

A Novel Obstacle Avoidance and Navigation Method of Outdoor Mobile Robot

Yunchong Li, and Kezhong He

Abstract—This paper presents a novel method for obstacle avoidance and navigation of outdoor mobile robot, in which, the 2-dimension obstacle information in the polar coordinate space of current view scene is transformed to the 1-dimension angle field. Repulsive forces produced by obstacles and attractive forces produced by the object location are estimated integratively to determine the pass function and the purpose angle. As thus, both the safety of the robot and the approach to the object location are considered. The method has been tested on our outdoor mobile robot THMR-V.

Index Terms—angle potential field method, navigation, obstacle avoidance, outdoor mobile robot

I. INTRODUCTION

THMR-V is a outdoor mobile robot developed by the State Key Laboratory of Intelligent Technology and Systems, Tsinghua University. Equipped with stereo cameras, laser radar, GPS receiver and other sensors, it has the ability of autonomous driving and remote driving.

Obstacle avoidance and navigation are important sections to realize autonomous driving, by which a control command was given based on the path planned and real situation of road and obstacles.

Circumstance sensing is a essential requirement of obstacle avoidance and navigation, and laser radars are widely employed to perform them on mobile robots. Based on the scanning distance data obtained by laser radar and the object location as a result of global path planning, we present a novel method of obstacle avoidance and navigation for outdoor mobile robot.

II. RELATIVE RESEARCH

The Potential Field Method (PFM)¹ was presented by Khatib for the obstacle avoidance of robot. The essential idea of PFM represent the circumstance with a force field, in which the object point produce attractive force and obstacles produce

repulsive force, and mobile robot is leaded by the vector sums of repulsive and attractive forces. PFM was widely applied and developed during the past two decades. Considering the dynamic circumstance of mobile robots, a time-varying PFM method² was presented by Ming Yang, and has been applied successfully to THMR-V.

However, Borenstein³ pointed out that in PFM, too much valuable information about the local environment is lost because of the compression of all information into one single resultant force. Aiming at this problem they presented Vector Field Histogram (VFH) method. In the method, an obstacle density is calculated for each polar sector, then the polar histogram is smoothed and thresholded, and the steering direction is chosen amongst several candidate valleys. VFH was improved to VFH+⁴ and VFH*⁵, and after that, Parameterized Path Families (PPF) method⁶ and Curvature-Velocity Method (CVM)⁷ were presented. A Widest Free Sector method⁸ presented by Hua Li, similar to VFH, was also applied to THMR-V. VFH method has a shortcoming that the result is sensitive to the threshold. A large threshold potentially leads to collisions or dead ends, while a low threshold may omit possible candidate valleys.

Focused on 4-wheel outdoor mobile robots, we present a Angle Potential Field (APF) method, which integrates the effect of all obstacles and the object location to the robot to make a decision, and resolved the threshold sensitiveness and the dead end programs in a certain extent.

III. ANGLE POTENTIAL FIELD METHOD

The most important guideline of obstacle avoidance and navigation is to ensure the safe moving of robot. The mobile robot must sense obstacles promptly and accurately and perform a proper avoidance behavior. With above precondition the robot should be moving towards the object location. Similarly to VFH, APF considers the current vision field of robot, and transform the 2-dimension obstacle information to 1-dimension angle field. The repulsive effect produced by obstacles and the attractive effect by the object are integratively estimated to obtain the leading angle.

A. Model and Coordinate Systems of Robot

The mobile robot THMR-V has the mechanism platform of a rear-driven 4-wheel vehicle. We can use a 2-wheel vehicle model to describe it when the velocity and curve radius is in a proper range. A polar coordinates system with the laser emit

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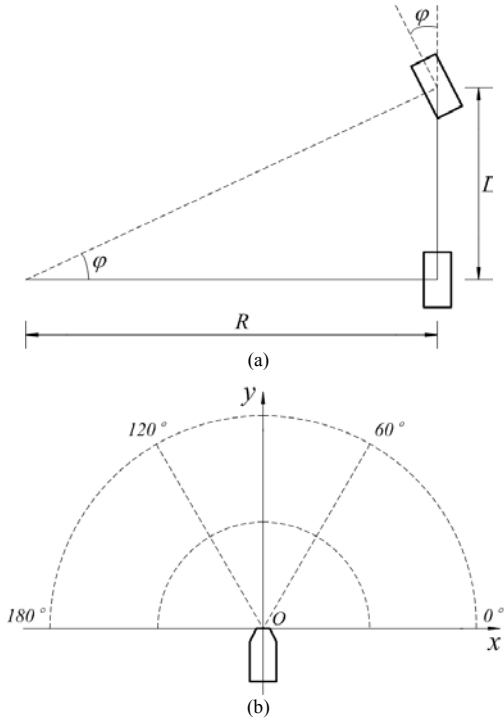


Fig. 1. Model and coordinates systems of mobile robot.
(a) Model of robot (b) Polar coordinates system of robot

point as origin is built as Figure 1.

THMR-V has the unavoidable kinematic restrictions because of the feature of its mechanism platform. Therefore, the obstacles give the robot different effect in radial direction and flank direction. We can define the Flank Safety Distance D_{sf} , meaning the flank distance of robot origin to obstacle that the robot can pass the obstacle safely, and the Radial Safety Distance $D_{sr}(v)$, meaning the moving distance that the robot (with a velocity v) decelerates, brakes and stops as follows.

$$D_{sx} = k_{sx} \cdot \frac{1}{2} \cdot W = \frac{1}{2} k_{sx} W$$

$$D_{sy}(v) = k_{sy} \cdot \frac{1}{2} \cdot v \cdot \frac{v}{-a} = \frac{-k_{sy} v^2}{2a}$$

where

W is the width of mobile robot

a is the acceleration of normal deceleration

B. Repulsive Forces Field

Repulsive forces are produced by obstacles in the vision field, and repulsive force grows while the distance of obstacle reduces. Moreover, repulsive forces also are produced in the neighboring danger angles of the obstacle angle. A platform function is adopted to describe the repulsive forces produced by an obstacle point. The repulsive force at angle θ by the obstacle at angle φ is defined as follows:

$$k_{RF}(\varphi, \theta) = \begin{cases} k_p(\varphi), & \varphi - \delta_s(\varphi) \leq \theta \leq \varphi + \delta_s(\varphi) \\ 0, & \text{Otherwise} \end{cases}$$

$$k_p(\varphi) = \begin{cases} +\infty, & d(\varphi) \leq D_{sy} \\ \frac{1}{d(\varphi) - D_{sy}(v)}, & D_{sy}(v) < d(\varphi) \leq D_m \\ \frac{1}{D_m - D_{sy}(v)}, & d(\varphi) > D_m \end{cases}$$

$$\delta_s(\varphi) = \arcsin\left(\frac{D_{sx}}{d(\varphi)}\right)$$

where

$d(\varphi)$ is the distance of obstacle at angle φ

D_m is the maximal estimate distance

For a certain angle θ , the total repulsive force is set as the maximum produced by the obstacles at all angles. The repulsive force function is illustrated in Figure 2 and formulated as follows:

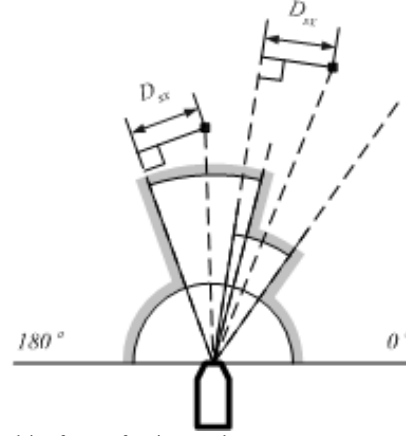


Fig. 2. Repulsive forces of various angles.

$$K_{RF}(\theta) = \max_{\varphi \in [0, \pi]} (k_{RF}(\varphi, \theta))$$

C. Attractive Forces Field

The repulsive forces field represents the resisting effects of obstacles to the mobile robot. Otherwise, for leading the robot move to the object location, attractive force produced by the object point should be considered. A cosine function is used to define the attractive forces at various angles:

$$K_{GF}(\theta) = \cos(\theta - \theta_{obj})$$

where

θ_{obj} is the direction angle of the object point

A cosine function is used because of follow reason: While the angle has a large departure from the object angle, the force varies significantly in order to lead the robot to object direction rapidly; On the other side, while the departure is small, the force varies insignificantly, to avoid that the robot is over attracted by the object point and ignore obstacles.

D. Pass function

For a certain angle θ , we defined the product of the reciprocal of the repulsive force and the attractive force as the pass function $K_p(\theta)$, which evaluate the possibility that the robot pass along this direction and approach the object point. The maximum of $K_p(\theta)$ is defined as the pass function of current scene K_{PG} , which evaluate the possibility that the robot pass obstacles and approach the object point in current vision field:

$$K_p(\theta) = \frac{K_{GF}(\theta)}{K_{RF}(\theta)}$$

$$K_{PG} = \max_{\theta \in [0, \pi]} (K_p(\theta))$$

Figure 3 shows the calculated pass function value of a simulative scene.

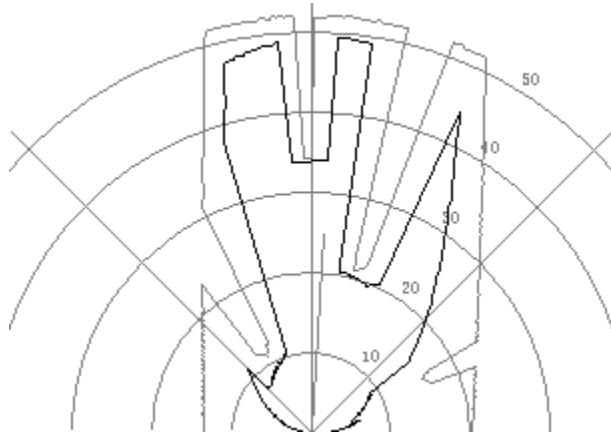


Fig. 3. Pass function of a simulative scene. The inner black line illustrates obstacle distance, and the outer gray line illustrates pass function value.

E. Command output

The rule of command output list as follows:

- (1) While K_{PG} equal to 0, decelerate and stop the robot.
- (2) While K_{PG} is positive, select the angle θ with maximal $K_p(\theta)$ as the purpose angle θ_{out} , and, if the velocity of robot is limited in the range from v_{MIN} to v_{MAX} , the purpose velocity is determined as this:

$$v_{out} = (v_{MAX} - v_{MIN}) \times \frac{K_{PG}}{K_{PGMAX}} + v_{MIN}$$

$$K_{PGMAX} = D_m - D_{sy}(v_{MIN})$$

Above θ_{out} and v_{out} can be used as the control object of control subsystem.

IV. RESULTS

Some simulation results of APF in various circumstances are showed in Figure 4. We can see that APF method has good performance in various circumstances.

The method was also adopted to THMR-V practically. The results were satisfying and had a large advantage over the

earlier obstacle avoidance approaches, such as the time-varying PFM method and the Widest Free Sector method, etc.

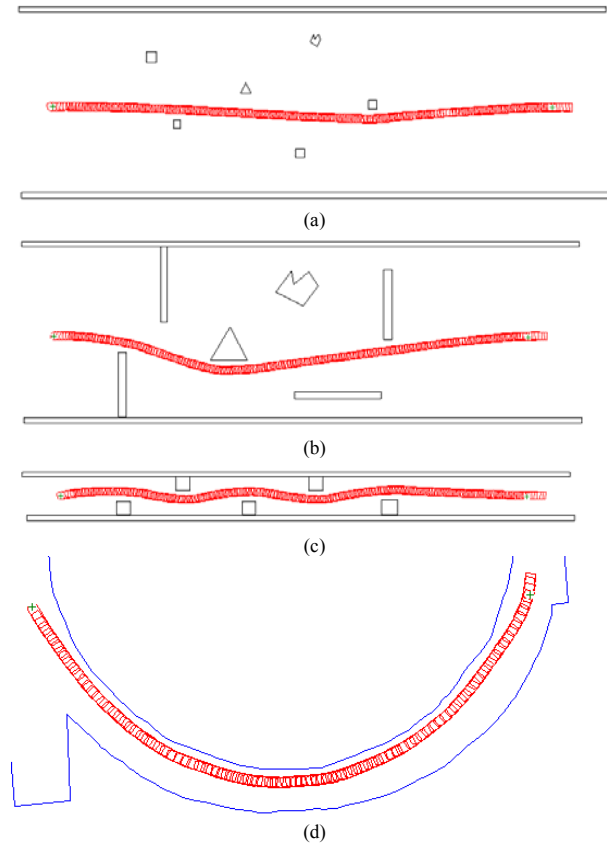


Fig. 4. Simulation results. (a) Spacious space and sparse obstacles (b) Spacious space and crowded obstacles (c) Narrow space (d) Curved path

V. CONCLUSION

The angle potential field method, a novel obstacle avoidance and navigation method of outdoor mobile robot was presented in this article. The kinematic restrictions of the outdoor mobile robot are considered, and the radial and flank effects produced by obstacles are discriminated. No global environment information, except the object location, is needed, and the approach is not sensible to the threshold. Therefore, the method has good flexibility facing the variability of environment. In addition, the idea is concise and has resemblance to the thought of human driving, giving the robot a human-like decision guideline. APF method shows a good performance in simulated and practical experiments.

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