Wall-following Control of Multi-Robot Based on Moving Target Tracking and Obstacle Avoidance

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Abstract. Studies on wall-following problem mostly focus on an single robot only. This study proposes a wall-following method of multi-robot, which is based on moving target tracking. The leader robot moves along walls by using position information include angle and distance between robots and walls. The follower robot moves along the walls, tracks its leader and avoids collision at convex corner of walls. Two E-puck robots are used in experiment in this study. The results of experiment verify the feasibility of this method.

Keywords: Wall-following · Obstacle avoidance · Tracking moving target.

1 Introduction

The wall-following control problem is characterized by moving the robot along a wall in a desired direction at the same time maintaining a constant distance to that wall [1]. It is worth mentioning that a map of the environment is not needed. There are several reasons why autonomous mobile robots must be able to follow walls, or in a more general sense, to follow the contours of an object. Mobile robots need to have the ability to follow walls in these scenes:

- obstacle avoidance [1–3]: When a mobile robot can 't get the shape of the obstacle, it can 't plan an effective path to avoid the coming collision. Therefore, moving along the contours of the obstacle become a reasonable strategy.
- navigation in unknown environment [1, 4]: When a robot is moving in an unknown environment, following the walls should be a reasonable and effective strategy of path planing for it.

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– mapping and localization [1, 5, 6]: When the location of the robot is known, the modeling of the environment can be realized by using wall-following strategy. On the contrary, if the robot moving along walls in a certain environment, it is possible to localize the robot.

At present, many researches have been done on wall-following problem of a single mobile robot. C. F. Juang e.g. proposed a reinforcement ant optimized fuzzy controller (FC) design method and applied it to wheeled-mobile-robot wall-following control under reinforcement learning environments [7]. R. Braunstingl e.g. designed a fuzzy logic controller and local navigation strategy [8]. Dain e.g. demonstrated the use of genetic programming (GP) for the development of mobile robot wall-following behaviors [9].

But all these studies focus on wall-following control of a single robot only. In our study, a simple controller is designed using the angle and distance measured by infrared sensors. On this foundation, a wall-following navigation of multi-robot based on moving target tracing is designed and implemented.

A simple method used to make one robot move following a wall is given in Section II. Section III proposes tracing and obstacle avoidance algorithm. In section IV, the wall-following of multi-robot is realized in experiments and a discussion is given. Finally, a brief summary is provided in Section V.

2 Wall-following Control Of A Single Robot

A diagrammatic description of wall-following problem is shown in Fig.1. The position of the robot in the Cartesian space is given by x , y and θ . The

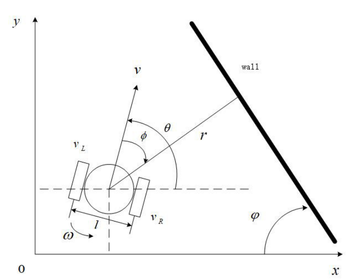

Fig. 1. Wall following of a single robot.

kinematics model of two wheeled robot is given as below.

$$\begin{cases} \dot{x} = v \cdot \cos\theta \\ \dot{y} = v \cdot \sin\theta \\ \dot{\theta} = \omega \end{cases} \tag{1}$$

The mobile robot can be considered as a system with two inputs and three outputs. The three outputs are the position coordinates x, y and θ. The two inputs are the speeds of the two wheels. However, instead of the wheel speeds, the translation and rotation speeds of the robot as a whole are more interesting. The relation of them can easily be found as

$$\begin{cases} v = \frac{1}{2}(v_R + v_L) \\ \\ \omega = \frac{1}{l}(v_R - v_L) \end{cases} \tag{2}$$

$$\begin{cases} v_R = R_w \cdot \omega_R \\ v_L = R_w \cdot \omega_L \end{cases} \tag{3}$$

with R_w the wheel radii, ω_R the palstance of the right wheel, ω_L the palstance of the left one, and l the distance between the two wheels.

In order to move along the wall, the robot needs to keep the wall on its right side(or left side) and maintain a safe distance from the wall. Therefore, the angle between the direction of the robot and the tangent direction of the wall needs to be stabilized at a particular angle which is marked as Φ, while the distance should be maintained at a constant which is described as R. The forward direction of robot is defined as 0 radians, and counterclockwise is positive while clockwise is negative. In general sense, when the robot is wanted to keep and move on the right side of the robot, the value of Φ is usually $\frac{\pi}{2}$. On the contrary, Φ is equal to $-\frac{\pi}{2}$ while the robot is supposed to move on the other side. The palstance of the wheel toward the wall is recorded as ω_I, and the palstance of another is ω_O. The relationship between ω_I, ω_O and ω_L, ω_R is represented as follows:

$$\begin{cases} \omega_L = \frac{1}{2}(1 - \sin\Phi) \cdot \omega_O + \frac{1}{2}(1 + \sin\Phi) \cdot \omega_I \\ \\ \omega_R = \frac{1}{2}(1 + \sin\Phi) \cdot \omega_O + \frac{1}{2}(1 - \sin\Phi) \cdot \omega_I \end{cases} \tag{4}$$

The equations above represent that, while Φ is fixed on $\frac{\pi}{2}$, the wall is kept on the left side of the robot, ω_L is equal to ω_I and ω_R is equal to ω_O as a result. The opposite is true, while Φ is equal to $\frac{\pi}{2}$ and the wall is on the other side of the robot, $\omega_L = \omega_I$ and $\omega_R = \omega_O$.

To move the robot along the wall, the palstances of its two wheels ω_O and ω_I can be divided into three parts. As below:

$$\begin{cases} \omega_O = \omega_k + \omega_\phi + \omega_r \\ \omega_I = \omega_k + \omega'_\phi + \omega'_r \end{cases} \tag{5}$$

in which, ω_k is a constant speed at which the robot moves forward, ω_ϕ, ω'_ϕ are speeds used to make ϕ to converge to Φ, and ω_r, ω'_r can regulate the distance r and make it stable at R. ω_ϕ, ω'_ϕ and ω_r, ω'_r are designed as:

$$\begin{cases} \omega_\phi = k_{p\phi} \cdot e_\phi + k_{i\phi} \cdot \dot{e_\phi} \\ \omega'_\phi = -\omega_\phi \end{cases} \tag{6}$$

$$\begin{cases} \omega_r = k_{pr} \cdot e_r + k_{ir} \cdot \dot{e_r} \\ \omega'_r = -\omega_r \end{cases} \tag{7}$$

where $e_\phi = \phi - \Phi$, $e_r = r - R$, which are the angle error and distance error of the system, $\dot{e_\phi}$, $\dot{e_r}$ are their rate of change, and $k_{p\phi}$, $k_{i\phi}$, k_{pr}, k_{ir} are parameters which can be adjusted artificially as required. This is a simple PD controller. Proper parameters can make the system stable.

3 Wall-following Control Of Multi-robot Based On Moving Target Tracking

Because of the subtle differences between the robots, it is difficult to use the same algorithm to keep multiple robots moving in a row along the wall. And the different efficiencies of the motors, make it easy to drift away or collide with each other when robots move in formation. In order to avoid this situation, the method based on moving target tracking is adopted to realize the multi-robot motion along the wall in this study.

3.1 Tracking Moving Target

Sketch of the problem tracking a moving target has been displayed in Fig.2 which is similar to the previous one. In the wall following problem, when robot is wanted to move along walls stably, the azimuth of the robot relative to walls ϕ is supposed to equal $\frac{\pi}{2}$ or $-\frac{\pi}{2}$, and r the distance between them should keep at R. Similarly in this moving target tracking problem:

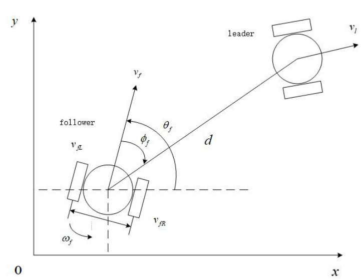

Fig. 2. Moving target tracking problem.

- $\phi_f \to 0$: the follower must always face to its target, so its path angle is wanted to be 0;
- $d \to D$: the distance between the two robots should be kept at a safe value which is described as D.

where ϕ_f is the angle from the direction of the follower to the connection between the follower and the leader, and d is the distance between them, while D is a constant. Detailed information has been shown is Fig.2.

The follower robot should face to and keep a safe distance with its leader. As a result, speeds of the follower's two wheels can be designed as:

$$\begin{cases} \omega_{fL} = \omega_{f\phi} + \omega_{fd} \\ \omega_{fR} = \omega'_{f\phi} + \omega_{fd} \end{cases} \tag{8}$$

$$\omega'_{f\phi} = -\omega_{f\phi} \tag{9}$$

where $\omega_{f\phi}$, $\omega'_{f\phi}$ are speeds which are related to path angle and used to rotate the robot and keep ϕ_f at 0, while ω_{fd} is related to distance and supposed to maintain a safe distance.

3.2 Obstacle Avoidance

Fig.3 shows the process of the obstacle avoidance algorithm.When there is any obstacle, robot will avoid the coming collision first instead of continuing to follow the leader. If the obstacle is on the right side, the robot will turn left; if the obstacle on the left side the robot will turn right; if there is no obstacle close enough to it, the robot will move toward the target.

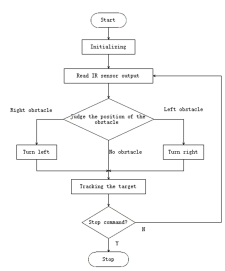

Fig. 3. Flowchart of obstacle avoidance algorithm.

4 Experiment

4.1 The E-puck Robot With Range & Bearing Board

This article verify the algorithms using the E-puck robote [10].

E-puck was equipped with several devices and features. The idea of this study is to navigate the robot using IR sensors and the open E-puck Range & Bearing board. The board allows the robots to have an embodied, decentralized and scalable communication system [11].

Beside Range & Bearing board, there are eight IR sensors on the E-puck robot.These IR sensors have been used in the experiment of obstacle avoidance algorithm.

4.2 Wall-following Of A Single Robot

Using the R&B board, the robot can measure the position and signal intensity which is inversely proportional to the distance between the robot and signal source, if the robot constantly sends out signals, it can calculate the position and distance of the obstacle according to the signal reflected by the obstacle.

Fig.4 shows the experiment of the wall-following controller of one robot given in Section II. In this experiment, the distance between robot and walls is set to 5cm, and Φ is fixed at $-\frac{\pi}{2}$(robot keeps wall on its right side). The trajectory of the robot is marked by a red line. In this experiment, the distance from the wall to the robot remains stable, while the wall is a straight line. The robot can well track walls, whether in a convex corner or a concave one.In general, robot using this method can move well along the wall.

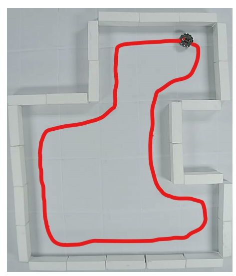

Fig. 4. Experiment a single robot moving along walls.

4.3 Moving Target Tracking And Obstacle Avoidance

Due to the leader moving along walls according to signals reflected by the walls, signals reflected by the follower robot will also have an impact on the leader when they are close enough to each other. In order to reduce the impact of the follower on its leader, the distance between them is set at 10cm. The threshold of sensors output is set at 150. When a certain sensor output is greater than the threshold, the robot will make such a judgment that there is an obstacle in the direction of this sensor, and obstacle avoidance algorithm will work then.

Fig.5 shows the results of the experiment of double robots moving along walls based on moving target tracing and obstacle avoidance. The red points describe the trajectory of the leader robot, while the green ones show how the other robot follows it. Obviously, the follower can track its target stably whether in the straight wall, the convex corner or the concave corner. While robots in the convex corner, the obstacle avoidance strategy given in Section III is adopted. The follower robot will not track the leader until its IR sensors output is below the threshold. However, while in the concave corner, the robot in the rear slows down because the robot in front makes a turn, and the distance between them will become smaller if the follower keeps its speed. Therefore, the trajectory of the follower is not agreement with the trajectory of the leader in concave corners. In addition, the trajectory of the follower appears wavy and zigzag at a straight wall. The cause of this phenomenon will be given in the discussion below.

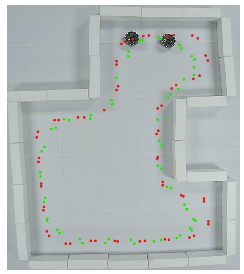

Fig. 5. Experiment of double robots moving along walls.

4.4 Discussion

The robot taking wall-following strategy get orientation of obstacles from receiving and calculating signals which are transmitted by the robot and reflected on the surface of obstacles. The signals are also received and calculated by the follower robot and used for tracking the moving one. Robot not only receives signals sending by its target, but also gets the signals reflected by walls. The result is that when the following robot tracks its moving target, it can not distinguish the real target and the mirror target produced by reflection. Therefore, the robot sometimes tracks the real target, and sometimes moves towards walls. While it is close enough to the wall, the robot will move away from the wall with the operation of obstacle avoidance algorithm. And go on like this. This is why the trajectory of the follower appears wavy and zigzag at a straight wall.

A filter can be used to reduce the effect of this mirror target. The distance between follower and the virtual robot which is caused by reflections must be longer than what between follower and the real target. So, mistakes can be reduced if the distant target, which is possible to be a virtual one, is filtered away. What needs to be noted is that the filter can only reduce the impact, instead of completely eliminated it. In fact, the filter described above has been adopted in this experiment.

5 Conclusion

This study provides a wall-following control method of multi-robot based on moving target tracing. The leader robot calculates position information of walls in real-time measurement and moves along the walls. The follower tracks the leader and takes obstacle avoidance algorithm into use while it gets close to walls. The results of experiment show that the leader can move along walls stably, and the follower tracks its target well.

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