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Design of Novel Fire Rescue System Based on Wireless Sensor Network

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Abstract: This document presents an innovative system for the traditional air respirator used for fire rescue. This system took advantage of the Micro-Electro-Mechanical Systems inertial acceleration sensor to supervise the real time posture of the personnel, conducted the pressure measurement by replacing the mechanical watch with electronic pressure transmitter, and transferred the residual aeration to the helmet and handheld instrument of the team members with 433 MHz wireless sensor network. The handheld collected the information, and sent it to the remote command center through the telecom General Packet Radio Service network. The management software can achieve the real-time information from the firemen. The system has a great significance in real application, which guarantees the life safety of the firemen to a great degree, and changes the situation in which each fireman is an information isolated island. Copyright © 2013 IFSA.

Keywords: Fire rescue, Positive pressure respirator, Wireless sensor network, Inertial acceleration sensor, GPRS.

1. Introduction

Fire is a major cause of human suffering and material loss. At present, the informatization of fire-fighting apparatus has already become a trend [1, 2]. Although the positive pressure respirator enjoys great development, for instance, the comfort degree of the mask, the strength of the gas bottle, etc. its system is still the mechanical structure, which cannot detect the vital signs of the firefighters, or send the information of the firefighter to the fire-fighting command center, the firefighter is still the information isolated island.

In recent years, some of the air respirators have been electronized, such as MSA [3], ISI [4], etc. but it can only transmit such information, like the pressure of the air bottle and if the human is motionless. The firefighter is still a mechanical watch, without knowing the time that the gas bottle can lasts, the on-spot temperature, etc. Meanwhile, since those products transmit information to the fire-control command vehicle, the fire-control command center cannot read the information. Moreover, due to the limited wireless transmission distance, the reliability of the information transmitted under complicated environment cannot be guaranteed. A DTI funded project “Secure Adhoc Fire &Emergency safety NETwork (SafetyNET)” provides an information infrastructure to enable buildings, firefighters, fire tenders, and their control centre to efficiently communicate during natural or manmade disasters by using sensor networks, wireless communications [5]. However SafetyNET need to be installed in the building in advance, this can’t meet all the condition. The wireless sensor network have been applied to in fire rescue field, but only used to humanitarian Search and navigation [6, 7].

Compared to the traditional air respirator, novel fire rescue system based on wireless sensor network presented in this paper. The system wear in the body of fireman, and bottom layer comprises a robust wireless sensor network. All the components communicate with each other depending on it has the following advantages:

- The handheld watch of the firefighter can monitor the environment, while the air bottle can provide breathing time.
- LED gas display has been added into the breathing mask, the firefighters can read the pressure of the air bottle.
- Vibration alarm has been added into the mask, so that when the sound-light alarm cannot be discovered under complicated on-spot environment, the vibrator can be used for alarm to remind the firefighter of withdrawal.
- The posture detection for the firefighters based on EMS inertial device has been added, which can not only detect the static and moving state, but also detect the posture of the firefighters.

2. System Structure

This system consists of four parts, including the multi-level management system, the portable wireless monitor worn by the firefighters, residual gas display in the helmet and alarm module, as well as positive air respirator. The overall design scheme is shown as follows: 1) The interface of the upper computer is designed with Labview, from which the code of the firefighter, the affordable service time of the respirator, as well as the posture can be seen. It can not only set the network scale, alarm limit, etc. but also display the real-time status information of the firefighters, which can monitor the state of the firefighters, and conduct the centralized dispatching for the firefighters according to the information. 2) Wireless monitor and helmet residual gas display, as well as the alarm module employ the advanced electronic design technology, with the function of wireless communication and alarm. It can receive the command and dispatch order in the fire scene, send the sound-light alarm signal and vibration alarm, monitor the status information of both the firefighters and air bottle, and generate corresponding alarm information, which will be transmitted to the command management system in GPRS. 3) The pluggable label is employed to realize one man one label, so that one set of equipment can be shared by several people, and it can correspond to the personnel as long as inserting the label equipment. 4) The intelligent positive pressure air respirator is added with pressure sensor and wireless transmission to improve the rescue efficiency. 5) The wireless communication of this system can be divided into two parts: a) Equipment conducts the short-distance communication through 433MHZ wireless. b) GPRS is adopted as the air interface between the firefighters and command center, which covers a huge area with stable and reliable link and fast access speed, and provides the seamless connections with the current data. 6) Low-power design. In the software design, the transmitting terminal will set the chip into sleep mode before launch, and send after the time is up. The receiving end will enter the sleep mode after receiving. The receiving mode should be opened about one second before the launch terminal, and it will enter the sleep mode after finishing receiving. The system structure diagram is shown in Fig. 1.

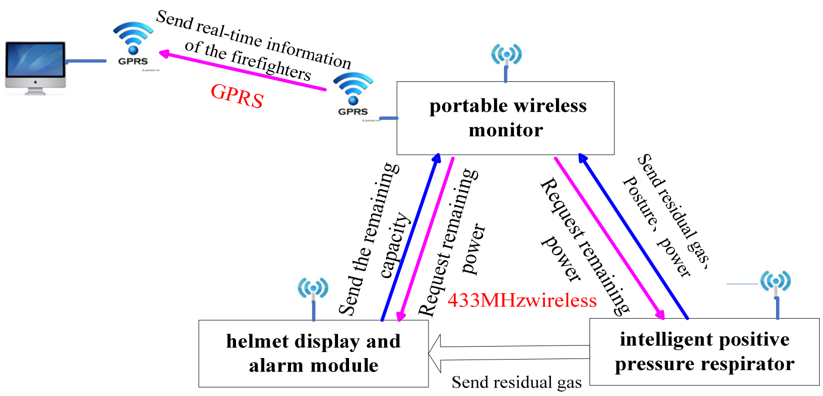

Fig. 1. System structure diagram.

2. Hardware Design

2.1. Portable Wireless Monitor

Analysis of the system demands. Since it is a portable instrument, its power consumption should be considered at first, and it should be a low-power-consumption MCU. Due to the wireless communication, it would be better if it integrates the wireless communication module. As a result, the CC430 chip of TI Company has been selected [8]. GRPS module adopts the EGSM900 of Huawei Company, which is small in volume, light in weight, with embedded TCP/IP and PPP protocol, and convenient for system design. The measurement of posture adopts the ADXL345 as the triaxial accelerometer to measure the posture [9]. ADXL345 can measure acceleration as high as±16 g, and its resolution ratio is as high as 13 bits. The chip requires low voltage, low power consumption and high precision, and it supports I2C and SPI communication model, provides self-updated function, and is quite applicable for the mobile portable instrument. Temperature sensor employs the common DS18B20, the staff number record employs the E2ROM and 24C02, the LCD display employs the Nokia 5110 LCD module. Since the internal chip of the power should be 3.3 V, the RT8009 is selected as the 3.3 V constant-voltage chip. As the portable design, the external power supply adopts the chargeable 4800 mAH lithium battery.

2.2. Intelligent Positive Pressure Respirator Module

Just like the MCU of portable wireless monitor, it also adopts the CC430. The pressure sensor adopts the HM2600, whose sensor response time is smaller than 2 ms, pressure measurement range reaches 0~40 MPa and working current is smaller than 5 mA. The pressure sensor is digital sensor, outputting PWM wave, which is convenient for the design and connection to the MCU.

2.2. Helmet Display and Alarm Module

MCU also employs CC430. In order to reduce the volume and power consumption, 6 LED lights are used to display the residual gas in the respirator. Meanwhile, a vibrator has been added to prevent the situations in which the firefighter cannot discover the audible and visual alarm, and it can alarm the firefighters with its vibration.

3. Algorithm Implementation

3.1. Human Posture Judgment

As shown in Fig. 2, the human posture coordinate can be seen. When people stand up, a gravitational acceleration G will be generated in Z axis due to the earth gravity, as shown by the black coordinate in Fig. 2.

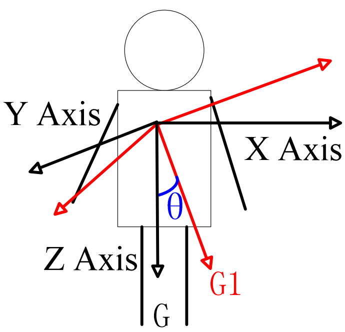

Fig. 2. Coordinate of human.

When people incline, as shown by the red coordinate in Fig. 2, a new gravitational acceleration G1 will be measured in the new Z axis. According to the mechanics principle, it can be calculated that:

$$G_1 = G * \cos\theta , \tag{1}$$

$$\theta = \arccos(G_1 / G) , \tag{2}$$

Owning to the gravitational acceleration g, $G = g$, G_1 can be measured in real time with the triaxial accelerometer. Therefore, the inclined angle θ can be calculated. When θ is greater than a pre-set value, it can be deemed that the firemen have already fallen down. In order to avoid the misjudgment, when θ is greater than a pre-set value and lasts for 10 seconds, alarm will be sent, suggesting that the firemen have already fallen down and rescue is needed.

3.2. Human Motion Judgment

Human motion and stillness can be judged in two ways. One is judged by SVM (signal vector magnitude):

$$SVM = \sqrt{a_x^2 + a_y^2 + a_z^2} , \tag{3}$$

When people stays still, SVM is about g, and when people move, SVM is about 1.5 g. Therefore, appropriate threshold value can be set to judge if people are in static or motion state. The other method is that when people walking, the g in Z axis will experience periodical changes, and when keeping still, the acceleration will be around g. In this system, since it only needs to judge if the firemen fall down, and in order to increase the acceleration, the second method will be adopted for judgment.

3.3. Calculation of the Remaining Time for Respirator

Before the experiment, the air bottle has been demarcated by the professional manufacturers, and mechanical pressure gauge is adopted as a reference for the output of electronic pressure transmitter. The algorithm accuracy of residual gas and available time can be verified through constant decompression and by recording the pressure data and time spent. The calculation formula for the gas volume can be calculated as follows:

$$V_r = 0.9 * C * P , \tag{4}$$

$$T = 10 * V_c / V_a , \tag{5}$$

where V_r is the residual gas in the air bottle, C is the air bottle volume , P is the working pressure of the air bottle, T is the remaining time, V_c is the current gas volume , and V_a is the air consumption in 10 s.

In order to increase the stability of the air consumption in 10 seconds, the filtering is set as:

$$V_a(n) = (V_{ac} + \sum_{k=1}^{4} V_a(n-k)) / 5, \quad (6)$$

where, V_{ac} is the gas consumption in the current 10 seconds.

4. Software Design

4.1. Fireware Design

The lower computer software design makes use of IAR to carry out the C language programming for three different modules, and the design thought is shown as follows: 1) Considering the convenience for maintaining the equipment and generality of the equipment, the address and frequency range of one wireless device will not be fixed. Owning to the interference of different equipment, the auto-match method is employed. The 16 address and frequency bands of CC430 will be allocated randomly. Therefore, the conflict probability of the two devices is:

$$1/(16 * 2 \wedge 16) = 1/1048576, \quad (7)$$

Since the transmitting power is limited within 1 meter, it guarantees that the equipment is free from each other's interference. 2) Due to the instantaneity of the data transmission, as well as the advantages of UDP protocol, low energy consumption and fast processing speed, the transmission between GPRS module adopts the UDP protocol. 3) Low power design. Integrating the on-spot situation and power-consumption of the firemen, the system will send data every 10 seconds.

The program chart of the portable wireless monitor is shown in Fig. 3, the program chart of the intelligent positive pressure respirator module is shown in Fig. 4, and the program chart of the helmet display and alarm module program is shown in Fig. 5.

4.1. Management Software Design

The upper computer software is developed with Labview [10]. According to the characteristics of Labview, it makes use of the imaging language design interface, data processing and algorithm to write the dynamic link library through VC++. The software interface compiled is shown in Fig. 6.

The function as the available breathing time, pressure of the respirator, on-spot temperature, human posture and systematic time can be displayed. There is an alarm light on the left bottom, and it will flicker for alarming if there are any accidents.

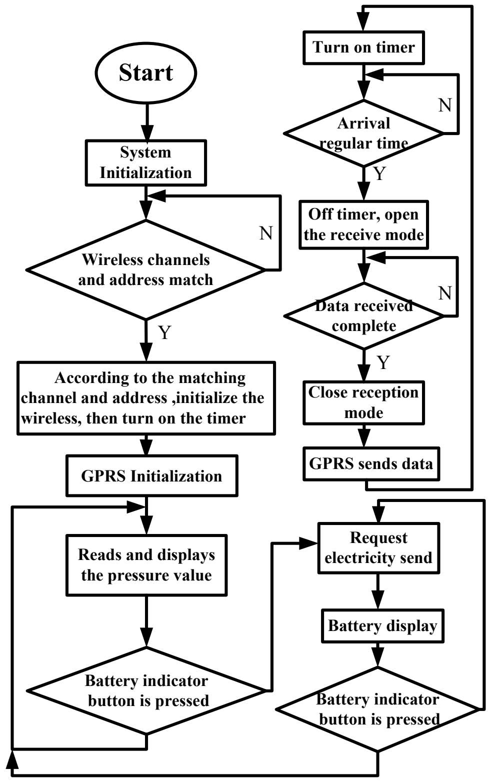

Fig. 3. Program chart of the portable wireless monitor.

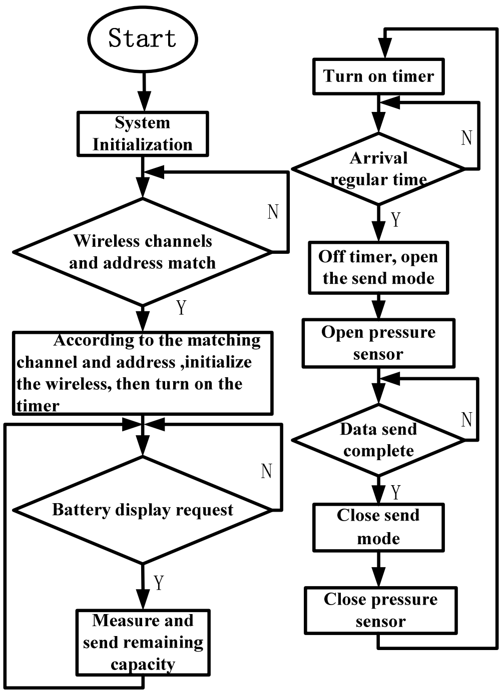

Fig. 4. Program chart of the intelligent positive pressure respirator module.

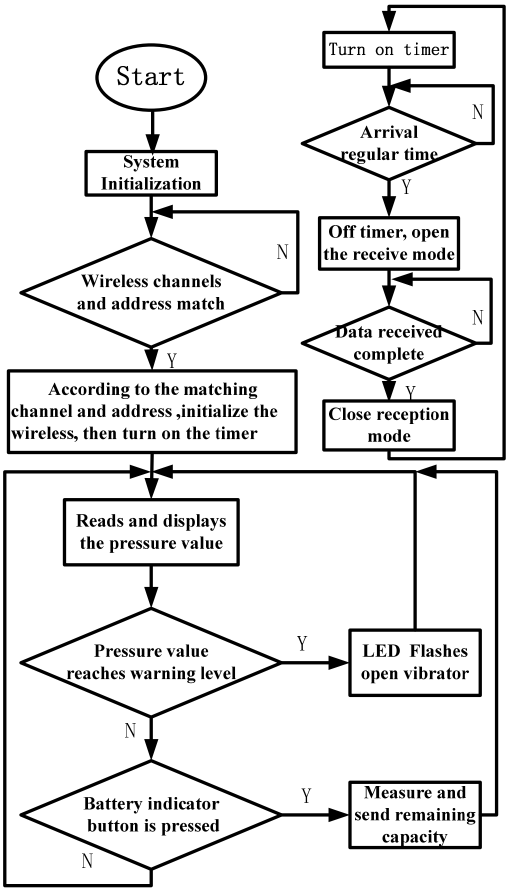

Fig. 5. Program chart of the helmet display and alarm module program.

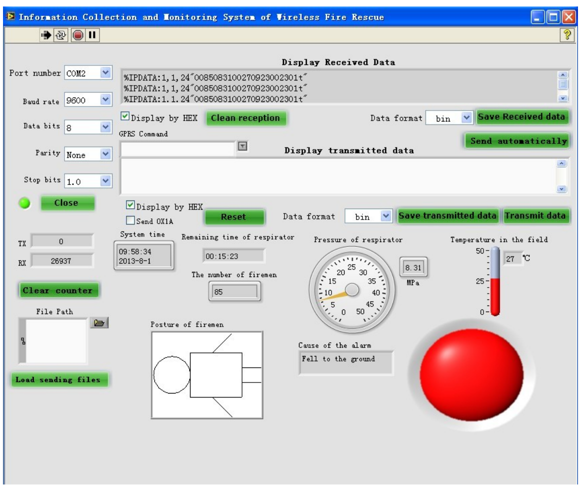

Fig. 6. Management software interface.

5. Test and Conclusion

The mechanical pressure gauge is around 8.3MPa in this test, as shown in the test results of upper computer interface in Fig. 6. It can be seen from the management software that the pressure of the pressure tank is 8.31 MPa, the available time is 15.23 minutes, and the on-spot temperature is 27 °C. It can be seen from the posture figure that the fireman falls down, and the alarm starts to flicker.

Based on the complete analysis of the current situation of domestic and foreign positive pressure respirator and combined with the future technology development trend, switchable positive pressure respirator is proposed as the key equipment, which will be informationized and intelligentized as the formation of on-spot information node as well as the intelligent rescue system for the site and each level of command central networking, changing the situation in which each fireman is an information isolated island. The system has a great significance in real application, which guarantees the life safety of the firemen to a great degree.

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