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ORIGINAL ARTICLE

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# A new method for mobile robots to avoid collision with moving obstacle

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**Abstract** A new method for helping mobile robots to avoid collisions with moving obstacles is proposed. This method 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 the direction of motion, and a new speed control law that considers more factors is designed. Hence, it is better at avoiding 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.

**Key words** Mobile robots · Obstacle avoidance · Moving obstacles

## 1 Introduction

Obstacle avoidance is one of the key issues for successful applications of mobile robots. Many methods[1–9] have been proposed to solve this problem over the past 20 years. However, most previous work focuses on static obstacles, and only a few articles[6–9] address the problem of dealing with moving obstacles.

To deal with moving obstacles, one concept is the advance planning of a safe path which takes moving obstacles into account when guiding the robot.[6] The drawback of this concept is that it assumes that the trajectories of the 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 practical, since it can adapt the changing motion of moving obstacles. One representative method based on this concept is the dynamic potential field (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 the resultant force.

Here, 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 vector field histogram (VFH) method,[1] which is a motion planning method mainly for static environments. However, the new method simplifies its description to lower the computational and spatial complexity, and takes the threat of moving obstacles into account when choosing the direction of motion. Hence, it is better able to handle moving obstacles than the VFH method. Another improvement in the new method is its speed control law, which takes more factors into account than the VFH method. The new method also has advantages over the DPF method in many respects which are discussed in this article. The remainder of the article is arranged as follows. The VFH method is briefly reviewed in Sect. 2 and the new method is presented in Sect. 3. Some simulations and experiments are presented in Sect. 4.

## 2 The VFH method

As an efficient obstacle avoidance approach, the VFH method[1] can generate a smooth trajectory without oscillations, and guide a robot through narrow corridors. The VFH method divides all the directions around the robot into some safe sectors so that the obstacle density (a value that is proportional to the negative of the distance from the robot to the obstacles) in any direction in these sectors is no less than a known threshold. The directions in the middle of such sectors are candidates for motion, and the one that has the minimum bias to the target direction is selected as

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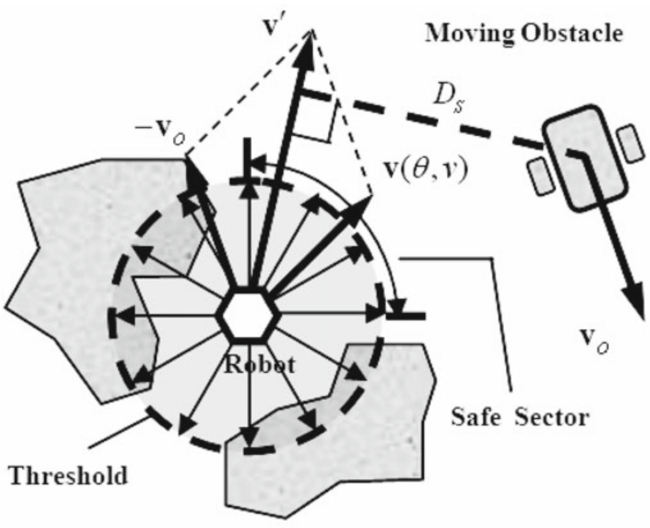


**Fig. 1.** An example with $\theta = 30°$ and $N = 3$

the final direction of motion. Nevertheless, the VFH method only takes the distances of obstacles into account and ignores their velocities. Therefore, it is not suitable for environments containing moving obstacles, especially when the obstacles are moving fast.

## 3 The proposed method

The new method proposed here adopts the basic concept of safe sectors in the VFH method, but improves it in three main ways. Firstly, the new method directly compares the distance of an obstacle in one direction with a known threshold in order to judge whether that direction is safe without computing 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 and computationally and spatially expensive. Secondly, we have designed a new speed control law that considers more factors, in particular the speed of the obstacle. The third and key improvement is that in the new method, we take the threat of moving obstacles into account when selecting the direction of motion. Hence, the new method is better at dealing with moving obstacles. The process for selecting the direction and speed of the robot in the new method is presented below. It is illustrated by the example shown in Fig. 1.

*Step 1. Find all the safe sectors and take their middle directions as candidates for the final direction of motion.* The new method divides all the directions around the robot into a series of sector units whose width is $\theta_0$ ($\theta_0 = 5°$ in our experiments). Any sector that consists of $N$ ($N = 24$ in our experiments) continuous units whose minimum obstacle distances are all larger than a threshold $d_S$ ($d_S = 0.4$ m in our experiments) is considered to be a safe sector. In addition, there is a special sector whose middle direction is the target direction $\theta_T$ and whose width is $\frac{N\theta_0}{2}$. If the minimum obstacle distance in this sector is larger than $d_S$, it is also considered as a safe sector. Note that two safe sectors can partially overlap. Only the middle directions of the safe sectors can be selected as the direction of motion of the robot. In the example in 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 the head direction of the robot and the anticlockwise direction is positive.)

*Step 2. Calculate the corresponding maximum speed of every candidate direction.* To remain safe, every candidate direction θ has a corresponding maximum speed, which is calculated by

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

where $d_n$ and $\theta_n$ are the obstacle distance and the direction of the $n$-th sector unit, respectively, $\bar{a}$ is the average acceleration of the robot, $v_0$ is a constant, and $v_{\max}^n$ represents the maximum speed, which is limited by the distance of the obstacle in the $n$-th sector unit based on the requirement that the distance of the obstacle must be large enough for the process of braking. The item $\cos^2(\ldots)$ in Eq. 1 is used to slow down the speed when the bias between θ and the current direction of the robot is large. This 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

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

where $r$ and $r_O$ are the radius of the robot and the obstacle, respectively, $v_O$ is the obstacle speed, and $D_S$ is the distance from the obstacle to the straight line that passes through the robot's center and is parallel to the vector **v′**, which is the relative velocity between the robot and the obstacle if a 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 a specific θ is chosen. If there are multiple moving obstacles, the final threat value is the maximum $Tht(\theta)$ generated by them all.

*Step 4. Select the final direction and speed of motion from all the candidates.* The final direction is selected by

$$\theta = \arg\min\{\alpha_1 \cdot |\theta - \theta_T| + \alpha_2 \cdot Tht(\theta)\} \tag{3}$$

where $\alpha_1$ and $\alpha_2$ are constants. For a soft landing, the final speed is calculated by $\{v, 0.5 \cdot D_T\}$, where $v$ is the corresponding speed calculated in Step 3, and $D_T$ is the distance between the robot and the target.

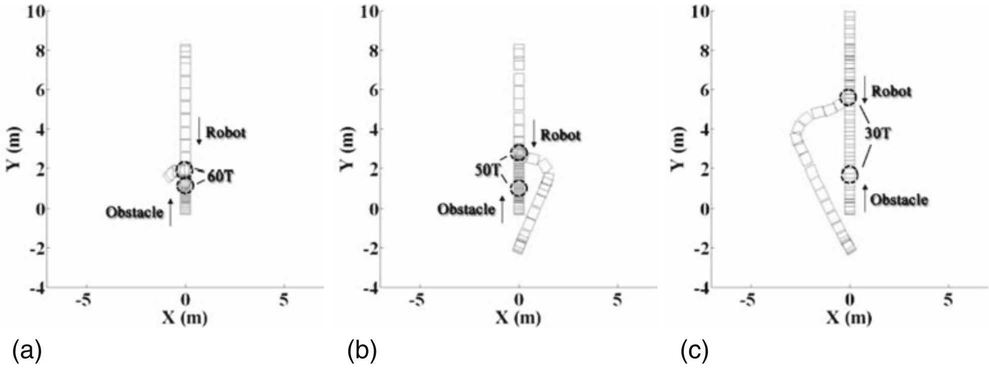


**Fig. 2.** Results of simulation 1. **a** The method ignoring the obstacle's speed. **b** The proposed method ($v_O = 0.1$ m/s). **c** The proposed method ($v_O = 0.4$ m/s)

This new method has 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 by Borenstein and Koren,[1] it loses detailed information about the distribution of obstacles and can lead to a series of problems, e.g., oscillations in the presence of obstacles, and difficulties in going through narrow corridors.[10] The VFH method has solved these problems well by introducing safe sectors to describe the distribution of obstacles.[1] The new method proposed here has also used the concept of safe sectors, as in the VFH method, and therefore it can also avoid the problems in the DPF method. Furthermore, some work[7] on the DPF method has not paid much attention to the speed control law, as proposed here. Simple linear functions are usually adopted, and these will affect the performance. The advantage of the DPF method is that some related works address the problem of how to pursue a moving target,[7,8] which has not been taken into account here.

## 4 Simulations and experiments

In order to demonstrate the performance of the proposed method, the results of several simulations are presented below. To test the performance of the new method, we designed a scenario where the robot meets an obstacle moving toward it, as shown in Fig. 2. (In all these simulations, the starting points of the robot and the obstacle are at (0,8) and (0,0), respectively. The robot's target is at (0,–2). The dash and the circle represent the locations of the robot and the obstacle, respectively, at the time given.) Figure 2a shows the result if the robot moves in the direction that has the minimum bias to the target direction from all the middle directions of the safe sectors ($d_S = 0.4$ m) without taking the obstacle's speed $v_O$ ($v_O = 0.1$ m/s) into account. This is the concept of the VFH method. The result is that the robot hits the obstacle at 60 $T$ (where $T$ is the length of the control cycle). This collision can be avoided if we increase $d_S$ to keep sufficient distance from 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. In comparison, a robot navigated by our method bypasses the same obstacle smoothly, as shown in Fig. 2b. Moreover, this method can be adapted when the obstacle increases its speed, as shown in Fig. 2c ($v_O = 0.4$ m/s). The simulation results in Fig. 2 indicate the importance of taking the obstacle's speed into consideration. This is the advantage of the method proposed here over the VFH method.

The simulations shown in Fig. 3 were carried out in order to compare this method with the DPF method proposed by Ge and Cui.[7] Figure 3a is the result of the work by Ge and Cui[7] in the same scenario as shown in Fig. 2b. Compared with Fig. 2b, there are oscillations in the trajectory in Fig. 3a which are due to the shaking of the potential force shown in Fig. 3b. Such shaking frequently occurs when the robot suddenly meets an obstacle, and it is an inherent drawback of the DPF method due to its oversimplified description of the effect of the obstacle. The proposed method also has advantages over the work by Ge and Ciu[7] in many aspects of speed control. For example, in the scenario in Fig. 3c and 3d (the robot moves from (0,8) to (0,–2), but its initial direction is away from the target), the method proposed here generates a shorter path when turning than in the work of Ge and Ciu[7] owing to the item $\cos^2$ (. . .) in Eq. 1.

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

## 5 Conclusions

A new method for mobile robots to avoid collisions with moving obstacles has been proposed. This method adopts the concept of safe sectors as in the VFH method, but simplifies its description. Moreover, it takes the threat of moving obstacles into account when selecting the direction of motion, and a new speed control law that considers more factors has been designed. Hence, it is better at dealing with moving obstacles than the VFH method. The simulation results show that the new method also performs better than the DPF method in many respects, and the experiments have further verified its applicability.

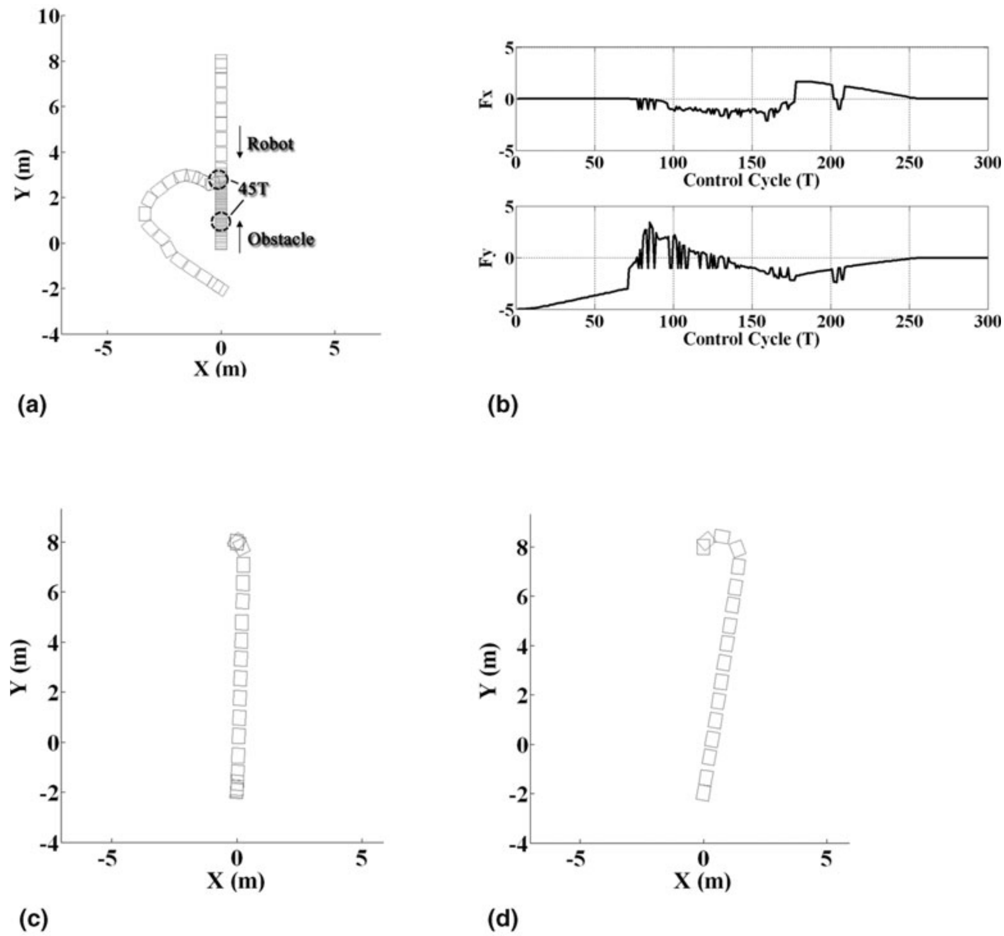


**Fig. 3.** Results of simulation 2. **a** The DPF method. **b** The force components of the DPF method in the $X$-axis and the $Y$-axis. **c** The performance of the proposed method for turning. **d** The performance of the DPF method for turning

**Fig. 4.** Scenario of experiments on real robots

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