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Trajectory Tracking Control of Mobile Robot Moving along Curved Wall Using Imaginary Wall

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Abstract: In this study, a trajectory tracking control method of a mobile robot moving along curved wall is proposed. To move along curved wall, we use imaginary wall that is generated by distance between the mobile robot and the wall the trajectory tracking control method consists of three control methods. The first one is a method that controls the mobile robot to move along a wall maintained constant. The second one is a method that controls the mobile robot to move along a wall in case of the wall direction changes. The third one is obstacle avoidance on a path. We developed a mobile robot which has two-driven wheels and the laser range finder to confirm the proposed method.

Keywords: Mobile Robot, Trajectory Tracking Control, Wall, Obstacle, Laser Range Finder.

I. INTRODUCTION

In recent year, differential type mobile robots have been applied in not only a factory but also a hospital and an office. For examples, a security robot for security patrols in a building, a cleaning robot and an information robot that works at a shop and an airport are developed. To move these robots autonomously, it is necessary to determine its own position and orientation. Dead-reckoning by using an internal sensor such as a rotary encoder and an external sensor such as a vision sensor are used so as to determine the position and orientation of the mobile robot. Many studies on the dead-reckoning of the mobile robot have been proposed. A position estimation method of a wheeled mobile robot by integrating the informations in an odometric dead reckoning and a laser navigation system (*e.g.*, [1]), a method of mobile robot localization on a Topological-Geometrical map which permits inaccurate description (*e.g.*, [2]) are reported. But measurement errors of the position and orientation of the mobile robot increase as the distance covered increases in the localization method using the dead-reckoning.

On the other hand, a motion control method for the mobile robot using an external sensor is studied. Sensor-based navigation used a target direction sensor for the mobile robot among unknown obstacles in work space (*e.g.*, [3]), long distance outdoor navigation of the autonomous mobile robot along a curbstone (e.g., [4]) are reported.

When the autonomous mobile robot moves the long distance, it often moves along the target such as the guide tapes, wall and curbs. Kojima et al [5] proposed a hierarchical vehicle control system of the mobile robot along the wall. Their control system consists of a desired signal generator of wheel velocities using two laser displacement sensors and a wheel velocity controller.

II. Development of Mobile Robot with Two Independently Drive Wheels

1. System construction

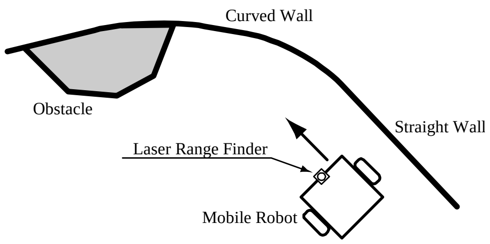
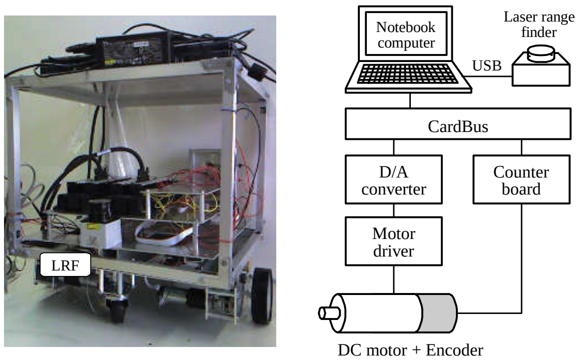


Fig.1 Mobile robot moving along wall and avoiding obstacle

We develop a mobile robot has two independently driven wheels shown in Fig.2 (a). The mobile robot has one laser range finder in the front of the body, two driving wheels on both sides and two non-driving wheels in the front and in the rear. The system construction of the mobile robot is shown in Fig.2 (b). A DC servomotor with a reduction gear and a rotary encoder actuates the driving wheel using a belt pulley. The mobile robot is controlled by a notebook computer. The DC motor which actuates the wheel is controlled by a DA converter and a motor driver. A signal of a rotary encoder is measured by a counter board and sent to the notebook computer. An angular velocity of wheel is detected by numerical differentiation of signal of the rotary encoder.



(a) Mobile robot (b) System construction

Fig.2 Mobile robot and system construction

2. Laser Range Finder

Figure 3 illustrates the 2-dimensinal laser range finder which was made by Hokuyo Automatic Co, Ltd... This sensor features compactness, lightweight, high precision and low power consumption, and provides the wide scan angle with high resolution, which is very important for environment recognition by mobile robots (*e.g.*, [6]).

Fig.3 Laser range finder "URG-04LX"

III. Wall Tracking Method for Mobile Robot using LRF

To move the autonomous mobile robot along the wall require maintaining a distance between the mobile robot and the wall constant, measuring a changing direction of the wall and avoiding obstacles on a path. In this study, the wall tracking control method for the mobile robot follows some rules as below conditions.

- The distance between the mobile robot and the wall is maintained constant.
- The mobile robot moves along a curved wall and a changing direction of the wall.
- The mobile robot avoids obstacles.

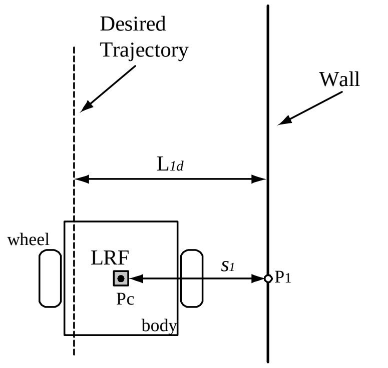


Fig.4 Relationship between mobile robot and wall

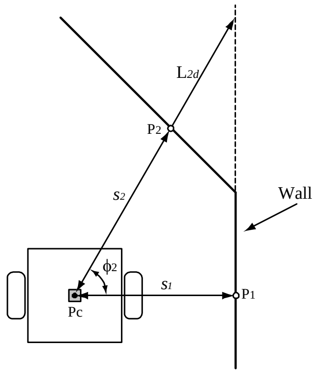


Fig.5 Calculation of the changing direction of wall

1. Control Method to Maintain the Distance between Mobile Robot and Wall Constant

Figure 4 shows a coordinate of the mobile robot and the wall. The LRF is mounted on the center of gravity of the mobile robot. The LRF can measure a precise distance to a target. A maximum scanning angle range is 270[degrees] and a resolution of the angle range is 0.36[degrees]. In this subsection, only a distance to a perpendicular direction to the forward direction is used. The distance to the perpendicular direction is s_1 and a point of intersection between s_1 and the wall is P1. Here a desired distance between the center of gravity of the mobile robot and the wall is L_{1d}, a deviation to maintain the distance between the robot and the wall is written as follows.

$$\delta = s_1 - L_{1d} \tag{1}$$

Next, the wall is not necessarily straight. It is difficult for the mobile robot to track not straight wall by eq. (1). Then to estimate the changing direction of the wall, a distance s_2 that inclines by ϕ_2 relative to the s_1 is measured. Assuming that the wall continues in parallel to the forward direction of the mobile robot as shown in the dotted line in Fig.5, a distance to the wall in the direction of s_2 is expressed as following equation.

$$L_{2d} = \frac{s_2}{\cos\phi_2} \tag{2}$$

If $s_2 < L_{2d}$, the changing direction of the wall is as shown in solid line in Fig.5. When a point of intersection between s_2 and the wall is defined to be P2, an imaginary wall that connects P1 with P2 is generated as shown in Fig.6. An angle of inclination of the imaginary wall ϕ is express as following equation.

$$\phi = \tan^{-1}\left(\frac{s_1 - s_2\cos\phi_2}{s_2\sin\phi_2}\right) \tag{3}$$

To move the mobile robot track the wall, control objectives are to bring δ and ϕ to 0. In case of the mobile robot with two independently driven wheels, δ and ϕ is able to bring to 0 by controlling the angular velocity. Let Δt be a frequency of sensing, a desired angular velocity of the mobile robot to move along the wall ω^{ref} is written as follow.

$$\omega^{ref} = \omega(t) - (K_\phi\phi + K_\delta\delta)\Delta t \tag{4}$$

Let v^{ref} be a desired forward velocity, desired angular velocity of right and left wheels ω_r^{ref}, ω_l^{ref} is expressed as follows.

$$\begin{pmatrix}\omega_r^{ref}\\ \omega_l^{ref}\end{pmatrix} = \begin{pmatrix}\frac{1}{R_w} & \frac{T}{2R_w}\\ \frac{1}{R_w} & -\frac{T}{2R_w}\end{pmatrix}\begin{pmatrix}v^{ref}\\ \omega^{ref}\end{pmatrix} \tag{5}$$

If the inclination of the wall changes as shown in Fig.6 ($s_2 > L_{2d}$), the angle of inclination of the imaginary wall cannot be calculated. In that case, the mobile robot can move along the wall shown in Fig.6 by setting ϕ to 0.

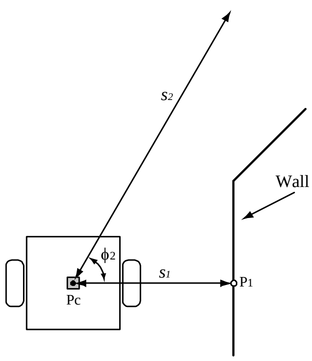


Fig.6 Relationship between mobile robot and wall

2. Obstacle Avoidance

It is difficult to avoid the obstacle and dead-end in the method of subsection III.1. Then, to avoid the obstacle and the dead-end as shown in Fig.7, a distance of forward direction s_3 is measured by the LRF. Let L_{3d} be a minimum allowed distance between the mobile robot and the forward object. If $s_3 < L_{3d}$, the mobile robot turns until $s_3 > \alpha L_{3d}$. α is safety rate.

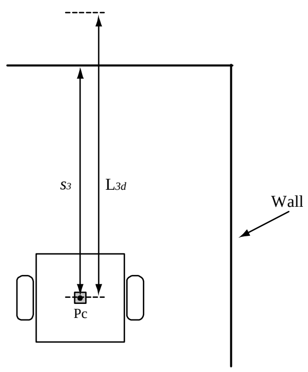


Fig.7 Obstacle and dead-end avoidance

3. Tracking Control

The mobile robot can move along the wall and avoid the obstacle and the dead-end by using the proposed method. But it is difficult to satisfy the tracking control, the obstacle avoidance and dead-end avoidance simultaneously. Then in this study, we introduce the concept of the order of priority into the tracking control method. Here, we place the first priority is given to obstacle and dead-end avoidance, the second priority is given to tracking control moving along wall. The algorithm of the proposed method is shown as follows.

STEP 1: The distance to a perpendicular direction to the forward direction s_1, the distance s_2 that inclines by ϕ_2 relative to the s_1 and the distance of forward direction s_3 are measured by the LRF.

STEP 2: If $s_3 < L_{3d}$, the mobile robot turn until $s_3 > \alpha L_{3d}$ then return to STEP 1. If $s_3 > L_{3d}$, go to STEP 3.

STEP 3: From eq.(2), L_{2d} is calculated. If $s_2 < L_{2d}$, the angle of inclination of the imaginary wall is calculated from eq.(3). If $s_2 > L_{2d}$, ϕ is set to 0. From eq.(1), δ is calculated.

STEP 4: From eq.(4), the desired angular velocity of the mobile robot ω^{ref} is calculated, the desired angular velocity of the right and left wheels ω_r^{ref} and ω_l^{ref} are calculated by eq.(5).

IV. Experiments

To verify the efficiency of proposed method, this section shows two experiments result. In first experiment, one obstacle is placed on the path. In second experiment, the path is dead end.

1. Experiment 1

Figure 8 shows the experimental environment composed of the obstacle, the straight line wall and the curved wall. A size of the obstacle is 0.5[m] x 0.5[m] and the other parameters are as follows; v^{ref} = 0.2[m/sec], L_{1d} = 0.5[m], L_{3d} = 0.6[m], Δt = 0.1[sec], t_f = 26.0[sec]. From Fig.8, the mobile robot is able to move along the wall and to avoid the obstacle. After the obstacle avoidance, the mobile robot moves toward the straight wall then follows again along the straight and curved one.

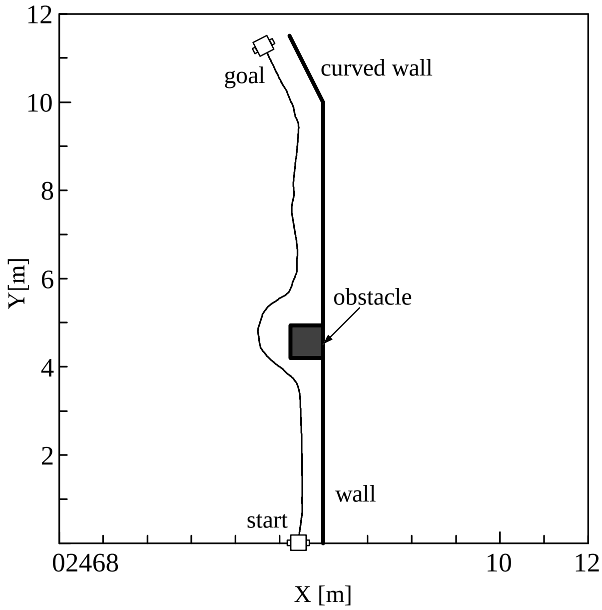


Fig.8 Experimental environment and resultant path in experiment 1

2. Experiment 2

Figure 9 shows the experimental environment composed of the obstacle, the straight line wall, the curved wall and the dead end. Parameters are as follows; v^{ref} = 0.2[m/sec], L_{1d} = 0.5[m], L_{3d} = 0.6[m], Δt = 0.1[sec], t_f = 37.0[sec]. Fig.8 the mobile robot moves along the wall and avoids the obstacle. Therefore, the efficiency of the proposed method is confirmed.

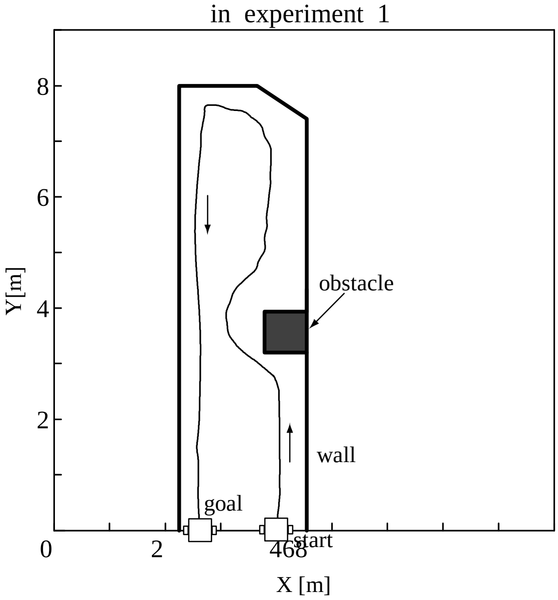


Fig.9 Experimental environment and resultant path in experiment 2

V. Conclusion

In this paper, we discussed the tracking control method for the mobile robot moving along the wall. This method consists of maintaining the distance between the mobile robot and the wall constant, estimating the changing direction of the wall and tracking it with avoiding the obstacle and the dead-end. To track the wall efficiently, we introduce the concept of the order of priority into the tracking control method. Finally, we demonstrate the effectiveness of proposed method in actual environments.

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