Mobile Robots Based Intelligent Fire Detection and Escaping System

Su Hsu-Shan
National Yunlin University of Science & Technology/Graduate school Engineering Science and technology, Yunlin
suss@tnvtc.gov.tw

Chia Song-Hiang
WuFeng University/Department of Fire Science, Chia-Yi, Taiwan
csh@wfu.edu.tw

Liou Jhen-Wei and Su Kuo-Lan
National Yunlin University of Science & Technology/Graduate school of Electrical Engineering, Yunlin, Taiwan
g9912736@yuntech.edu.tw, sukl@yuntech.edu.tw

Abstract*—The paper researches the fire sources and programs escaping path using mobile robots for intelligent building, and presents the movement scenario in the experimental platform. The mobile robot has the shape of cylinder and its diameter, height and weight is 10cm, 18cm and 1.5kg. The controller of the mobile robot is MCS-51 microchip, and acquires the detection signals from flame sensor and reflecting IR sensors, and receives the control command from the supervised compute via wireless RF interface. The mobile robot searches fire sources and obstacles moving in the experimental platform autonomously, and transmits the locations of the detected fire sources and obstacles to the supervised computer, too. The supervised computer uses Gauss probability distribution function to compute the risk values around the fire location, and uses Bayesian estimation algorithm to calculate the total risk values of each location of the experimental platform. We proposed A* searching algorithm to program escaping paths according to the risk distribution of each cross point in the platform. We develop user interface on the supervised computer for the fire detection and escaping system. The supervised computer displays the escaping path on the user interface, and guides peoples moving to the safety area using mobile robots. In the experimental results, we use two mobile robots searching the fire sources autonomously and locating the positions of the fire sources. The supervised computer programs the escaping paths using Bayesian estimation algorithm and A* searching algorithm on the user interface. The mobile robot guides people moving to the safety area according to the programmed escaping path.

***Index Terms*—intelligent building system, wireless RF interface, Gauss probability distribution function, A* searching algorithm, Bayesian estimation 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. There are approximately many thousand million dollars buried each year. Fire event is many risks to human life and property of societies which must be managed. How to develop a safety processing to search fire sources and guide people leaving the dangerous environment is an important issue.

In the past literatures of the fire detection, many experts research mobile robots. Wang [1] developed the multisensor fire detection algorithm using neural network. One temperature and one smoke density sensory signal are fused for ship fire alarm system. Healey [2] presented 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] applied 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] used one smoke sensor, one temperature sensor and one flame sensor to detect fire event using adaptive fusion method. Cheong [6] described a ZigBee-based sensor network node for the ultraviolet (UV) detection of flame. Zou [7] used multi-channel image noise filter to detect noise pixels in the image by utilizing PCCN's specific feature of the fire source. Tjokorda [8] focused on video processing method in temporal analysis phase in order to build a more responsive fire alarm system. Ha [9] proposed block-based fire detection algorithm consist s of three basic steps, and distinguish the fire region. Liu [10] used three different sensors to collect temperature, smoke concentration and CO concentration feature, and decides the fire using the decision tree.

The paper considers the problem of the fire sources, and integrates the multiple robot system with passive detection modules working together. Mobile robots are active detection modules to be more merits than passive detection modules, and are applied in fire detection and escaping system. The multiple mobile robot system has more advantages than one single robot system [11]. First, the multiple mobile robots have the potential to finish some tasks faster than a single robot [12]. Furthermore, using several robots introduces redundancy. Multiple

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Corresponding author: Su Kuo-Lan, sukl@yunrech.edu.tw

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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 can help compensation for sensor uncertainty [13]. Xu [14] designed and implemented the mobile robot remote fire alarm system using flame detection module. These papers focused on the fire detection using image recognition system or fire sensors, and were weakness of the escaping motion planning for fire region. The paper not only detects fire sources, but also programs the escaping motion path using mobile robots.

II. SYSTEM ARCHITECTURE

The system architecture of the fire detection and escaping system is shown in Fig. 1, and contains a supervised computer, an experimental platform, some wireless RF modules, and some mobile robots. The supervised computer receives detection signal (location, orientation and ID code) of each mobile robot via wireless RF interface. Mobile robots search fire sources using flame sensors moving along the experimental platform autonomously, and decide the position of the fire source in the experimental platform. Mobile robots search the horizontal and vertical direction of the fire source. Then the supervised computer defines the location of the fire source.

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).

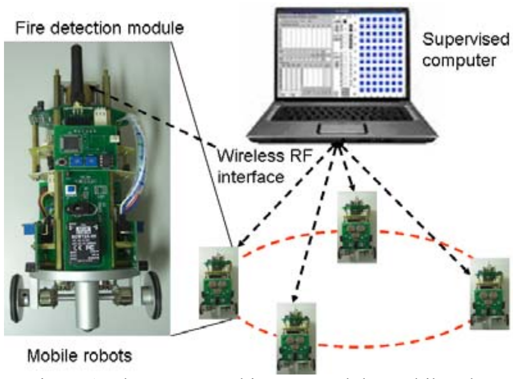

Figure 1. The system architecture and the mobile robot

The block diagram of the mobile robot is shown in Fig. 2. 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. The power of the mobile robot is three Li batteries to be connected with parallel arrangement.

The user interface of the fire detection and escaping system is in Fig. 3. The right side of the user interface contains searching mode, communication port setting and starting, communication speed setting, transmission and received data (starting and clearing). The bottom of the user interface calculates the pulse numbers of the two mobile robots (A and B). The location of exit door is settled at (1,1), and peoples are arranged by users. The location of fire source is searched by mobile robots. The location of the fire source is detected by one mobile robot. The user interface must know the other direction of the fire source from mobile robots, and plots the location of the fire source on the user interface. The supervised computer displays the risk probability distribution using Gauss function for the fire source.

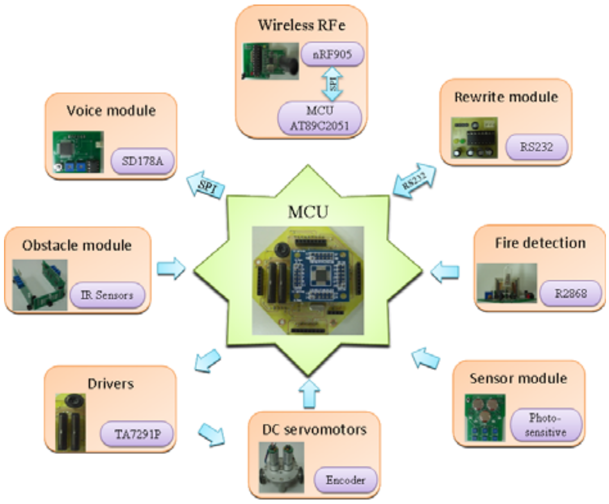

Figure 2. The block diagram of the mobile robot

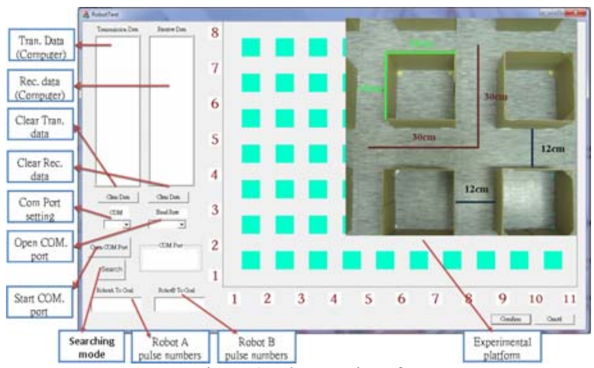

Figure 3. The user interface

III. ALGORITHM ANALSIS

We compute the risk values of each cross point using Bayesian estimation algorithm for each fire source in the experimental platform. Bayesian estimation provides formalism for multisensor fusion that allows sensory information to be combined according to the rules of probability theory. The Gauss distribution function of each fire source is defined as:

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$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad (1)$$

The parameter x is the distance far from the fire source for each cross point. The conditional probability $P(Y|X)$ takes a value between 0 and 1. Bayesian estimation is based on the well-known Bayes' rule:

$$P(Y \mid X) = \frac{P(X \mid Y)P(Y)}{P(X)} \quad (2)$$

Where $P(Y|X)$, the "posterior probability', represent the belief accorded to the hypothesis Y, given the information represent by X. The redundant information from a fleet of fire sources to be fused using the likelihood ratio formulation of Bayes' rule.

$$L(X_i|Y) = \frac{P(X_i|Y)}{P(X_i|-Y)} \quad (3)$$

We can defined the 'prior odds' on Y as

$$O(Y) = \frac{P(Y)}{P(-Y)} \quad (4)$$

And assume that the operation of each sensor is independent in the intelligent building system. The "posterior odds" on Y given the information $X_1, X_2, ..., X_n$ from the n flame sensors are given by the product

$$O(Y \mid X_1, X_2, ..., X_n) = O(Y)\prod_{i=1}^{n} \frac{P(X_i \mid Y)}{P(X_i \mid -Y)} \quad (5)$$

The posterior odds are related to the posterior probability by

$$O(Y \mid X_1, X_2, ..., X_n) = \frac{O(Y \mid X_1, X_2, ..., X_n)}{1 + O(X_1, X_2, ..., X_n)} \quad (6)$$

We make an example to calculate the risk value of each cross point for fire event Y. The fire event is happen by two sources that are defined, X_1, X_2. We compute the risk probability values of the cross point from two fire sources to be $P(X_1|Y) = 0.8$ and $P(X_2|Y) = 0.2$. We can calculate the posterior odds and posterior probability of the point,

$$O(Y|X_1, X_2) = \frac{0.8}{1-08}\frac{0.2}{1-0.2} = 1 \quad (7)$$

$$P(Y|X_1, X_2) = \frac{1}{1+1} = 0.5 \quad (8)$$

The posterior probability value is 0.5 for the cross point. Then we can compute posterior probability values of all cross points in the experimental platform. In the motion planning, we use A* searching algorithm to program the safety escaping path, and connect the low probability values from the people to the exit door. The formula of A^* searching algorithm is following:

$$f(n) = g(n) + h(n) \quad (9)$$

The core part of an intelligent searching algorithm is the definition of a proper heuristic function $f(n)$. $g(n)$ is the exact cost at sample time n from start point to the target point. The cost is displacement to be computed by encoder of the DC servomotor. $h(n)$ is an estimate function of the minimum cost from the start location to the target location. A good $h(n)$ function is the most important factor to obtain a good searching result. In this study, n is reschedules as n' to generate an approximate minimum cost schedule for the next point. The Eq. (9) can be rewritten as follows:

$$f(n) = g(n) + h(n') \quad (10)$$

IV. EXPERIMENTAL RESULTS

In the fire source searching, we use two mobile robots (A and B) to detect fire source in the experimental platform to be shown in the left side of the Fig. 4 (a). We use candle to present fire source. The two mobile robots use the symbols "A" and "B" to be shown in the right side of the Fig. 4 (a). We use the symbol "C" to define the people. The mobile robot B moves in the experimental platform, and detects the obstacle using the reflecting IR sensors. Then the robot transmits the locations of the obstacle to the supervised computer. The experimental scenario is shown in Fig. 4 (b).

In the Fig. 4 (c), the mobile robot A detects the other obstacle, and transmits the location to the supervised computer, too. The mobile robot A searches the fire source on the horizontal direction simultaneously. The mobile robots move in the experimental platform, and search the fire source on the horizontal direction and vertical direction, and transmit the location of fire source to the supervised computer. The fire source is detected by mobile robot to be recoded horizontal and vertical direction on the user interface. The user interface appears the fire symbol, and displays the risk probability values around the fire source to be shown in the center of the Fig. 4 (d).

The fire source is detected by mobile robots A and B, and displays the fire symbol in the user interface. The supervised computer calculates the posterior probability values of each cross point in the experimental platform. Then the supervised computer can programs the escaping path using A* searching algorithm, and connects all low risk probability values to be shown in Fig. 5 (a). The location of the mobile robot B is approach to the people, and guides the people (robot C) moving to the exit door (1,1). Then the two mobile robots (A and B) program the escaping paths to be shown in Fig. 5 (b). We can see the mobile robot A programming the escaping path from (11,4) to (1,2). The robot A programs the other escaping path from (4,7) to the exit door (1,1).

The people follow the mobile robot B moving to the exit door according to the escaping path far from the fire source. The mobile robot B moves to the position (4,4) to detect the new obstacle, and transmits the location of the

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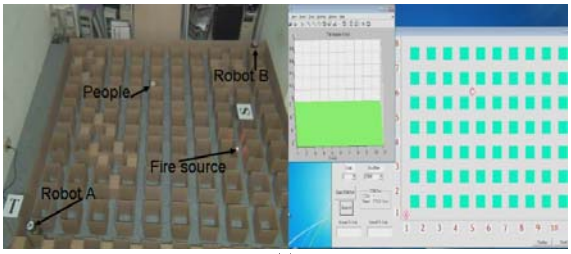
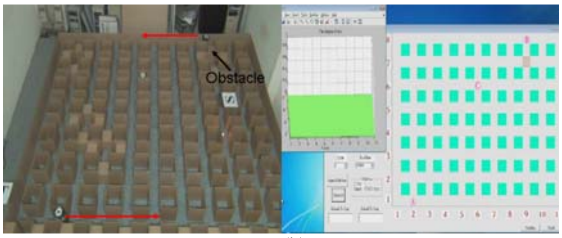
detected obstacle to the supervised computer. The robot programs the new escaping path, and guides the people leaving the fire field. The experimental scenario is shown in Fig. 5 (c). Finally, the two mobile robots and the people leave the fire field. The user interface displays the escaping paths of the two mobile robots, and displays the position of the fire source and the detected obstacles. The experimental results are shown in Fig. 5 (d).



(a)



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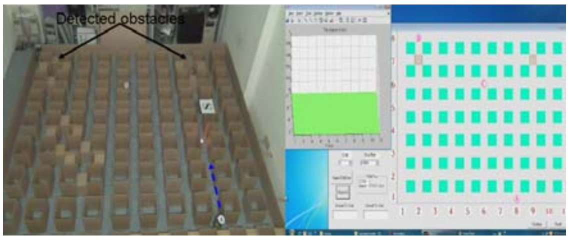
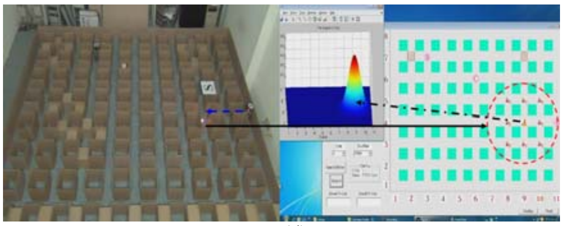
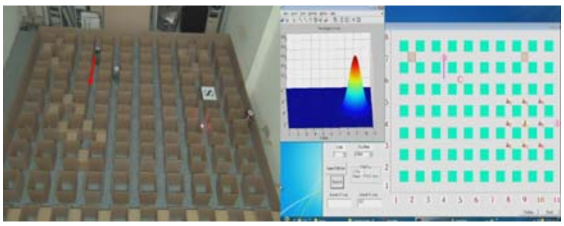


(c)

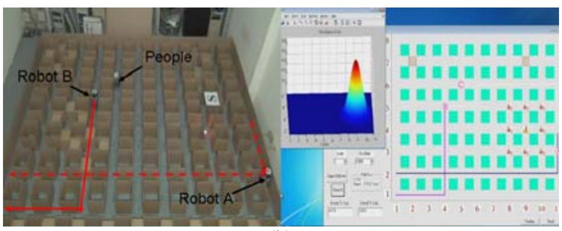


(d)

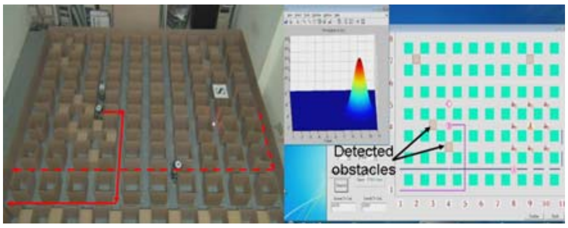
Figure 4. Fire source searching



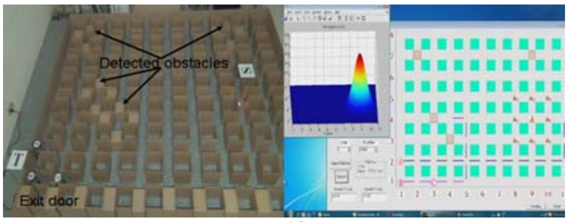
(a)



(b)



(c)



(d)

Figure 6. Program the escaping path

V. Conclusion

We have developed the fire source searching and escaping path programming system to guide peoples leaving the dangerous area. The system contains a supervised computer, some wireless RF modules, an experimental platform and some mobile robots. Mobile robots search fire sources moving in the experimental platform autonomously, and transmit the position of the fire source to the supervised computer via wireless RF interface. The user interface calculates the risk probability values of each cross point using Bayesian estimation algorithm, and program the more safety escaping path using A* searching algorithm. The supervised computer selects the mobile robot that is more approach to the peoples. The mobile robot guides people leaving the fire field using the programmed escaping path.

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Su Hsu-Shan My name is Su Hsu-Shan. I study in Graduate school Engineering Science and technology, National Yunlin University of Science & Technology, Douliou, Yunlin 640, Taiwan, and received M. S. degrees in I-SHOU University. My research interests include security systems and robotics. I like to read philosophy and Buddhism.

Chia Song-Hiang received the B. Sc. Degree in Electrical Engineering from the National Cheng Kung University, Tainan, Taiwan, R.O.C. in 1982, and received the Ph.D. in electrical engineering at National Yunlin University of Science & Technology, Taiwan, R.O.C. Since 1982, he has been at Wu-Feng university (Taiwan), where he is teaching the subjects of Instrument Electronic, Electric Circuits, Sensor and Transformer. Currently, he is an associate professor of fire science at Wu-Feng University. His current research interests are in the areas of Control System and Module-Based Intelligent Mobile Robot Applications.

My name is **Liou Jhen-Wei**. I study in Graduate school Electrical Engineering, National Yunlin University of Science & Technology Douliou, Yunlin 640,Taiwan, and I Bachelor student at LUNGHWA University of Science & Technology. My research interests include MCU software design and application and robotics. In my spare time, I like outing and listening to music. I think reading could enlarge my Knowledge. I have a great advisor working in National Yunlin University of Science & Technology, and he provides a good learning environment and resources.

Kuo Lan Su received the B. S. and M. S. degrees in automatic control engineering from Feng-Chia University, Seatwen, Taiwan, R. O. C., and received the PH. D. degree in electrical engineering at National Chung-Cheng University, Chia-Yi,Taiwan, R. O. C., He is currently a teacher in the Department of Electrical Engineering, National Yunlin University of Science & Technology. His research interests include multisensor fusion and robotics.

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