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Design of Automatic Obstacle Avoiding Rescue Robot in Coal Mine Environment

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Abstract: A coal mine rescue robot is designed in the paper. It can be used in the complex environment when the mine tragedy happened. The robot avoids sinking into the zero potential energy point by using the improved artificial potential field. An algorithm of obstacle avoidance is developed in the paper. The robot employs the algorithm to move automatically in the mine tunnel according to the navigation of the electronic map. There are eight infrared sensors in the robot. These sensors are divided into two groups which have different frequencies and detection ranges. All parameter of the robot is transmitted to the ground control center through the wireless network module by using the camera and gas sensors to detect the video information and dangerous gas content.

Key words: Rescue robot, wireless transmission, artificial potential field, automatic obstacle avoidance

INTRODUCTION

China has abundant coal reserves. However, due to the exhaustive exploitation and lack of safety measures, mine accidents frequently occurs (Wang and Ge, 2003). The original communication infrastructure will be destroyed when the accident occurred. The underground environment is complex and dangerous, so the coal mine rescue robot research is a meaningful project. The rescue robot collects information and then transmits the information to the over ground rescue workers through the wireless communication module (Yanbo, 2011; Li and Liu, 2008). Through this, the rescuers can quickly develop a rescue plan. The automatic obstacle avoidance algorithm (Wei and Yu, 2009) used in rescue robot is a key problem. The scientists have proposed several algorithms such as the artificial potential field algorithms, cell decomposition algorithms and the grid method (Russell and Norvig, 2003). Among them, the artificial potential field algorithm has been widely used (Khatib, 1986) as it is a simple, intuitive and easily to achieve real-time controlled algorithm. The basic idea of ??the artificial potential field is generates a gravity forces on the robot. The vectors composed by the two forces will eventually determine the robot's moving direction. But there are some difficulties in static artificial potential field method, such as the zero potential energy point (Dai and Wang, 2010). The rescue robot often falls into the regional minima point. If the rescue robot falls into the minima point so it can not find the target point. In this paper we added an auxiliary gravitation to improve the algorithm.

HARDWARE DESIGN

Overall structure of the hardware: This mine rescue robot employs the internal integrated ARM as the CPU. This CPU is with Cortex-M3 core and with 32-bit RISC performance, internal memory, general-purpose timers, recyclable ARM FIRN standard watchdog timer, Synchronous Serial Interface (SSI), UART, ADC, analog comparator, I2C, PWM, GPIO, and the flexible reset sources. Figure 1 shows the block diagram of the robot’s hardware. The entire circuit including a microprocessor module (LM3S615), AdHoc wireless communication module, the video capture module, intelligent obstacle avoidance module, electronic map module.

In this system, the electronic map is used as the robot’s navigation and the video capture module uses the camera to shoot the on-site state scene. The video image

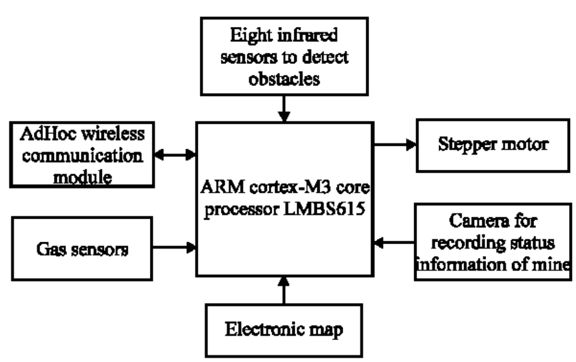

Fig. 1: Block diagram of the hardware

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will be transmitted to the remote client by the AdHoc module to update the information. In addition, the gas sensors detect the concentration of gas under the coal mine (Fig. 1).

Obstacle avoidance module: There are many obstacles in the mine tunnel after the coal mine accident happened, so the rescue robot can not reach the destination easily. The rescue robot determines the motion direction and the destination coordinates based on the navigation electronic map. The robot carries eight infrared sensors to detect obstacles in the tunnel real-timely and uses the artificial potential field algorithm to determine the robot motion direction. Finally, the rescue robot automatically avoids the obstacles and finds the target point.

This rescue robot uses eight infrared sensors. Infrared wavelength is 940 nm, can be PWM modulated. The receiver is also a wavelength of 940 nm infrared receiver tube, angle of 45°, 38 K band-pass filtering, high anti-interference ability, using in the relatively harsh environment. In order to detect the underground obstacles more accurately, the distributions of the robot's infrared sensors are shown in Fig. 2. The eight infrared sensors are divided into two groups: sensor 1, sensor 2, sensor 3, and sensor 4 connect with the CPU PWM1 pin; sensor 5, sensor 6, sensor 7, and sensor 8 connect with the CPU PWM2 pin. These two kinds of sensors are controlled by different PWM pins which send infrared ray with different frequency and transmit power. The first group sensors can detect closer obstacles, while the second group of sensors can detect farther obstacles. The frequencies of the two groups are not same which greatly reduce the interference between adjacent sensors.

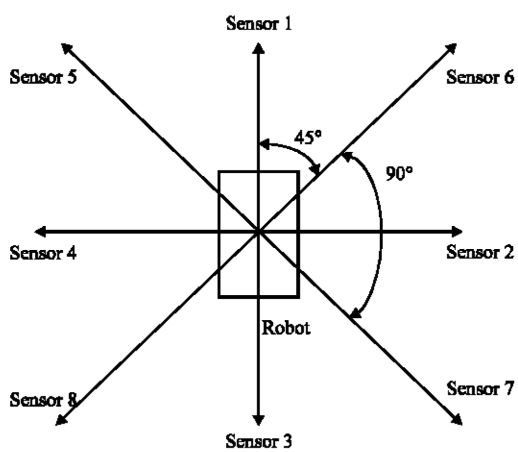

Fig. 2: Distribution of the robot's infrared sensors

SOFTWARE DESIGN

There are a lot of algorithms about the obstacle avoidance of the mobile robot, such as the cell decomposition algorithm, the grid method and so on. Among them, the artificial potential field algorithm has been widely used because of its simple form and quick description of the environment. In this system, based on the navigation of the electronic map, the intelligent obstacle avoidance algorithm uses the artificial potential field algorithm in a static environment. Artificial potential field algorithm proposed in 1986 by Katib.

ARTIFICIAL POTENTIAL FIELD OBSTACLE AVOIDANCE ALGORITHM

Artificial potential field algorithm is to create a virtual potential filed in the process of the robot motion. The obstacles and the area where robots do not want to crash into belong to repulsion pole, also called high potential point. The target belongs to the gravitational pole, also called low potential point. Rescue robot moves from the high potential point to the low potential point. Suppose rescue robot moves in a potential field, it is driven by the guidance of joint force, eventually reach the destination. In the potential field, the repulsive force can keep a safe distance between the robot and obstacle, at the same time the gravitational force can ensure the robot moves toward the target. The force diagram shows in Fig. 3.

The workspace of the robot is $X = [x, y]^T$, the potential filed value in any point on the x-axis is:

$$U(X) = U_G(X) + U_O(X) \tag{1}$$

Here, U_G (X) is the gravitational force field and U_o (X) is the repulsive force field. So the force acting on the robot is:

$$F = F_G + F_o \tag{2}$$

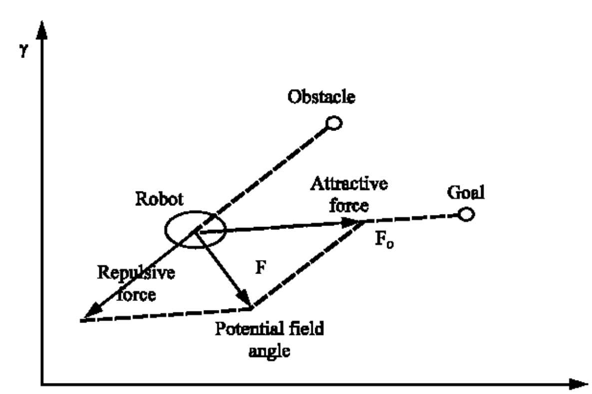

Fig. 3: The force diagram of the robot

Here,

$$F_G = -\text{grad}[U_G(X)],\ F_0 = -\text{grad}[U_0(X)]$$

The potential function should be continuously derivability. Usually the target potential function is:

$$U_G(X) = \frac{1}{2}k_p\left|X - X_G\right|^2 \quad (3)$$

Here, K_p is the constant of the gravitational potential field. X is the robot's current location. X_G is the vector of the target position.

Then, the gravitation is the negative gradient for target potential function:

$$F_G = -\text{grad}[U_G(X)] = -k_p(X - X_G) \quad (4)$$

For the repulsion potential function, Katib used the FIRAS (Force Inducing an Artificial Repulsion from the Surface) function:

$$U_0(X) = \begin{cases} \frac{1}{2}k_r[\frac{1}{\rho(X, X_{obs})} - \frac{1}{\rho_0}]^2 & \text{if } \rho \le \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases}$$

Here, K_r is the constant of the repulsive potential field; ρ_0 is the maximum distance range of one obstacle; ρ (X,X_{obs}) is the distance between the robot and the obstacle; the repulsion can not affect the robot's movement when the distance between the robot and the obstacle more than ρ_0. Then, the corresponding repulsion is:

$$F_0 = -\text{grad}[U_0(X)] = \begin{cases} K_r(\frac{1}{\rho(X, X_{obs})} - \frac{1}{\rho_0})\frac{1}{\rho^2_{(X,X_{obs})}}\frac{\partial\rho(X, X_{obs})}{\partial X} & \text{if } \rho \le \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases}$$

Here,

$$\frac{\partial\rho(X, X_{obs})}{\partial X} = [\frac{\partial\rho(X, X_{obs})}{\partial x}\frac{\partial\rho(X, X_{obs})}{\partial y}]^T$$

Here only considered single obstacle. For more obstacles, uses the superposition of the potential field to get the repulsive potential field.

THE REALIZATION OF INTELLIGENT OBSTACLE AVOIDANCE

There are some difficulties in static artificial potential field method, such as the zero potential energy point. The rescue robot often falls into the regional minima point, can not escape to find the target point. The more obstacles in the tunnel, the more zero potential energy point. In order to avoid the robot fall into the zero potential energy point, it is necessary to seek the assistance of electronic map navigation. Once the robot approaches the zero potential energy point, adding an auxiliary gravitational along with the target orientation to help the robot escape the zero potential energy point.

The rescue robot can detect the obstacles by the guidance of the electronic map and the feedback of the infrared sensors. Two kinds of infrared sensors with different frequencies real-timely detect the obstacles. When an obstacle is detected, the course angle can be calculated by the measured data of the gyro. Then the coordinate of the obstacle can be recorded to the memory of the robot. The process is illustrated in Fig. 4.

The obstacle's coordinate is:

$$\begin{cases} x_0 = x_r + (L_n + L)\cos(\theta + \alpha_n) \\ y_0 = y_r + (L_n + L)\sin(\theta + \alpha_n) \end{cases} (n = 1, 2, \cdots 8) \quad (5)$$

where, (x_0, y_0) is the coordinate of the virtual obstacle, (x_r, y_r) is the coordinate of the robot, is the distance between the n-th infrared sensor and the robot, is the distance between the sensor and the obstacle, θ is the robot course angle, is the clockwise rotation angle from the robot heading to the n-th sensor.

The artificial potential field around the robot is changed by the repulsion generated by the obstacle when one obstacle is detected. Then integrate the repulsion vector by the obstacle with the gravitational vector by the target. The resultant will determine the new direction of the robot.

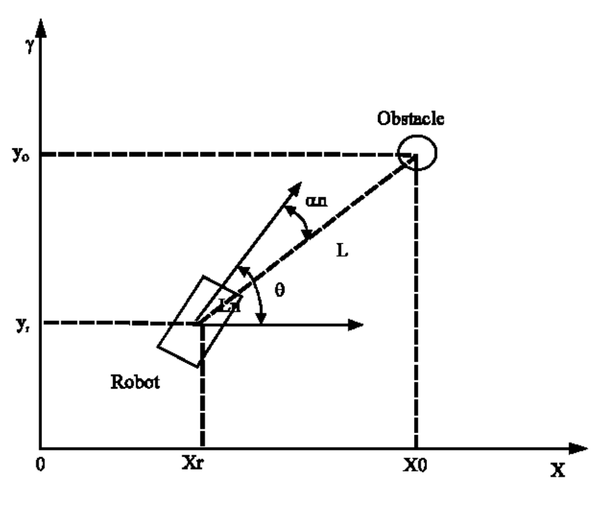

Fig. 4: Schematic diagram of obstacle coordinates

Table 1: Results for robot autonomous walking simulation

Set of sensors	Open PWM1 Set off PWM2		Open PWM2 Set off PWM1		Open 1,2,4,5,6 Set off 3,7,8		Open all sensors	
Experimental group	1	2	3	4	5	6	7	8
Speed m s^{-1}	0.3	0.8	0.3	0.8	0.3	0.8	0.3	0.8
Number of collisions to obstacles	8	14	7	12	10	16	5	7
Number of stop moving use not improved algorithm	5	7	4	6	3	6	2	3
Number of stop moving use improved algorithm	2	3	2	2	1	2	0	1
Time to the target sec	531	420	465	393	560	486	410	354
Distance from target point/m	3.1	2.9	2.9	2.6	4.2	3.2	1.3	1.1

EXPERIMENTAL RESULTS AND ANALYSIS OF OBSTACLE AVOIDANCE

In order to test the obstacle avoidance performance of rescue robot, we simulated a mine tunnel in the laboratory. Specifically, places approximately 30 barriers in the path. The target point is 100 meters away from the starting point. In the same road conditions, eight groups of experiment are produced with different sensor switch states and moving speeds. The experimental results are shown in Table 1.

Two groups infrared sensors with different frequencies and measure distances are used to detect obstacles. Using the improved artificial potential field method will improve the autonomous obstacle avoidance in the tunnel.

From the experimental result we can see that when we open the 1st, 2nd, 4th, 5th, 6th sensors and close the 3rd, 7th, 8th sensors we got the worst result. The robot used the longest to find the target. However, when we open all the sensors we got the best result. The rescue robot took the least time to reach the target area and few collided with the obstacles on its way to the target area.

If we don't use the auxiliary gravitation to improve the algorithm the rescue robot will often fall into the regional minima point on its way and can not continue to reach the target point. On the contrary, if we use the auxiliary gravitation to improve the algorithm the rescue will few falls into the regional minima point and can succeed to find the target point.

The experimental result indicates that using two groups of infrared sensors with different frequency and measure distance can make robot autonomous obstacle-avoiding performance has improved significantly. The improved algorithm can help the robot avoid falling into the zero potential energy point observably.

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