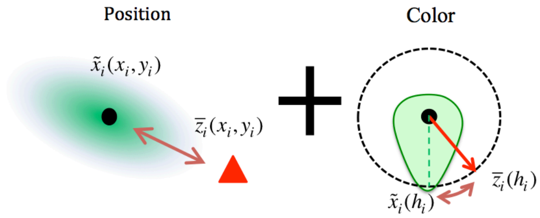


Fig. 4. Data association with position and color information

The association between the predicted state $\tilde{x}_i(k)$ and measurement $\bar{z}_i(k)$ was performed based on Mahalanobis distance considering both position and color as shown in Fig. 4. The state of each person near the robot is estimated with Kalman filtering method [5]. Resultantly the target was selected from the objects recognized by the method.

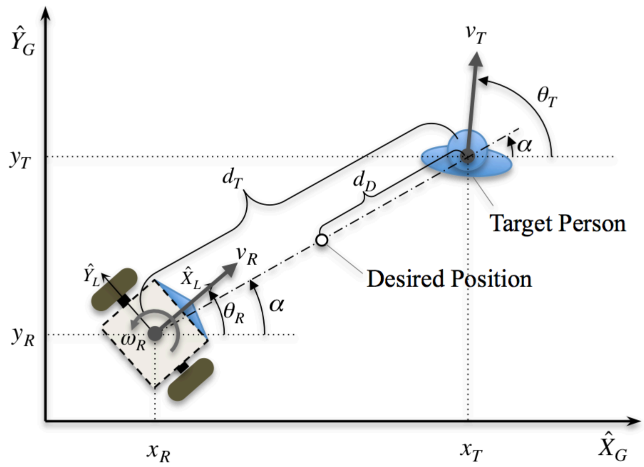


Fig. 5. Schematic representation of motion control for a mobile robot to follow a target person

3 MOTION CONTROL ALGORITHM

3.1 Velocity control for human following

Figure 5 shows the schematic representation of motion control for the robot to follow a target person. For target following navigation, the velocity of the robot should be controlled based on the position relationship between the robot and the target. Besides, the velocity of the target is also considered at the same time. The desired velocity is realized by controlling both motors of wheels resultantly.

The desired velocity for the robot is computed as follows. The desired linear velocity of the robot is decided based on the velocity of the target person and the relative distance from the robot to target as following.

$$v_D = v_T + K_D(d_T - d_D) \tag{2}$$

where, v_T denotes the velocity of the target person. The distance from target person to robot, d_T is given as

$$d_T = \sqrt{(x_T - x_R)^2 + (y_T - y_R)^2}\ , \tag{3}$$

and its desired distance is defined as d_D. K_D denotes the feedback gain related to control the distance.

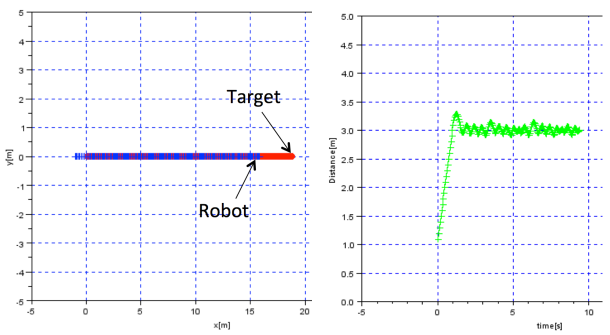
The desired angular velocity of the robot is decided based on the moving direction of the target person and the direction from the robot to the target as follows.

$$\omega_D = -K_{\theta 1}(\theta_R - \alpha) + K_{\theta 2}(\theta_T - \alpha) \tag{4}$$

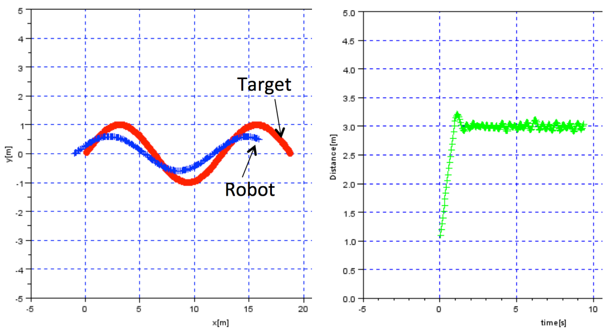
where θ_T denotes the moving direction of the target with respect to the fixed global coordinate. α is the direction from the robot to the target on the global coordinate. $K_{\theta 1}$ and $K_{\theta 2}$ are the feedback gains related to control the moving direction.

3.2 Computer simulation

Computer simulation with the above mentioned algorithm has been carried out. Two results of following a target in linear and sinusoidal motion are given as follows.



(a) Change of robot's position (left) and distance (right) from the target in linear motion



(b) Change of robot's position (left) and distance (right) from the target in sinusoidal motion

Fig. 6. Simulation results of target following control

The target was set to move with the linear velocity of 2 [m/s] in the simulation. The relative distance between robot and target was set to 3 [m]. The left figures of Fig. 6 (a) and (b) show the motion trajectories of both the robot and the target, and the right figures show the change of robot velocity, respectively. It is observed that the robot can follow the target and the distance between them can be controlled in both cases.

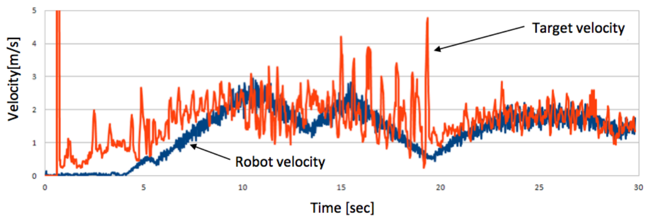
4 EXPERIMENT

In order to test both algorithms for people recognition and human following control, experiments with the developed robot system had been carried out.

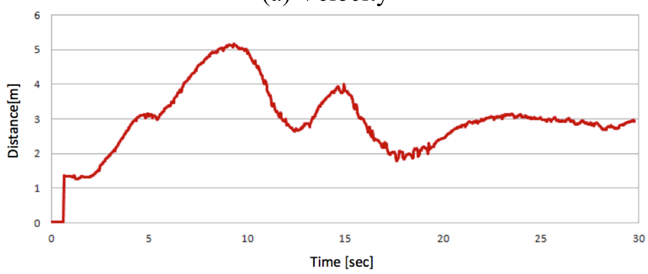
4.1 People recognition

Experiment of people tracking was performed with the mobile robot in passive running by manual operation. Figure 7 shows an example of tracking three people, in which three people running in front of the robot were recognized robustly.

Fig. 7. Experiment of recognizing running people with the robot system in motion



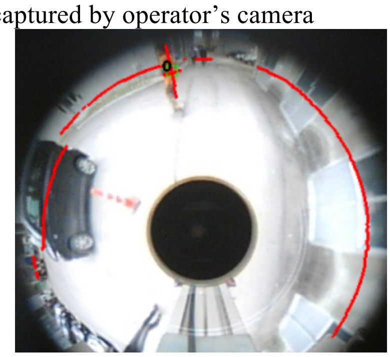
(a) Velocity



(b) Distance between the robot and the target

Fig. 8. Experimental results of target following control

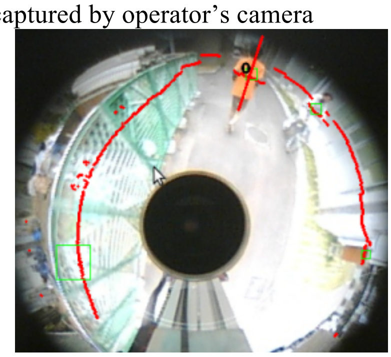
(a) Image captured by operator's camera



(b) Omni-directional image captured by the robot

Fig. 9. Example 1 of human following experiment

(a) Image captured by operator's camera



(b) Omni-directional image captured by the robot

Fig. 10. Example 2 of human following experiment

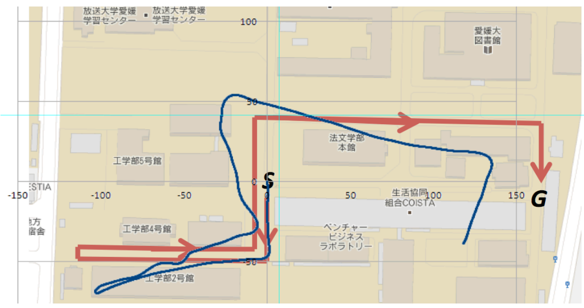


Fig. 11. Motion trajectory of the robot in human following experiment

4.2 Human following

Human following experiment was demonstrated with the developed robot system with the proposed method. The robot could follow the target person without failure during the navigation whose total distance was about 500 [m]. Overall velocity of the robot was changed in the range around 2 [m/s]. It was found that the robot's velocity was controlled according to the target's in spite of its noisy situation as shown in Fig. 8 (a). Besides, the desired distance between the robot and the target was controlled as shown in Fig. 8 (b), though fine tune is also required for more effective motion of fast response. Two representative scenes of the experiment, captured by the omnidirectional camera on the robot and the operator's, are displayed in Fig. 9 and 10. The target person was recognized stably and marked as '0' in the omni directional images. The resultant trajectory measured by odometry is depicted on the map as displayed in Fig. 11, where it shows distortion owing to its natural characteristics.

5 CONCLUSION

Based on people tracking method with both laser scanner and omni directional camera, the robot system that can follow a runner was developed in this research. Through computer simulations and experiments in urban outdoor environment, it was confirmed that the robot with the proposed control could perform human following navigation robustly. As future work, intelligent motion control considering moving and static obstacles will be investigated.

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