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Automatic Fire Detection System Using Adaptive Fusion Algorithm for Fire Fighting Robot

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Abstract—**Multisensor Fire detection algorithm (MSFDA) is one of the current important research issues for intelligent building. First, we design a fire fighting robot with extinguish for the intelligent building. The fire fighting robot is constructed using aluminium frame. The contour of the robot is cylinder. The diameter is 40 cm, and height is about 80 cm. There are six systems in the fire fighting robot, including structure, avoidance obstacle and driver system, software development system, fire detection, remote supervise system and others. We design the fire detection system using three flame sensors in the fire fighting robot. The adaptive fusion method is proposed for fire detection of fire fighting robot. We use computer simulation to improve the method to be adequate for fire detection. We design the fire detection system in the fire fighting robot, and program the fire detection and fighting procedure using sensor based method. Finally, we implement the fire detection system using fire fighting robot. If fire accident is true, the robot can find out fire source using the proposed method by fire detection system, and move to fire source to fight the fire using extinguish.**

I. Introduction

Home can provide safety, convenience, and efficiency for people in the 21st century. An intelligent home system is integrated by many function and systems. One of the most important systems is the fire detection function system in an intelligent home [1]-[6]. The fire event may involve dangerous in life. In generally, the fire detection device is fixed on the wall or ceiling. But the method is not flexibility to detect fire event. It is not very convenience that uses many fire detection modules in the home. In the paper, we design a fire fighting robot to detect fire event, and use extinguish to fight the fire source, and can transmits the fire event to the remote supervised computer using RF interface and Internet, and transmit fire information to cell phone using GSM modern.

In the past literatures, many experts research in the service robot. Some research addressed in developing target-tracking system of service robot [11]-[12], such as Hisato Kobayashi et al. proposed a method to detect human being by an autonomous mobile guard robot [13]. Yoichi Shimosasa et al. developed Autonomous Guard Robot [10] witch integrate the security and service system to an Autonomous Guard Robot, the robot can guide visitors in daytime and patrol in the night. D. A. Ciccimaro developed the autonomous security robot – "*ROBART III*" which equipped with the non-lethal-response weapon [8]-[9]. Moreover, some research addressed in the robot has the capability of fire fighting [7]. There are some products that have been published for security robot. Such as SECON and SOC in Japanese, and International Robotics in USA, and Chung Cheng #1 in Taiwan [20].

Wang et al [14] 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. [15] 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 [16] 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 [17] described the fire detection with a combination of ultrasonic and microwave Doppler sensor. Luo and Su [18]-[19] 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.

The paper is organized as follows: Section II describes the system structure of the automatic fire fighting system. Section III presents the function of the fire fighting robot. Section IV explains the fire detection algorithm for the fire fighting robot, and the simulation and experimental result is implemented in section V. Section VI presents brief concluding comments.

II. System Architecture

The system architecture of the home security system is shown in Fig 1. The system contains fire fighting robot, supervise computer, remote supervise computer, GSM modern, security module, appliance control module and wireless RF controller. The robot and security device can receive the status of security module and appliance control module using wireless RF interface. In the security module, it uses one-way communication with the fire fighting robot. But the appliance module uses two-way communication with fire fighting robot. The fire fighting robot can communicate with GSM modern using RS232 interface, and can communicate with supervise computer using wireless RS232 interface, and the user can control the fire fighting robot using wireless RF controller.

The supervise computer can get security module data from the fire fighting robot through wireless RS232 interface. The remote supervise computer can interact with the supervise computer through Internet. The user can connect to the supervise computer to get security information of the home or building, and control the fire fighting robot to everywhere in the home The user can control the fire fighting robot using personal computer through wireless RS232 interface. The supervised computer can transmit the reality status to the client computer through Internet, and transmits the message to cell phone using GSM modern.

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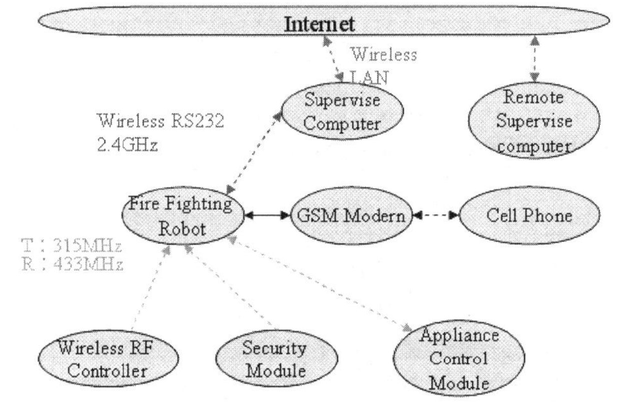

Fig. 1. The overview of the home security

The fire fighting robot is constructed using aluminium frame. The contour of the robot is cylinder. The diameter is 40 cm, and height is about 80 cm. The main controller of the fire fighting robot is microprocessor. There are six systems in the fire fighting robot, including structure, avoidance obstacle and driver system, software development system, fire detection, remote supervise system and others. Fig. 2 is the hierarchy structure of the fire fighting robot, and each system includes some subsystem. Each system contains some functions in the fire fighting robot. For example, the fire detection system contains fire fighting device, fire detection rule and fire detection hardware.

III. Fire Fighting Robot

The hardware configuration of the fire fighting robot is shown in Fig. 3. The main controller of the robot is microprocessor (MCS-51). The hardware devices have display device, extinguish, CCD, sensors and sensory circuits, driver system, GSM modern and wireless RF interface. The supervised computer is personal computer (PC) with a Pentium-IV 2.4G CPU.

The block diagram of the fire fighting robot is shown in Fig. 4. In the drive device, there are fire fighting device, auto-charging device and appliance control interface. In the motion control function, it cans orders command to control two DC motors through PWM and driver device. In the avoidance obstacle function, the robot catches eight pieces IR sensor status, and measure distance of obstacle using three ultrasonic sensors. We use extend I/O interface to acquire the distance from obstacle. We design ultrasonic driver circuit and use multisensor fusion method to get exactly decision output. The transmission interface between supervised computer and the fire fighting robot is wireless RS232 interface. There are some devices communicate with main controller of the fire fighting robot. Such as LCD display, wireless image, wireless RS 232 interface, alarm device and GSM modern.

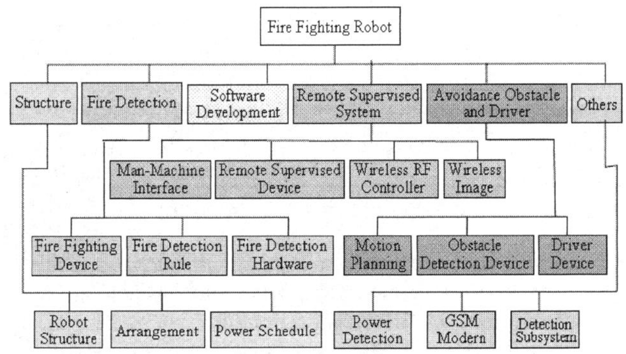

Fig. 2. The hierarchy structure of the fire fighting robot.

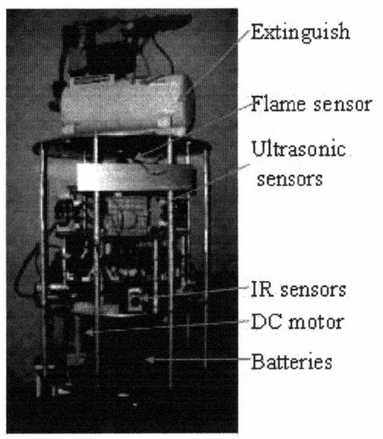

Fig. 3. The hardware structure of the fire fighting robot.

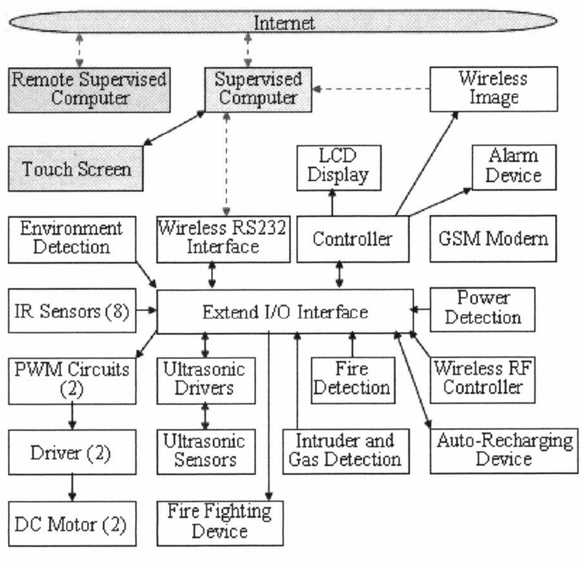

Fig. 4. The block diagram of the fire fighting robot.

In the avoidance obstacle and driver system, the fire fighting robot uses ultrasonic sensors and infrared sensor to detect obstacle and recon structure the surrounding environment by using multisensor fusion and integration technique. The fire fighting robot uses eight pieces SMC-10R infrared reflection sensors to detect obstacle, and uses Polaroid 6500 ultrasonic range sensors to measure the distance from obstacle.

There are two type objects are defined as "obstacle" and "free space", as shown in Fig. 5. Eight infrared sensors are used for obstacle detection in the uncertain environment, where each sensor is set on fixed location around the fire fighting robot. The angle is $\frac{\pi}{4}$ from X axis to the centre of infrared beam. The radius of the robot is R (R=40cm), and the distance between the centre of the robot and obstacle is Di, and the safe distance (infrared reflection senor detection distance) between robot and obstacle is Ds. The Ds is a threshold to ensure that the fire fighting robot is not closes the obstacle. The obstacle detection rule can written as

If $Di - R \leq Ds$ then Ii has found obstacle

If $Di - R > Ds$ then Ii has not found obstacle

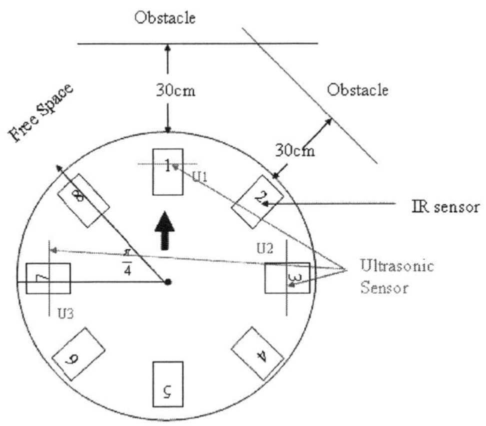

Fig. 5. The arrangement of IR and ultrasonic sensors

We use five IR sensors (1, 2, 3, 7 and 8) and three ultrasonic sensors (U1, U2 and U3) to detect obstacle. The IR sensor can detects distance from obstacle to be 60 cm. The ultrasonic can detects distance range from 25cm to 10m. We fuse the advantages of these sensors to increase the precious of the detection obstacle. We use three IR sensors (4, 5 and 7) to detect intruder and dynamic obstacle behind the fire fighting robot.

The driver system is designed by us. In the low cost part, we use PWM signal to control two gear-based DC motor. In generally, the DC servomotor is very expensive. We design the cheaper-based encoder device to calculate the displacement of the fire fighting robot. In the rule of motion planning, the mobile robot must turn left, and IR sensors 1, 2 or 3 detect obstacle. The mobile robot must turn right, and IR sensors 7 or 8 detect obstacle. Otherwise, the mobile robot move forward, and IR sensors 1, 2, 3, 7 and 8 detect free space. The cost of the fire fighting robot is about US1300 dollars (no extinguish).

The remote supervised system contains supervised computer, remote supervised computer, wireless RF interface and internet interface. The user interface of the supervise system on supervise computer is shown in Fig. 6. The panel can display the sensory status (bottom) that is detected using variety sensors, and display the detection results using sensors from the fire fighting robot. The client-side program's function is to order command to the robot and continuously update the sensory data, which receive from the robot supervise computer. The program of the client's user interface be designed by VB.

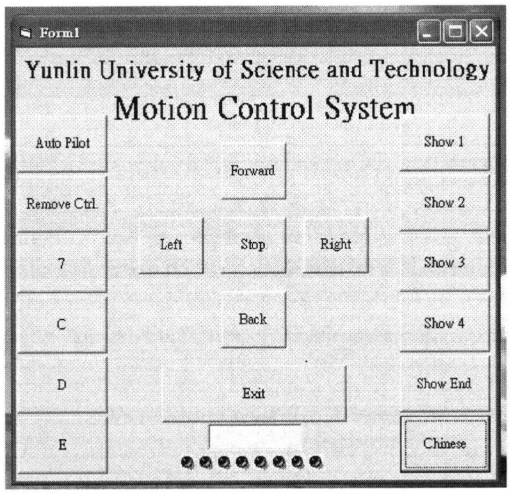

Fig. 6. The supervise panel of the fire fighting robot

The fire fighting robot communicates with mobile phone using GSM (Global System for Mobile) modern. The GSM modern (WMOD2) was made by Wavecom. The modular is a seft-contained E-GSM900/GSM1800 (or E-GSM900/GSM1900) dual band modern. We develop the software system for the mobile robot using Visual Basic and assembly language. The assembly language is designed as the main program of the fire fighting robot. The supervise system uses Visual Basic to program the supervise panel.

IV. FIRE DETECTION ALGORITHM

We use three variety sensors to detect fire event in fire detection system. We want to get more reliable and have high accuracy in the detection capability. In order to enhance the detection capability, we use the adaptive data fusion algorithms to obtain the high reliable result in the fire detection system.

In detection system, the weight is a function of the probability of detection P_D, the probability of false alarm P_F and miss probability P_M of the sensor. The relation of detection rule is shown in Fig. 7. We can determine P_D and P_F for different sensors through experiments. However, in reality P_D, P_M and P_F may vary with time. Therefore, the weight function may vary with time. The principles of every sensor are not the same and the weight vales are time-varying in real conditions. Hence the weight values are not equal at all time and we can use the adaptive decision to obtain the optimal values.

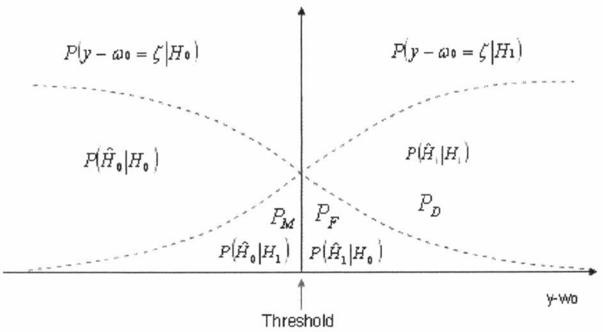

Fig. 7. The Relation of detection rule

At first, let us consider a binary hypothesis experimental problem with the following two hypotheses: H_0: fire detection signal is absent, and H_1: fire detection signal is present. Then a priori probabilities of the two hypotheses are defined by $P(H_0)=P_0$, and $P(H_1)=P_1$. So that we can find the initial weight:

$$\omega_0 = \log\frac{P_1}{P_0} \tag{1}$$

$$\omega_i = \begin{cases} \log\dfrac{1-P_{Mi}}{P_{Fi}} & \text{If } U_i=+1 \\ \log\dfrac{1-P_{Fi}}{P_{Mi}} & \text{If } U_i=-1 \end{cases} \tag{2}$$

We further assume that these observational signals at the individual sensors are statistically independent and then the conditional probability is defined by $P(H_i|H_j)$, i=1, 2, 3. j=0, 1. Each sensor employs a decision rule U_i i, where

$$U_i = \begin{cases} -1 & \text{if no fire is detected.} \\ +1 & \text{if fire is detected.} \end{cases} \tag{3}$$

The distributed fire detection system is assumed to have no knowledge of the probability mass functions of the observations. Thus, the estimated probability of detection and false alarm for the ith sensor P_{Di} and P_{Fi} can be approximated by relative frequencies.

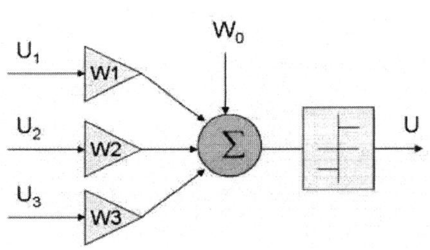

Fig. 8. Fusion Center Structure

In the Fig. 8, the final decision U was determined by the data fusion center for the system based on the individual decision. So that

$$F = \omega_0 + u_1\omega_1 + u_2\omega_2 + u_3\omega_3 \tag{4}$$

$$y = \omega_0 + \sum_{i=1}^{3}\omega_i u_i \tag{5}$$

$$y - \omega_0 = \sum_{i=1}^{3} W_i U_i \tag{6}$$

Where ζ is a possible value that y_i takes on. The range of y_i is divide into reliable and unreliable ranges. We denote the lower and upper limit of the unreliable range as τ_1 and τ_2, as shown in Fig. 9. Usually $\tau_2 \geq 0$, $\tau_1 \leq 0$. We call τ_1 and τ_2 the reliability threshold. These decision are considered reliable decision, defined by $\hat{H}_1$ when $y_i > \tau_2$ and $\hat{H}_0$. When $y_i < \tau_1$. The decision is considered unreliable. When $\tau_1 < y_i < \tau_2$, denoted by $\hat{H}_x$. Obviously,

$$P(\hat{H}_1) + P(\hat{H}_0) + P(\hat{H}_x) = 1 \tag{7}$$

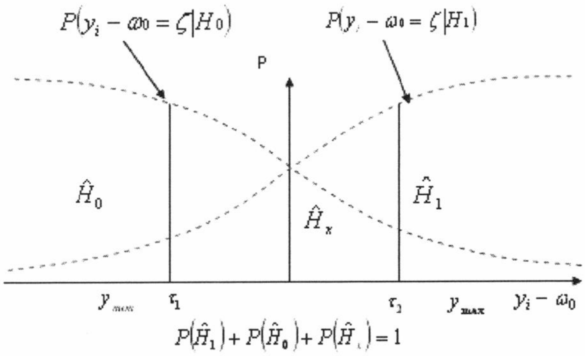

Fig. 9. The fusion decision result

Based on the above condition, Chair and Varshney developed the optimal fusion rule as

$$U(t) = \begin{cases} -1, & F(t) \leq 0 \\ +1, & F(t) > 0 \end{cases} \tag{8}$$

We can assume the probability functions of $P(H_i|H_0)$, and $P(H_i|H_1)$ are Gauss function.

$$\begin{aligned} P(H_i|H_0) &= \frac{1}{\sqrt{2\pi}}\exp\left[-\frac{1}{2}(x+1)^2\right] \\ P(H_i|H_1) &= \frac{1}{\sqrt{2\pi}}\exp\left[-\frac{1}{2}(x-1)^2\right] \end{aligned} \tag{9}$$

Hence m, n, m_{1i}, m_{0i}, n_{1i} and n_{0i} can simply be got. That is:

$$\frac{m}{n} \approx \frac{P(H_1)}{P(H_0)}$$

$$\frac{m_{1i}}{n_{1i}} \approx \frac{P(U_i = +1, H_1)}{P(U_i = +1, H_0)}$$

$$\frac{m_{0i}}{n_{0i}} \approx \frac{P(U_i = -1, H_0)}{P(U_i = -1, H_1)} \qquad (i = 1, 2, 3) \qquad (10)$$

If we take $n=n_{1i}=n_{0i}=1$. We can find

$$m \approx \frac{P(H_1)}{P(H_0)}$$

$$m_{1i} \approx \frac{P(U_i = +1, H_1)}{P(U_i = +1, H_0)} \qquad (i = 1, 2, 3) \qquad (11)$$

$$m_{0i} \approx \frac{P(U_i = -1, H_0)}{P(U_i = -1, H_1)}$$

We can obtain the reinforcement updating rules are [21]-[22]:

$$\Delta\hat{\omega}_i = \begin{cases} \dfrac{1}{m_{1i}} & \text{If } u_i = +1 \text{ and } \hat{H}_1 \\ \dfrac{1}{m_{0i}} & \text{If } u_i = -1 \text{ and } \hat{H}_0 \\ -\dfrac{1}{m_{1i}} e^{\hat{\omega}_i + \hat{\omega}_0} & \text{If } u_i = +1 \text{ and } \hat{H}_0 \\ -\dfrac{1}{m_{0i}} e^{\hat{\omega}_i - \hat{\omega}_0} & \text{If } u_i = -1 \text{ and } \hat{H}_1 \end{cases} \qquad (12)$$

$$\Delta\hat{\omega}_0 = \begin{cases} \dfrac{1}{m} & \text{When } \hat{H}_1 \text{ occurs} \\ -\dfrac{1}{m} e^{\hat{\omega}_0} & \text{When } \hat{H}_0 \text{ occurs} \end{cases} \qquad (13)$$

$\hat{\omega}_i^+ = \hat{\omega}_i^- + \Delta\hat{\omega}_i$, i=0, 1, 2, where $\hat{\omega}_i^+$ and $\hat{\omega}_i^-$ represent the weight value after and before each update. Finally, we can analyze the estimate error ε_i , and we can achieve

$$\begin{cases} \varepsilon_0 = \log\left(\dfrac{1+\dfrac{\alpha_{\min}}{\gamma_0}}{1+\gamma_0\beta_{\min}}\right) + \log(\gamma) \\ \varepsilon_i = \begin{cases} \log\dfrac{1+\beta_{\min}\gamma_0}{1+\dfrac{\alpha_{\min}}{\gamma_0}} + \log\dfrac{1+\dfrac{\alpha_{\min}}{\gamma_0\gamma_i}}{1+\beta_{\min}\lambda_0\gamma_i} & \text{if} \quad u_i = +1 \\ \log\dfrac{1+\dfrac{\alpha_{\min}}{\gamma_0}}{1+\beta_{\min}\gamma_0} + \log\dfrac{1+\dfrac{\beta_{\min}\gamma_0}{\gamma_i}}{1+\gamma_i\dfrac{\alpha_{\min}}{\gamma_0}} & \text{if} \quad u_i = -1 \end{cases} \end{cases} \qquad (14)$$

The computation of up rule is very complex, and the proposed method is implemented in supervised computer. The fire fighting robot transmits signals of these flame sensors to the supervised computer using wireless RS232 interface. The decision output transmits to mobile robot from the supervised computer. The adaptive multisensor fusion architecture is shown in Fig. 10. S1, S2 and S3 represent three flame sensors dependably. These signals of sensors must be processed to be binary digital by comparison circuits. That is to say, when these sensors detect fire happened. These sensor signals must be high; otherwise, these sensor signals must be low.

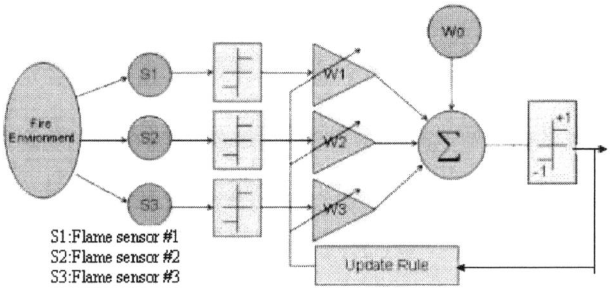

Fig. 10. Adaptive multisensor fusion architecture.

V. Experimental Results

In the motion control experimental scenario of the fire fighting robot, we can select autonomous mode or wireless control mode. In the autonomous mode, the fire fighting robot can move according to environment state using IR sensors and ultrasonic sensors. In the wireless control mode, we can supervise the fire fighting robot for walking forward, walking backward, stop, rotation, turn right and turn left through multiple interface system (wireless RF interface or wireless RS232 interface). In the supervise computer, the computer monitor display panel of remote supervised function is shown in Fig. 11. We click the walking forward. The command must be transmitted to the supervised computer through Internet. Then, the command will control the mobile robot by main controller through wireless RS232 interface, and the wireless RF controller can controls the mobile robot walking forward or backward, too.

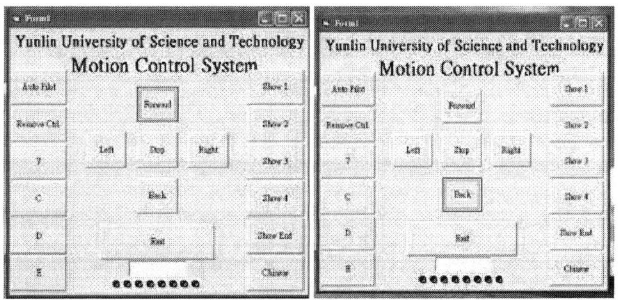

Fig. 11. The mobile robot is guarding by the remote supervise computer

We use the developed fire detection system to evaluate the fused results of the proposed scheme. The variable weights of adaptive multisensor fusion were define W_1 (flame sensor #1), W_2 (flame sensor #2) and W_3 (flame sensor #3) in the fire detection system. We assume that the reliability of each sensor is the same and the initial weight values are P_D=0.8888, P_F=0.1112. First, we can get the weight variable curve in Fig. 12 by using adaptive fusion algorithm. The final weight values are approaching to steady state W1=2.084468, W2=2.242067 and W3=2.251.

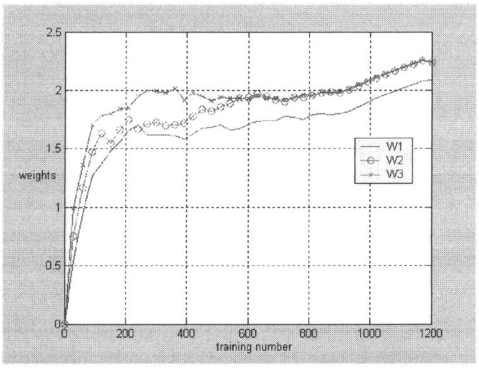

Fig. 12. The weight variation for adaptive fusion method

VI. Conclusion

We have presented a multi sensor based real time monitoring system that is applied in the fire fighting robot. We have presented a multiple interface based real time monitoring system that is applied in home automation. The security system of the home and building contains fire fighting robot security device, supervise computer, remote supervise computer, GSM modern, wireless RF controller security module and appliance control modular. The main controller of the fire fighting robot is microprocessor. We program assembly language to control the mobile robot to acquire sensor data, and program the supervised system and remote supervised system using Visual Basic to receive security information from wireless RS232 interface, and design a general user interface on the supervised computer. In the experimental results, the user controls the mobile robot through the wireless RF controller, supervised computer and remote supervised compute. Then, we have presented a fire detection method using adaptive fusion algorithm. In the future, we want to implement the proposed method using the fire fighting robot and supervised computer.

References

[1] C. W. Wang and A. T. P. So, "Building Automation In The Century," in Proceedings of the 4-th International Conference on Advance on Advances in Power System Control, Operation Management, APCOM-97, Hong Kong, November 1997, pp.819-824.

[2] M. Azegami and H. Fujixoshi, "A Systematic Approach to Intelligent Building Design," IEEE Communications Magazine, October 1993, pp.46-48.

[3] Kujuro and H. Yasuda, "Systems Evolution in Intelligent Building," IEEE Communication Magazine, October 1993, pp.22-26.

[4] M. R. Finley, J. A. Karakura and R. Nbogni, "Survey of Intelligent Building Concepts," IEEE Communication Magazine, April 1991, pp.18-20.

[5] M. Fiax, "Intelligent Building," IEEE Communications Magazine April 1991, pp.24-27.

[6] L. C. Fu and T. J. Shih, "Holonic Supervisory Control and Data Acquisition Kernel for 21st Century Intelligent Building System," IEEE International Conference on Robotics & Automation, Sam Francisco, CA, April 2000, pp. 2641-2646

[7] Bradshaw, "The UK Security and Fire Fighting Advanced Robot project," IEE Colloquium on Advanced Robotic Initiatives in the UK, 1991, pp. 1/1-1/4.

[8] Gilbreath, G.A., Ciccimaro, D.A., and H.R. Everett, "An Advanced Telereflexive Tactical Response Robot," Proceedings, Workshop 7: Vehicle Teleoperation Interfaces, IEEE International Conference on Robotics and Automation, ICRA2000, San Francisco, CA, 28 April, 2000.

[9] Ciccimaro, D.A., H.R. Everett, M.H. Bruch, and C.B. Phillips, "A Supervised Autonomous Security Response Robot,", American Nuclear Society 8th International Topical Meeting on Robotics and Remote Systems (ANS'99), Pittsburgh, PA, 25-29 April, 1999.

[10] Y. Shimosasa, J. Kanemoto, K. Hakamada, H. Horii, T. Ariki, Y. Sugawara, F. Kojio, A. Kimura, S. Yuta, "Some results of the test operation of a security service system with autonomous guard robot," The 26th Annual Conference of the IEEE on Industrial Electronics Society, 2000 (IECON 2000), Vol.1, pp.405-409.

[11] Sung-On Lee, Young-Jo Cho, Myung Hwang-Bo, Bum-Jae You, Sang-Rok Oh , "A stable target-tracking control for unicycle mobile robots," Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS 2000) , Vol.3 , 2000 , pp.1822-1827.

[12] L. E. Parker, B. A. Emmons, "Cooperative multi-robot observation of multiple moving targets," Proceedings of the IEEE International Conference on Robotics and Automation,, vol.3, 1997, pp.2082-2089.

[13] H. Kobayashi, M. Yanagida, "Moving object detection by an autonomous guard robot," Proceedings of the 4th IEEE International Workshop on Robot and Human Communication, 1995, TOKYO, pp.323-326.

[14] W. Xihuai, X. Jianmei and B. Minzhong, "A ship fire alarm system based on fuzzy neural network,"in Proceedings of the 3rd World Congress on Intelligent Control and Automation, Vol. 3, 2000, pp. 1734 -1736.

[15] Healey, G., Slater, D., Lin, T., Drda, B. Goedeke and A. D., "A system for real-time fire detection," in Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 1993, pp. 605-606.

[16] Neubauer A., "Genetic algorithms in automatic fire detection technology," Second International Conference On Genetic Algorithms in Engineering Systems: Innovations and Applications, 1997, pp. 180-185.

[17] Ruser, H. and Magori, V., "Fire detection with a combined ultrasonic-microwave Doppler sensor," in Proceedings of IEEE Ultrasonics Symposium, Vol.1, 1998, pp. 489-492.

[18] R. C. Luo, K. L. Su and K. H. Tsai, "Fire detection and Isolation for Intelligent Building System Using Adaptive Sensory Fusion Method," Proceedings of The IEEE International Conference on Robotics and Automation, 2002, pp.1777-1781.

[19] R. C. Luo, K. L. Su and K. H. Tsai, "Intelligent Security Robot Fire Detection System Using Adaptive Sensory Fusion Method," The IEEE International Conference on Industrial Electronics Society ,2002 (IECON 2002), pp.2663-2668.

[20] Ren C. Luo, Kuo L. Su and Te Yi Hsu, "The Development of a Multisensor Based Intelligent Security Robot : Chung Cheng #1," IEEE International Conference on Hand-on Intelligent Mechatronics and Automation (HIMA2005), pp.105.

[21] N. Ansari, E. S. H. Hou, B. O. Zhu and J. G. Chen, "Adaptive Fusion by Reiforcement Learning for Distributed Detection Systems," IEEE Transa- ctions on Aerospace and Electronic System Vol32, NO.2,April 1996,PP524-531

[22] N. Ansari, J. G. Chan and Y. Z. Zhang," Adaptive Decision Fusion for Unequiproable Sources," IEEE Proceedings online NO.1997,PP.105-111.