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Path Planning of Fire Escaping System for Intelligent Building

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Abstract: We present the path planning techniques of the fire escaping system using multiple smart mobile robots for intelligent building. The fire escaping system contains a supervised computer, an experimental platform, some fire detection robots and some navigation robots. These mobile robots have the shape of cylinder and its diameter, height and weight is 10cm, 15cm and 1.5kg, and contain a controller module, two DC servomotors (including drivers), three IR sensor modules, a voice module and a wireless RF module, and acquire the detection signal from reflective IR sensor through I/O pins, and receive the command from the supervised computer via wireless RF interface. The fire detection robot carries the flame sensor to detect fire sources. The supervised computer controls the fire detection robots to detect fire source moving on the grid based experiment platform, and calculates the more safety escaping path using piecewise cubic Bezier curve on all probability escaping motion paths on the user interface. Then the system uses A* searching algorithm to program escaping motion paths to approach to Bezier curve. Then the navigation robot guard peoples moving to the safety area or exit door using the escaping motion path. In the experimental results, the supervised computer can programs the escaping paths using the proposed algorithms, and presents the scenario using the multiple smart robots on the platform. The user interface transmits the motion command to the mobile robots moving on the grid based platform, locates the positions of fire sources by the fire detection robots. The navigation robots guard peoples leaving the fire sources using the low risk escaping motion path, and moves to the exit door.

Keywords: path planning, fire escaping system, multiple smart robots, intelligent building, wireless RF module, piecewise cubic Bezier curve, A* searching algorithm

I. INTRODUCTION

Fire event is one of the great scourges on the human life. Thousands of people are injured each year by accidental fire event explosions on the known or unknown environment. There are approximately many thousand million dollars buried each year in many countries. Fire event is many risks to human life and property of societies which must be managed. How to develop a safety processing method to detect fire sources and guard peoples leaving the dangerous environment very quickly is a challenge problem.

In the past literatures, many experts research in the mobile robot. Wang et al [1] develops a multisensor fire detection algorithm using neural network. One temperature and one smoke density sensor signal are fused for ship fire alarm system. Healey et al. [2] presents a real-time fire detection system using color video input. The spectral, spatial, and temporal properties of fire were used to derive the fire-detection algorithm. Neubauer [3] apply genetic algorithms to an automatic fire detection system. The on-line identification of stochastic signal models for measured fire signals was presented. Ruser and Magori [4] described the fire detection with a combination of ultrasonic and microwave Doppler sensor. Luo and Su [5, 6] use two smoke sensors, two temperature sensors and two flame sensors to detect fire event, and diagnosis which sensor is failure using adaptive fusion method. These papers have not considered how to program the escaping paths on the fire environment on real-time, and reduce the risks of human life and property.

The paper considers the problems of the fire event, and uses the multiple robot system working together. Mobile robots are active detection modules to be more merits than passive detection modules, and are applied in fire source detection and escaping system. The multiple mobile robot system has more advantages than one single robot system [7]. First, the multiple mobile robots have the potential to finish some tasks faster than a single robot [8]. Furthermore, using several robots introduces redundancy. Multiple mobile robots therefore can be expected to be more fault tolerant than only one robot. Another advantage of multiple mobile robots is due to merging of overlapping information, which helps compensate for sensor uncertainty [9]. How to program the escaping motion path in the fire area is a important research problem. The paper uses piecewise cubic Bezier curve and A* searching algorithm to program the safety escaping path, and guards people leaving the fire area using navigation robots.

II. SYSTEM ARCHITECTURE

The system architecture of the fire escaping system is shown in Fig. 1, and contains a supervised computer, an experimental platform, some wireless RF modules, some fire detection robots and some navigation robots. The supervised computer transmits the command to control all mobile robots, and receives detection signal, and location, and orientation, and ID code of each mobile robot via wireless RF interface. The fire detection robot (FDR) detects fire sources using flame sensors moving along the experimental platform. The navigation robot (NR) guards people leaving the fire sources according to the programmed escaping motion path. The supervised computer transmits motion command to the mobile robots, and improves the mobile robot moving to the assigned location or not.

The mobile robot has the shape of cylinder, and is equipped with a microchip (MCS-51) as the main controller. Two DC servomotors transmit the pulse signals to the controller, and program orientation and displacement according to pulse numbers. The reflective IR sensors detect obstacles and cross points of the experimental platform, and decide the location of the mobile robot. The flame sensor is R2686 to detect fire sources on the front side of the mobile robot, and detection range is about 6m. The mobile robot can control two DC servomotors and voice module through I/O pins, and communicate with the supervised computer using wireless RF module. The core of the RF module is microprocessor (AT89C2051), and communicates with the controller via wire series interface (RS232).

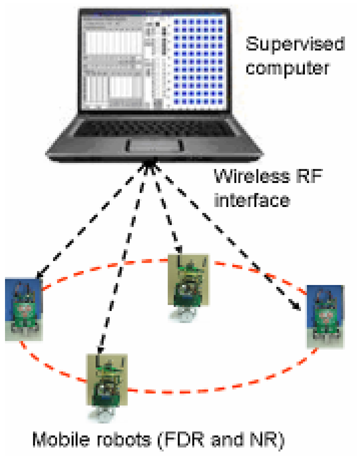


Fig. 1. System architecture

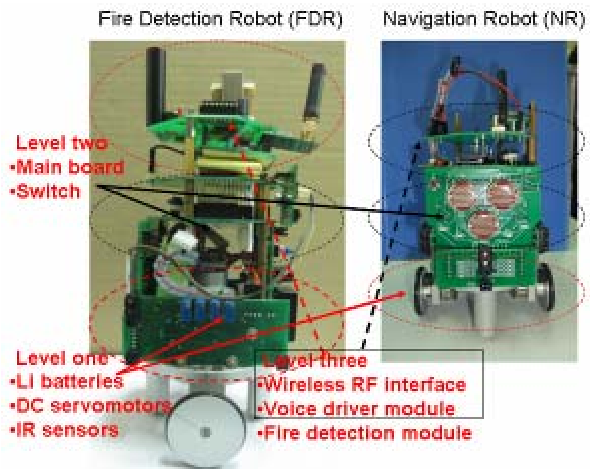


Fig. 2. The mobile robots (FDR and NR)

The structures of the two mobile robots are shown in Fig. 2. The two mobile robots contain some hardware circuits that are classified three levels. The level one of the mobile robot is two DC servomotors, three IR sensor modules and Li batteries. The three reflective IR sensors are embedded on the right side, left side and front side of the mobile robot. In general, the mobile robot moves on the aisle of the experimental platform, and detects obstacles using the three reflective IR sensors. Otherwise the mobile robot detects obstacles on the right side, left side and front side. The power of the mobile robot is three Li batteries to be connected with parallel arrangement. The level two of the mobile robot has main board. The controller of the mobile robot receives the status of the environment, and communicates with the supervised computer via wireless RF interface. The switch input can turn on the power of the mobile robot, and selects power input to be Li batteries or adapter. The level three contains a wireless RF module, a fire detection module and a voice driver module for the FDR. The NR has not fire detection module in the level.

The encoder module of the DC servomotor calculates the movement displacement on the experimental platform. We can set the pulse numbers for per revolution to be A, and the mobile robot moves total pulse numbers to be B. The controller of the mobile robot can calculates the movement displacement D on the platform as following

$$D = 4.25 \times \pi \frac{B}{P} (cm) \quad (1)$$

The diameter of the driver wheel is 4.25 cm. We can calculate per pulse number to be 0.0845cm displacement. Each grid of the platform is 30cm to be computed about 355 pulse numbers. Users can set the grid numbers for mobile robots moving on the platform. The controller of the mobile robots improves the motion trajectory to be right according to the pulse numbers.

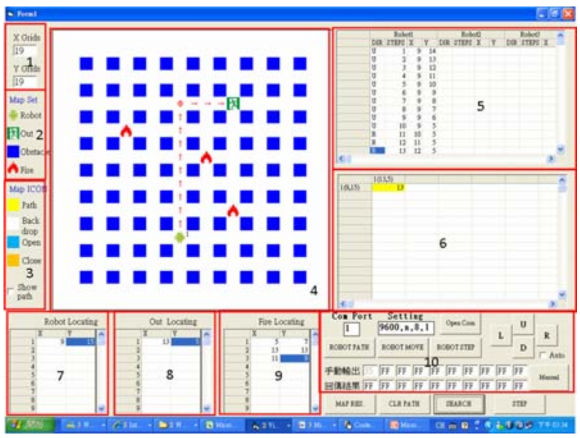


Fig. 3. The user interface

The user interface of the multiple mobile robot based escaping system has ten parts to be shown in Fig. 3. Users can set the size of the experimental platform in the part "1". The graphic labels of each function are listed in the part "2" and "3". Such as fire source, exit door, FDR and NR. The part "4" is the experimental platform to display the motion path that is computed by piecewise cubic Bezier curve and A* searching algorithm. The part "5" displays the searching processing of A* searching algorithm. The part "6" calculates the cost functions for navigation robot moving to the exit door. The supervised computer transmits the control command to the mobile robot, and receives the status of the mobile robot, and displays the position of the mobile robot moving on the platform simultaneously to be shown in the part "7". The parts "8" and "9" display locations of exit doors and fire sources. The part "10" sets the communication protocol between the user interface and mobile robots. The communication port of the user interface is 1, and sets baud-rate to be 9600.

III. PATH PLANNING

We use Piecewise cubic Bezier curve (PCBC) to program the escaping path of the intelligent building, and use A* searching algorithm to approach the programmed escaping path and decide the final escaping motion path to leave the fire sources using mobile robots. The piecewise cubic Bezier curve (PCBC) is used between each waypoint to connect with smooth curve. The equation of a cubic Bezier curve is listed as following [10].

$$\vec{p}(t) = \vec{a}t^3 + \vec{b}t^2 + \vec{c}t + \vec{p}_0, \quad \text{For } 0 < t < 1$$
$$\text{where } \vec{p} = (x, y), \vec{c} = 3(\vec{p}_1 - \vec{p}_0) \tag{2}$$
$$\vec{b} = 3(\vec{p}_2 - \vec{p}_1) - \vec{c}, \vec{a} = \vec{p}_3 - \vec{p}_0 - \vec{b} - \vec{c}$$

Since the parameter of Bezier curve is not time or distance dependence, the curve trajectory cannot be used directly. Some researchers used a modification method of curves as a time variable [11]. Others used an approximation of curves by dividing the parameter t into n intervals [13].

We use numerical method to calculate parameter t of Bezier curves with respect to the distance s of curve. If the curve parameter t of the current position can be calculated, then the directional vector of the curve can be calculated at the position, too. Finally, we can fine the relation between the distance and the parameter t can be shown in equation (3). We can use a fourth order Runge-Kutta method to calculate the inverse of the equation as following.

$$\frac{ds}{dt} = \sqrt{\left(\frac{d}{dt}x(t)\right)^2 + \left(\frac{d}{dt}y(t)\right)^2} = S(t) \tag{3}$$

$$t_{n+1} = t_n + T(t_n, s_n)$$
$$\text{where } T(t_n, s_n) = \Delta s \frac{(f_1 + 2f_2 + 2_3 + f_4)}{6} \tag{4}$$
$$f_1 = \frac{1}{S(t_n)}, \ldots, f_4 = \frac{1}{S(t_n + \Delta s f_3)}$$

Finally, we can calculate the directional vector as following [12].

$$\vec{V} = \left(\frac{dx(t)}{dt}, \frac{dy(t)}{dt}\right) \tag{5}$$

We use the proposed method to program the escaping path to be a curve. The programmed curve is tuning by two control points that are fixed on the fire sources. Then we use A* searching algorithm to improve the curve to be applied in the grid based experimental platform. We select the minimum distance between the programmed Bezier curve and the improved escaping motion path. A* searching algorithm is explained in the reference [14].

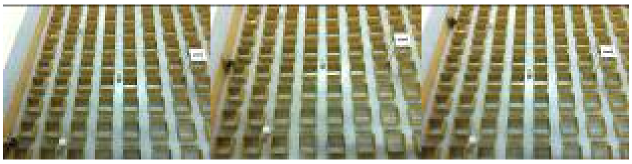
IV. EXPERIMENTAL RESULTS

In the fire escaping system, we use multiple mobile robots to detect fire sources on the experimental platform to be shown in Fig. 4. The mobile robots transmit the location of fire source to the supervised computer, and detect the other fire source moving on the horizontal direction and vertical direction. We use candle to present fire source on the experimental platform. The mobile robot starts at the initial position is shown in Fig. 4(a). The mobile robot moves one grid, and turns right to face the aisle. Then the mobile robot finds the first fire source using flame sensor, and transmits the detection results to the supervised computer via wireless RF interface. The fire source is detected by the mobile robot, and is recoded the horizontal direction on the user interface. The fire detection robot moves over the horizontal direction to record the positions of the three flame sources. The supervised computer only knows the horizontal locations of the three fire sources, and can't appear the fire symbol on the user interface. The experimental results are shown in Fig. 4(b) - (d).

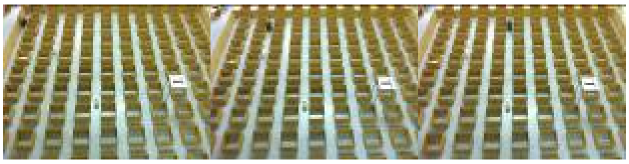
Then the mobile robot turns right 90^0 to detect the vertical direction of the platform. Finally, the robot (FDR) detects the vertical locations of the three flame sources to be shown in Fig. 6(e) - (g), and transmits vertical locations of the three fire sources on the user interface of the supervised computer. The supervised computer locates the coordinate locations of the three flame sources.

Next the supervised computer uses piecewise cubic Bezier curve to program the escaping curves from the people to the exit door to be shown in Fig. 5(a). The leaving people are the start position, and the exit door is the target position. The navigation robot can't moves according to the escaping curve. The supervised computer uses A* searching algorithm to decide the final escaping motion path that is approach to the escaping curve. The experimental result is shown in Fig. 5(b). We can see the final escaping motion path to be near the escaping curve. The final escaping motion path is plotted along the aisle of the experimental platform, and is implemented the movement scenario by the navigation robots. Finally, the navigation robot guards the people moving to the exit door, and leaves the three fire sources. The experimental results are shown in Fig. 5(c) – (h).

(a)

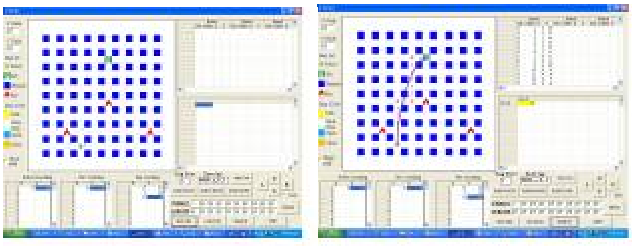


(b) (c) (d)

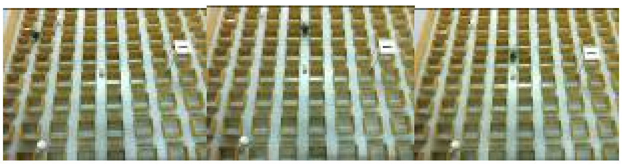


(e) (f) (g)

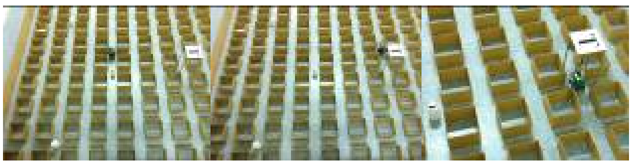
Fig. 4. FDR detects fire sources



(a) (b)



(c) (d) (e)



(f) (g) (h)

Fig. 5. NR guard people leaving fire sources

V. CONCLUSION

We have developed the fire escaping system to guard peoples leaving the dangerous area using some smart mobile robots. The system contains a supervised computer, some wireless RF modules, a experimental platform and some mobile robots. Mobile robots contain two types. One is fire detection robot; the other is navigation robot. In general, the intelligent mobile robot has huge size, and is not easily to implement the experimental scenario in the environment. We use some smart mobile robots to integrate the supervised computer to instead of the huge size based intelligent mobile robots. The supervised computer programs the escaping path using piecewise cubic Bezier curve and A* searching algorithm, and controls multiple mobile robots to present the movement scenario via wireless RF interface. In the future, we want to extend the escaping path programming algorithms using mobile robot, and develop more application fields of the multiple robots' system to be work cooperation in free space. The mobile robot can communicates with the other robots, and combines with the passive security modules in the intelligent building.

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