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A Moving Object Tracked by A Mobile Robot with Real-Time Obstacles Avoidance Capacity

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Abstract

This paper describes a robotic application that tracks a moving object by utilizing a mobile robot with multiple sensors. The robotic platform uses a visual camera to sense the movement of the desired object and a range sensor to help the robot detect and then avoid obstacles in real time while continuing to track and follow the desired object. In terms of real-time obstacle avoidance capacity, this paper also presents a modified potential field algorithm called Dynamic Goal Potential Field algorithm (DGPF) for this robotic application specifically. Experimental results show that the robotic and intelligent system can fulfill the requirements of tracking an object and avoiding obstacles simultaneously when the object is moving.

1. Introduction

Video tracking, surveillance systems, and robotic platforms are fields that have been well studied in the past decade [1]. However, in the majority of surveillance and video tracking systems, the sensors are stationary. The stationary systems require the desired object to stay within the surveillance range of the system. If the object goes beyond this range, it no longer becomes tractable. One solution to this problem is to design the system as a mobile system that uses a laser range sensor, and a visual-spectrum camera, to track the moving object and avoid obstacles [3]. This research topic has been partially studied in several different areas. Studies made by the automotive industry in this area develop systems that assist a human driver for safety or comfort [6, 8]. NASA has applied this to help astronauts to carry more equipment while walking on the moon [7]. These systems are primarily concerned with object tracking, and are not concerned with the obstacle avoidance problem. One popular approach used for obstacle avoidance is the Potential Fields method [4, 5]. In the Potential Fields method, an artificial field is generated where a goal position produces an attractive force to the robot, and obstacles generate a repulsive force on the robot. The resultant force will decide the moving direction of the robot. Since traditional applications of Potential Fields methodologies do not allow tracking a moving object, the development of a modified version of a potential fields method that can be used for a mobile system is necessary. Therefore, the contributions of this paper are to present a mobile robotic system which can simultaneously track a moving object and avoid obstacles in real-time. We first introduce the system architecture, then present the object tracking strategy, obstacle detection and avoidance mechanism, and robot control. Finally, the experiment and conclusion will be addressed.

2. System architecture

Figure 1 represents the whole system architecture.

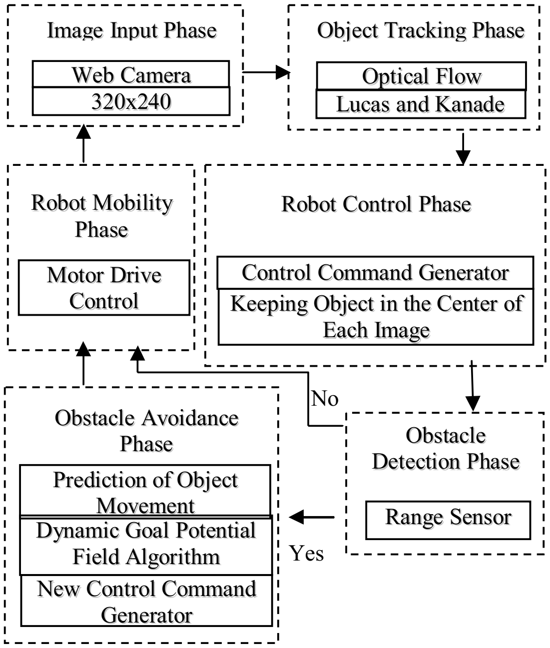


Figure 1. This block diagram shows the overall system.

In general, the overall system consists of six main phases: image input, object tracking, robot control, obstacle detection, obstacle avoidance, and robot mobility phases. If no obstacles are detected, the system skips the obstacle avoidance phase, and only uses five phases. The following sections explain how each phase works individually, and how the various phases work in conjunction with each other.

2.1. Image Input Phase

The Logitech Web Camera has a fixed view and is attached to the robotic platform. It is used to acquire color 320x240 images. The camera is tasked to follow the tracked object.

2.2. Object Tracking Phase

Lucas and Kanade's algorithm [2] does not use an iterative method to compute the optical flow and it is less affected by illuminant changes, which makes this method a more appropriate choice for real-time object tracking operations. We use this method to compute motion vectors for the tracked object in two consecutive images and then perform four different directions of the tracked object which include moving forward, moving backward, moving toward right, and moving toward left. Because there are so many motion vectors for the tracked object in the two consecutive images, we use equation (1) to obtain the mass motion vector of the tracked object.

$$M = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (1)$$

In equation (1), M represents the mass motion vector of the tracked object (in 1x2 matrix form). X_i represents each motion vector of the tracked object (in 1x2 matrix form). N represents amount of total motion vector.

2.3. Robot Control Phase

Once the object tracking phase is in control of monitoring the direction of the moving object, it will continue to send the robot control phase the current mass motion vector, M, of the moving object. It uses this to compute the difference between it and the origin, M_0, which represents the motion vector of the tracked object that stays in the center of the image. These operations facilitate the calculation of the robot's control commands. Equation (2) represents the method used in the robot control phase that eventually generates the difference vector between the world coordinate system and the image coordinate system.

$$(M - M_o)\times\begin{bmatrix} X_i & Y_i \\ X_j & Y_j \end{bmatrix} = W \qquad (2)$$

In equation (2), $\begin{bmatrix} X_i & Y_i \\ X_j & Y_j \end{bmatrix}$ represents the conversion matrix which converts the image coordinates into the 2D world coordinate system. W represents the difference vector in the world coordinate system. Figure 2 shows the concept of the conversion method.

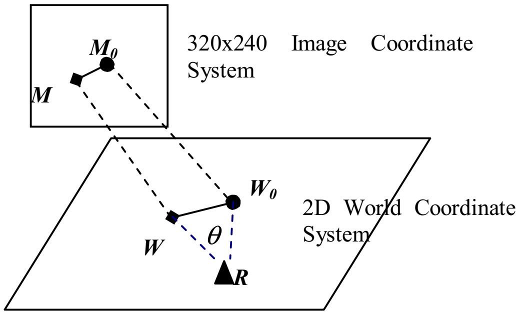


Figure2. Conversion from image to 2D world coordinate system.

In Figure 2, W_0 represents the origin vector, [0, 0], in the 2D world coordinate system. R represents the robot vector, $[R_x, R_y]$, in the 2D world coordinate system. θ describes the angular measure of turn required for the robot in order to keep the tracked object in the origin of the 2D world coordinate. θ can be computed by equation (3).

$$\theta = \cos^{-1}\frac{(\overrightarrow{W_0 - R})\cdot(\overrightarrow{W - R})}{\left\|(\overrightarrow{W_0 - R})\right\|\left\|(\overrightarrow{W - R})\right\|} \qquad (3)$$

After making a turn, the robot then determines the distance to move, either forward or backward, for keeping it in a fixed distance from origin vector, W_0.

2.4. Obstacle Detection Phase

Before the robot sends a command to move forward (or backward), it uses a laser scanner (SICK - LMS 200) to sense if there is any obstacle in its projected path. If no obstacle is detected, the robot mobility phase is activated. Subsequently, the control of the system returns back to the image input phase.

Otherwise, the system uses the obstacle avoidance phase for generating another robot control command in order to avoid the obstacle.

2.5. Obstacle Avoidance Phase

The obstacle avoidance phase uses the modified Potential Fields methodology mentioned earlier. The advantage of Potential Fields methods is that they are simple and fast. The most significant disadvantage concerns local minima problems, which plague potential fields methods.

For this application, the robot needs to keep tracking the object while avoiding obstacles. Since the object might move to a new position when the robot is avoiding obstacles, traditional Potential Fields methods can not be directly applied because these methods assume the goal position is static (while the mobile robot is avoiding obstacles).

To deal with this dynamic goal position problem, the obstacle avoidance algorithm needs to adjust its path corresponding to the change of its destination during obstacle avoidance. We propose a new algorithm called dynamic goal potential fields (DGPF) which is based on the traditional Potential Fields methods to solve this type of problems.

The DGPF algorithm is based on the following:

1. Using the current configuration, goal configuration and sensor data, it runs a basic potential fields algorithm to predict a path;
2. If the goal configuration does not change too much, then the robot follows this path to avoid any obstacle;
3. If the goal configuration moves to a new position which has a big change from the old position, the algorithm randomly chooses some points in the predicted path and runs the basic Potential Fields method to compute several paths starting from these points based on current sensor data;
4. The path with the lowest cost is selected (based on Euclidian distance). The robot is now using the new path to move to the new goal configuration.

Figure 3 shows the DGPF Method.

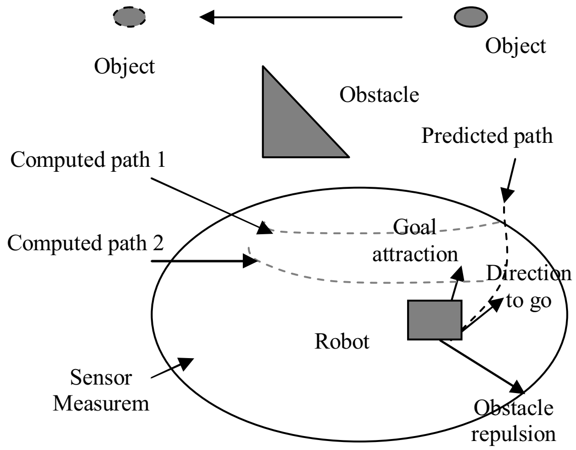


Figure 3. The concept of dynamic goal potential field method.

If the goal configuration does not change too much during the obstacle avoidance procedure, the Dynamic Goal Potential Fields method is similar to the traditional Potential Fields method except that a predicted path is retained in every step. This predicted path might not be the same as the exact path taken by the robot because it is based only on the current sense data. If the goal configuration has a big change, the DGPF method has the capability to quickly adjust its path to move to the new position with low cost.

3. Experimental Results

Figure 4 shows the entire system, including the web camera, range sensor, and robotic platform. Robotic mobility is accomplished through two independent tracks. These two tracks are modularly interchangeable, and each is capable of moving the robot by itself. Motion can be controlled directly by a computer sending motion commands into the track motors via a RS232 signal. Figure 5 shows the experimental results.

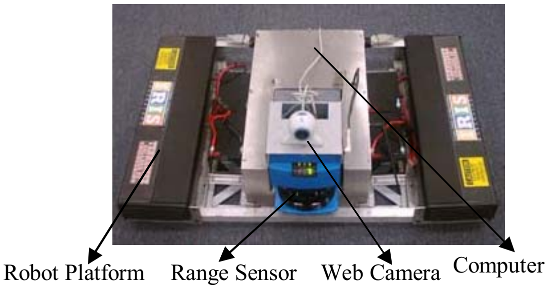
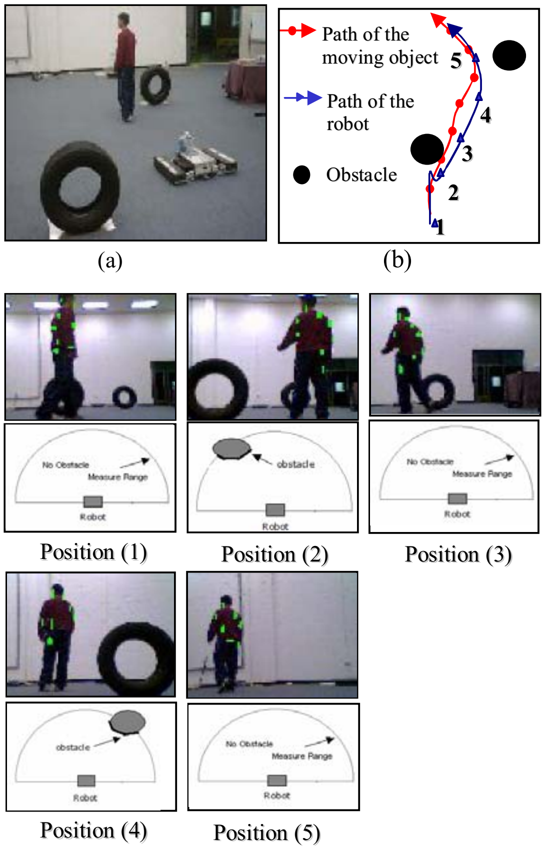


Figure 4. This system picture shows the platform components.



(a) (b)

Position (1) Position (2) Position (3)

Position (4) Position (5)

(c)

Figure 5. Experimental result: (a) represents the indoor experimental environment, two obstacles, an object, and a robot, (b) represents the relative path of the moving object and robot, (c) represents the visual image and range scan information in each point depicted in (b).

In Figure 5, the robot initially moves backward to avoid the first obstacle which is lying very close to the beginning position of the robot. Without this backward movement, the robot could strike the obstacle (while turning for following the object), potentially losing sight of the tracked object. In positions (1), (3), and (5), since there is no obstacle sensed in the laser scan range, the system does not trigger the obstacle avoidance phase. Experiment results show that the robot can continuously tract the moving object and the dynamic goal potential fields method can guide the robot to move to a new position without colliding with any obstacle while the tracked object is moving with a low speed.

4. Conclusion

This paper represents a mobile robotic application with real-time obstacle avoidance capacity that tracks a moving object using a modular sensor-based mobility platform. The system uses two sensors: a visual camera to sense the movement of any tracked object, and a range sensor to help the robot detect and then avoid obstacles in real-time while continuing to track the object. This paper also presents a modified potential fields method called DGPF method which is used to deal with real-time obstacle avoidance for object tracking. Experiments show DGPF can fulfill the requirement of object tracking when the object moves at a maximum speed of 5 km/hr.

5. Acknowledgement

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