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A New Method for Mobile Robots to Avoid Collision with Moving Obstacles

Yi Zhu[1], Tao Zhang[1], Jingyan Song[1], Xiaqin Li[1], Masatoshi Nakamura[2]

[1]*Department of Automation, Tsinghua University, Beijing 100084, China*
(*Email: taozhang@tsinghua.edu.cn*)
[2]*Research Institute of Systems Control, Saga University, Saga 840-0047, Japan*

Abstract: A new method for mobile robots to avoid collision with moving obstacles is proposed in this paper. It adopts the concept of safe sectors in the vector field histogram (VFH) method but simplifies its description. Moreover, the new method takes the threat of moving obstacles into account when selecting motion direction and a new speed control law that considers more factors is designed. Hence it can better avoid moving obstacles than the VFH method. Simulation results indicate that the new method also shows many advantages over the dynamic potential field (DPF) method which is a representative approach for avoiding moving obstacles. Experiments have further verified its applicability.

Keywords: mobile robots; obstacle avoidance; moving obstacles

I. INTRODUCTION

Obstacle is one of the key issues in many fields. Many methods [1]-[9] have been proposed to indicate the influence of obstacles and solve this problem over the past twenty years. For example, In [2][3], they found recess shape to play an important role in the performance of aerostatic bearings, and found vortex flows in the recess by numerical experiments which cause instabilities and vibrations of the bearing. The elimination of obstacle influence is one of important reasons in this research. This paper mainly studies on the obstacle avoidance of mobile robots. Although there are many methods on this research, most previous works focus on static obstacles and only a few works [6]-[9] address the problem of dealing with moving obstacles.

To deal with moving obstacles, one concept is previously planning a safe path which takes moving obstacles into account to guide the robot [6]. The drawback of this concept is that it assumes the trajectories of moving obstacles are known in advance, which is unrealistic in many scenarios. Another concept is dynamically planning the motion in every control cycle by sensory information [7]-[9]. This concept is more practicable since it can adapt the changing motion of moving obstacles. One representative method based on this concept is the DPF method [7], [8]. In this method, the target generates an attractive force and the threat of all the moving obstacles is represented by a repulsive force. The robot always moves in the direction of their resultant force.

In this paper, we propose a new obstacle avoidance method for mobile robots to deal with moving obstacles. The new method adopts the concept of safe sectors in the VFH method [1] which is a motion planning method mainly for static environments. But the new method simplifies its description to lower the computational and spatial complexity and takes the threat of moving obstacles into account when choosing motion directions. Hence it can better handle moving obstacles than the VFH method. Another improvement of the new method is its speed control law that takes more factors into account than the VFH method. The new method also shows advantages over the DPF method in many aspects, which has been discussed in this paper. The remainder of this paper is arranged as follows: the VFH method is briefly reviewed in Section 2 and the new method is presented in Section 3. Some simulations and experiments are presented in Section 4.

II. THE VFH METHOD

As an efficient obstacle avoidance approach, the VFH method [1] can generate smooth trajectory without oscillations and guide the robot to go through narrow corridors. The VFH method divides all the directions around the robot into some safe sectors that the obstacle density (a value that is proportional to the negative of the distance from the robot to obstacles) in any direction of these sectors is no less than a threshold. The middle directions of such sectors are candidates for motion and the one that has the minimal bias to the target direction is selected as the final motion direction. Nevertheless, the VFH method only takes the distances of obstacles into account and ignored their velocities. Therefore it's not suitable to be applied in environments containing moving obstacles especially when they move fast.

III. THE PROPOSED METHOD

The new method proposed in this paper adopts the basic concept of safe sectors in the VFH method but improves it in three main aspects. Firstly, the new method directly compares the obstacle distance of one direction with a threshold to judge whether the direction is safe without figuring out a density value based on a grid map that needs updating in every control cycle as the VFH method does since the latter is unnecessary but computational and spatial expensive. Secondly, we design a new speed control law that considers more factors especially the obstacle speed. The third also the key improvement is that in the new method, we take the threat of moving obstacles into account when selecting motion directions. Hence the new method can better deal with moving obstacles. The process for selecting the direction and speed of the robot in the new method is presented below. It can be illustrated by the example shown in Fig.1.

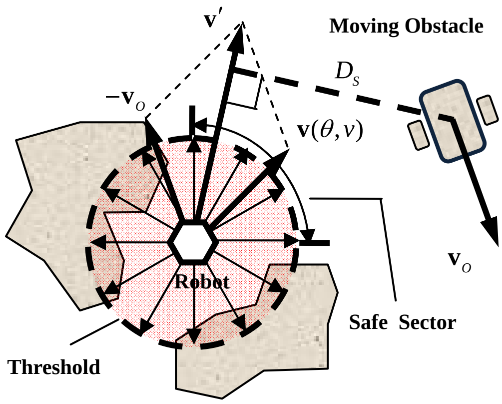


Fig.1. An example that $\theta_0 = 30^\circ$ and $N = 3$

Step 1 (Find all the safe sectors and take their middle directions as candidates for the final motion direction) The new method divides all the directions around the robot into a series of sector units whose width is θ_0 ($\theta_0 = 5^\circ$ in our experiments). Any sector that consists of N ($N = 24$ in our experiments) continuous units whose minimal obstacle distances are all larger than d_S ($d_S = 0.4\text{m}$ in our experiments) is considered as a safe sector. Additionally, there is a special sector whose middle direction is the target direction θ_T and width is $N\theta_0 / 2$. If the minimal obstacle distance in this sector is larger than d_S, it is also considered as a safe sector. Note that two safe sectors can overlap in part. Only the middle directions of the safe sectors can be selected as the motion direction of the robot. In the example of Fig.1, there is only one safe sector whose middle direction is θ (All the angles in this paper refer to the local coordinates where the original angle equals to the head direction of the robot and anticlockwise direction is positive).

Step 2 (Calculate the corresponding maximum speed of every candidate direction) To keep safe, every candidate direction θ has a corresponding maximum speed that is calculated by

$$v_{\max} = \min_{0\le n\le N}\left\{v_{\max}^{n}\right\}\cdot\cos^2\left(\min\left\{\theta,\frac{\pi}{2}\right\}\right)$$
$$v_{\max}^{n} = \begin{cases} \dfrac{\sqrt{2\bar{a}(d_n - d_S)}}{\cos|\theta_n - \theta|} & d_n > d_S \\ \dfrac{v_0\cdot d_n^2}{d_S^2\cdot\cos|\theta_n - \theta|} & d_n \le d_S \end{cases} \tag{1}$$

where d_n and θ_n are the obstacle distance and the direction of the n^{th} sector unit, $\bar{a}$ is the average acceleration of the robot, v_0 is a constant, $v_{\max}^n$ represents the maximum speed limited by the obstacle distance of the n^{th} sector unit based on the requirement that the obstacle distance must be large enough for the process of brake. The item $\cos^2(\cdots)$ in (1) is used to slow down the speed when the bias between θ and the current direction of the robot is large, which can shorten the path length generated by turning.

Step 3 (Evaluate the threat from moving obstacles for every candidate direction) We define the threat value $Tht(\theta)$ from a moving obstacle for a candidate direction θ as

$$Tht(\theta) = \begin{cases} \dfrac{v_O}{\sqrt{2\bar{a}(D_S(\theta,v) - r - r_O)}} & D_S > r + r_O \\ +\infty & D_S \le r + r_O \end{cases} \tag{2}$$
$$v = \arg\min_{0\le v\le v_{\max}}\left\{\frac{v_O}{\sqrt{2\bar{a}(D_S(\theta,v) - r - r_O)}}\right\}$$

where r and r_O are the radius of the robot and the obstacle, v_O is the obstacle speed, D_S is the distance from the obstacle to the straight line that passes through the robot's center and parallels the vector $\mathbf{v}'$ which is the relative velocity between the robot and the obstacle if specific θ and its corresponding v are selected as shown in Fig.1. Note that v is the speed that generates the lowest threat value in the speed boundary if specific

θ is chosen. If there are multiple moving obstacles, the final threat value is the maximum $Tht(\theta)$ generated by them.

Step 4 (Select the final motion direction and speed from all the candidates) The final direction is selected by

$$\theta = \arg\min\left\{\alpha_1 \cdot \left|\theta - \theta_{\mathrm{T}}\right| + \alpha_2 \cdot Tht(\theta)\right\} \tag{3}$$

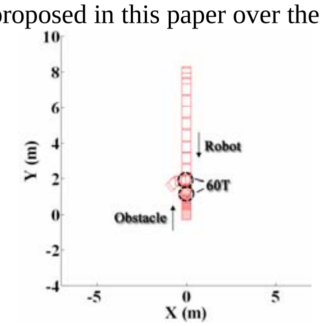
where α and α_2 are constants. For soft-landing, the final speed is calculated by $\min\left\{v, 0.5 \cdot D_{\mathrm{T}}\right\}$ where v is the corresponding speed calculated in Step 3, D_{T} is the distance between the robot and the target.

The new method described above shows many advantages over the DPF method for avoiding moving obstacles. In the DPF method, all the effects of moving obstacles are abstracted as a repulsive force. Such a description is simple for implementation. However, as pointed out in [1], it loses detailed information about the obstacle distribution and can lead to a series of problems, e.g., oscillations in the presence of obstacles, difficulties in going through narrow corridors [10]. The VFH method has well solved these problems by introducing safe sectors to describe the distribution of obstacles [1]. The new method proposed in this paper has inherited the concept of safe sectors in the VFH method and therefore it can also avoid the above problems in the DPF method. Furthermore, some works [7] about the DPF method hasn't paid much attention to the speed control law as the method proposed in this paper. Simple linear functions are usually adopted, which will affect their performances. The advantage of the DPF method is that some related works address the problem of how to pursuit a moving target [7], [8], which hasn't been taken into account in this paper.

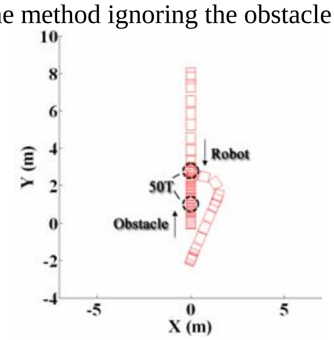
IV. SIMULATIONS AND EXPERIMENTS

To show the performance of the proposed method, several simulation results are presented below.

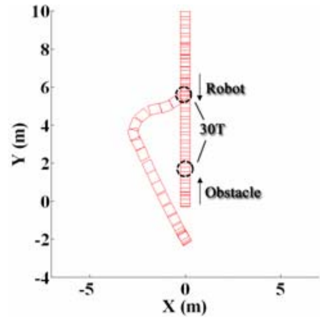
For testing the performance of the new method proposed in this paper, we design a scenario that the robot meets an obstacle moving toward it as shown in Fig.2 (In all the simulations in this paper, the start points of the robot and the obstacle are respectively at (0,8) and (0,0); the robot's target is at (0,-2); the dash circle represents the locations of the robot and the obstacle at the time labeled aside). Fig.2(a) shows the result if the robot moves in the direction that has the minimal bias to the target direction from all the middle directions of safe sectors ($d_s = 0.4\text{m}$) without taking the obstacle speed v_O ($v_O = 0.1\text{m/s}$) into account, which is the concept of the VFH method. The result is that the robot hits the obstacle at 60T (T is the length of the control cycle). This collision can be avoided if we increase d_s to keep enough distance to the obstacle. However, it will be not safe again if the obstacle increases its speed and a large d_s will make it difficult to go through narrow corridors. As a comparison, navigated by the new method proposed in this paper, the robot smoothly bypasses the same obstacle as shown in Fig.2(b). Moreover, the new method is adaptive when the obstacle increases its speed as shown in Fig.2(c) ($v_O = 0.4\text{m/s}$). The simulation results of Fig.2 indicate the importance of taking the obstacle speed into account for obstacles avoidance, which is just the advantage of the method proposed in this paper over the VFH method.



(a) The method ignoring the obstacle speed



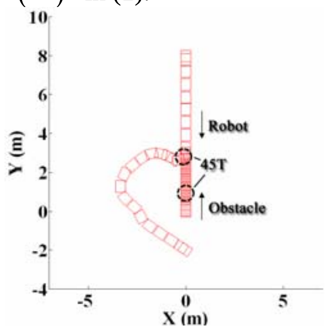
(b) The proposed method ($v_O = 0.1\text{m/s}$)



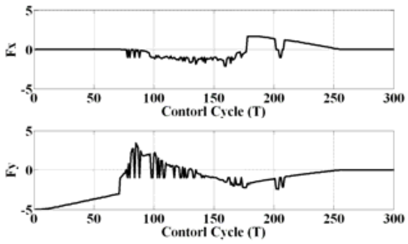
(c) The proposed method ($v_O = 0.4\text{m/s}$)

Fig.2. Results of simulation 1

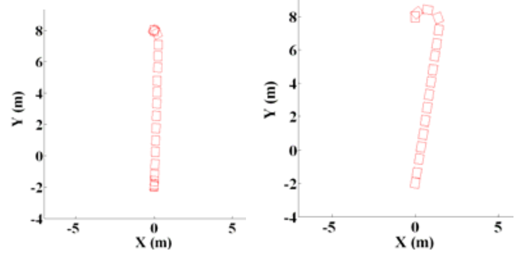
The simulations in Fig.3 have compared the new method with the DPF method proposed in [7]. Fig.3(a) is the result of the work in [7] in the same scenario of Fig.2(b). Compared with Fig.2(b), there are oscillations in the trajectory of Fig.3(a) due to the shake of the potential force shown in Fig.3(b). Such shakes occur frequently when the robot suddenly meets an obstacle and it is an inherent drawback of the DPF method due to its oversimplified description of the obstacle effect. It can be also observed that the trajectory in Fig.3(a) is much longer than the result in Fig.2(b). The proposed method also shows advantages over the work in [7] in many aspects of the speed control. As an example, in the scenario of Fig.3(c) and Fig.3(d) (the robot moves from (0,8) to (0,-2) but its initial direction is opposite to the target), the method proposed in this paper generates shorter path than the work in [7] when turning due to the item $\cos^2(\cdots)$ in (1).



(a) The DPF method



(b) The force components in X-axis and Y-axis



(c) The proposed method (d) The DPF method

Fig.3. Results of Simulation 2

Fig.4. A scenario of experiments on real robots

The proposed method has also been implemented on real Pioneer3-AT robots as shown in Fig.4. Experiment results have further verified its validity and applicability.

V. CONCLUSIONS

A new method for mobile robots to avoid collision with moving obstacles is proposed in this paper. The new method adopts the concept of safe sectors in the VFH method but simplifies its description. Moreover, it takes the threat of moving obstacles into account when selecting motion direction and a new speed control law that considers more factors is designed. Hence it can better deal with moving obstacles than the VFH method. Simulation results show that the new method also performs better than the DPF method in many aspects.

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