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Gas Monitoring System Based on ZigBee Pro and a New Method for Safety Grade Evaluation

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Abstract

Aiming at the mine safety problem, this paper proposes a gas concentration monitoring system design scheme based on ZigBee Pro. The scheme designs a set of ZigBee Pro wireless network combined software with hardware based on KGS-20 gas sensor and CC2530 chip as the controller core. According to the fuzzy reasoning technology and multi-factors information fusion technology, a new method for the gas safety grade evaluation is put forward and achieves a high-precision prediction for gas safety grade. The system with the merits of security, anti-interference, high sensitivity, low power consumption, high life expectancy and easy application, has a huge advantage in practical applications.

Keywords: *ZigBee Pro, CC2530, Gas detection, Information fusion and fuzzy reasoning technology*

1. Introduction

In recent years, the coal mine safety increasingly causes the attention of people. Coal mine accidents occur frequently, causing serious influence in society [1]. Therefore, it is particularly urgent to study the effective safety monitoring system [3]. In order to meet the needs of monitoring information tending to network, the gas concentration monitoring system based on ZigBee Pro is proposed.

Using the wired way for signal transmission [2], the traditional gas concentration monitoring equipment detects the gas concentration on the spot with the disadvantages of trivial wiring and strong dependence on the line. While the wireless sensor network is able to accurately acquire and monitor various environment parameters in real time, making up for the deficiency of cable monitoring mode effectively. The wireless sensor network avoids the risk of testing personnel on site and realizes the multi-point continuous measurement of monitoring area with high-reliability data. According to the fuzzy mathematics fusion theory, a new method for mine safety grade evaluation is put forward. The simulations of multi-group data prove that the proposed method is practical and high reliable.

2. ZigBee Pro Technology and Network Overall Design

ZigBee is a kind of wireless network technology which works in 900 MHZ and 2.4 GHZ frequency band [6], with the characteristics of the medium communication distance, low power consumption, low complexity, low data rate, low cost behavior [4]. As ZigBee developing gradually, the upgraded version ZigBee Pro comes out. "At the greatest extent ZigBee Pro enhances ZigBee's ability to promote the ease of use and advanced support for large network [5]". The outstanding characteristics of ZigBee Pro are using random addressing instead of original tree addressing, putting forward Many-to-one routing and providing commercial-grade encrypted communications, etc.

The commonly used network topology structures of ZigBee Pro mainly include star network topology and mesh network topology [7]. Because in ZigBee Pro specifications the way to allocate network location is random, and there is no relationship between the network position of all child nodes and the actual relative position of the whole system network topology [8]. Therefore, ZigBee Pro does not support tree routing. In order to avoid faults in a certain part of the network node or system not working normally for disrupted link due to environmental reasons, the system scheme in the paper designs the reticular network as wireless communication network topology. The overall frame of gas content automatic monitoring system controlled by wireless network is shown as figure 1.The system is mainly composed of ZigBee Pro wireless sensor nodes, central coordinator and remote control center composition. Its working principle is that the mobile modes and the sensor nodes of temperature,

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methane, carbon monoxide and other gas as RFD (reduced function equipment), the center coordinator as FFD (full function equipment), each sensor node sends data to the center coordinator, that the center coordinator collecting data from each sensor node transmits data to the remote control center to be processed and displayed in real-time; and then the PC evaluates the density collected using the mult-information fusion technology and fuzzy reasoning technique; and finally the PC issues a warning information evaluating the possibility of the current gas explosion and concludes that risk rate[9].

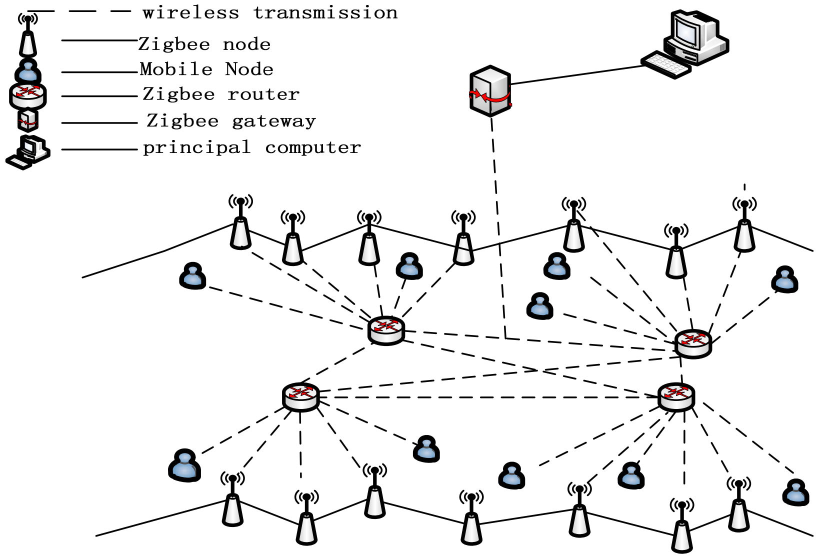

Figure1 Automatic monitoring system overall structure

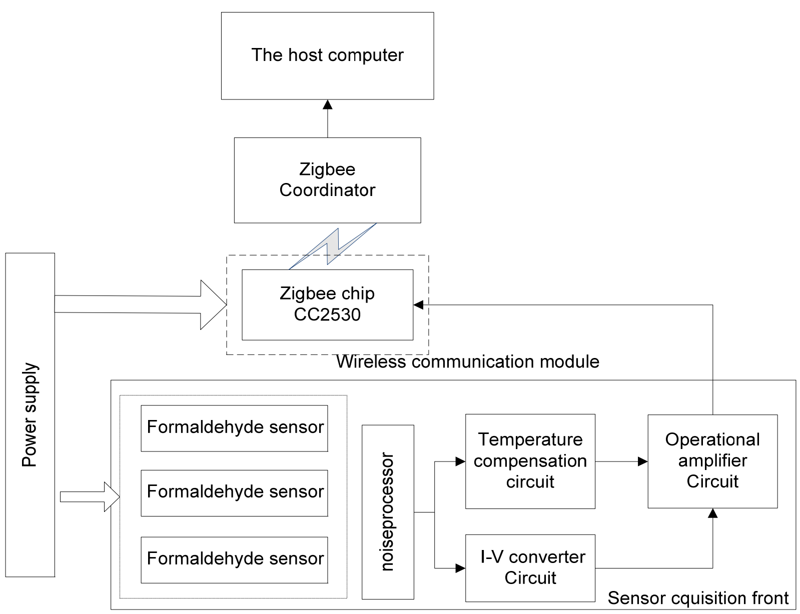

Figure2 Schematic diagram of the system hardware

3. The System Hardware and Software Design

The system mainly consists of sensors collection part and wireless communication module. The sensor collection part is mainly responsible for gathering the CH4 and CO, CO2 and H2S, dust, temperature, air output acquisition from the external environment. The acquired signal after denoising, temperature compensation, the I-V circuit conversion, signal amplification and a series of operations will be sent directly to the communication module. Wireless communication module is responsible for sending the real-time data collected in the front of the sensor to ZigBee coordinator and then ZigBee coordinator deals with the data correspondingly, and the data is transmitted by ZigBee coordinator to host computer for display and wireless monitoring. Hardware design schematic diagram is shown in figure 2.

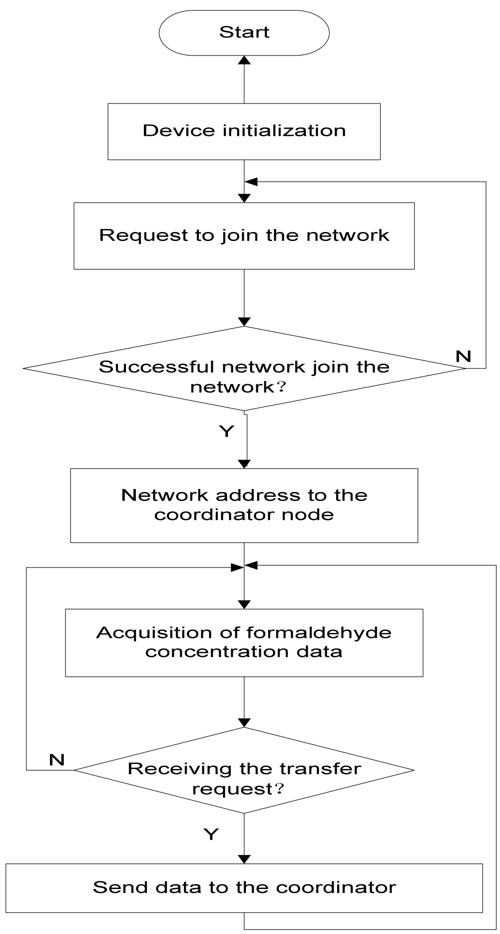

Figure3 Sensor program flow chart

Software is the center of the monitoring system, and hardware circuit can realize its function smoothly only under the correct guidance of the software. This system uses IAR7 as development environment, adopting the protocol Stack for TI. Z - Stack software which has been open for free download. The protocol stack achieves ZigBee alliance reference platform level, and is already widely adopted by global ZigBee developers at present. By testing the system's overall layout, it is known that the sensor module and coordinator module play a main role. Finally the information is transmitted from the coordinator to the control center and received and displayed by the upper computer in real time.

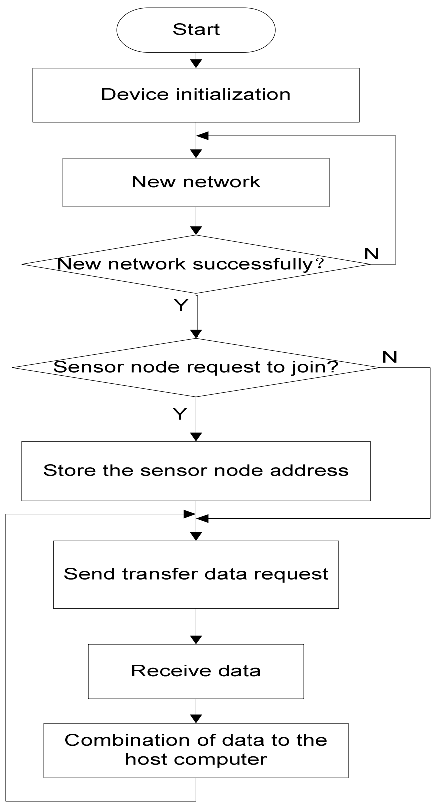

Figure4 Coordinator program flow chart

The sensor node initializes hardware and network after starting, and attempts to join the network. When the equipment joins the network, the joint network address will be sent to coordinator. On receiving instruction, the instruction will be analyzed and then be carried on. At the same time the sensor node starts to acquire data through the sensor module. After the acquisition of the data completely, the sensor node sends data to the coordinator node. Then the node steps into waiting for instruction state after the sensor node sends successfully. Program flow chart below 3, 4 figure.

4. Gas Safety Grade Evaluation Model of Fuzzy Data Fusion

The traditional gas safety assessment standard only simply uses a gas concentration threshold limit to judge whether the mine is safe. However the gas is compounded and gas safety grade evaluation also needs to consider CO, CO_2, H_2S and others' concentration which are related to each other. Therefore, the author evaluates the mine gas concentration by using the fuzzy data fusion, which effectively uses mathematical theory of fuzzy language non-determinism. And the detected signal is transformed from qualitative information into quantitative information, so that the monitoring personnel can monitor more intuitively.

Fuzzy comprehensive evaluation method [10] is a kind of comprehensive evaluation method based on the fuzzy mathematics [12]. The comprehensive evaluation method based on fuzzy membership degree theory translates the qualitative evaluation into the quantitative, which uses fuzzy mathematics to make an overall evaluation restricted by various factors things or objects. It has the characteristic that the result is clear and the systemic is strong, to solve the problem which is fuzzy and difficult to quantify. It is suitable to solve all kinds of uncertain problems [9].

Fuzzy comprehensive evaluation method regards the evaluation target as the fuzzy set (called factor set q) made up of a variety of factors, and then sets evaluation level of these factors selected, forming the fuzzy set of comments (called evaluation set v)[11]. After that the membership grade of each single factor to each evaluation grades (called fuzzy matrix) is respectively calculate. According to weights distribute of various factors in the evaluation target, the quantitative value of the evaluation is obtained through the fuzzy matrix synthesis.
Its principle is expressed as:

$$Q = W \bullet R \tag{1}$$

Where W =(w1,w2,w3,…wi…wm) is fuzzy vector or called fuzzy converter, and it is the weight distribution of evaluation factor X = {x1, x2,... , xi,... , xm}. R is a fuzzy relation matrix composed of the evaluation factors X = {x1, x2,... , xi,... , xm} and the evaluation set U = {u1, u2,... , ui,... , un}. After getting the set Q, it is fuzzy processed by the maximum membership degree.

To the gas test system, we can evaluate comprehensively from CH4, CO, CO2 and H2S, temperature, air output as the six aspects. The above six domains are: CH4 concentration A, CO concentration B, CO2 concentration C, H2S concentration D, temperature F, exhaust air volume G. Evaluation factor X = {A, B, C, D, F, G}.The gas safety state evaluation is set V: {safety S, warning W, alarm D}. In order to transform the evaluation index from qualitative to quantitative analysis, the evaluation set of various index is determined.

S-coal mine explosion won't happen, where the interval of the score is [80,100] and median is 90.
W-coal mine explosion may occur, where the interval of the score is $[60, 79]$ a median is69.5.
D-coal mine gas explosion will occur, where the interval of the score is $[40, 59]$ a median is 49.5.
Select the median in each interval as the parameters of the level, and then the three grades of the corresponding parameter are: 90, 69.5, 49.5, and its column vector are $u = (90, 69.5, 49.5)^T$.

To determine weight coefficients, analytic hierarchy process (AHP) is adopted. Through the coal mine experts' investigation, the moreover weights are determined and successfully get passed from the one-time test. Finally the scientific and reasonable weights are acquired, as shown in table 1.

Table.1 The judgment matrix of Gas explosion risk

X	A	B	C	D	F	G
A	1	3	5	3	3	5
B	1/3	1	3	3	1	5
C	1/5	1/3	1	1	1/3	3
D	1/3	1/3	1	1	1/3	1
F	1/3	1	3	3	1	2
G	1/5	1/5	1/3	1	1/2	1

Normalize the matrix X by columns:

$$b_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} (i, j = 1,2,\dots,n) = \begin{bmatrix} 0.4167 & 0.5114 & 0.375 & 0.25 & 0.4865 & 0.2941 \\ 0.1389 & 0.1705 & 0.225 & 0.25 & 0.1622 & 0.2941 \\ 0.0833 & 0.0568 & 0.075 & 0.0833 & 0.0541 & 0.1765 \\ 0.1389 & 0.0568 & 0.075 & 0.0833 & 0.0541 & 0.0588 \\ 0.1389 & 0.1705 & 0.225 & 0.25 & 0.1622 & 0.1176 \\ 0.0833 & 0.0341 & 0.025 & 0.0833 & 0.0811 & 0.0588 \end{bmatrix} \tag{2}$$

Sum the matrix X by lines:

$$v_i = \sum_j^i b_{ij} = \begin{bmatrix} 2.3337 \\ 1.2407 \\ 0.529 \\ 0.4669 \\ 1.0642 \\ 0.3656 \end{bmatrix} \tag{3}$$

Normalize:

$$w_i = \frac{v_i}{\sum_{i=1}^{n} v_i} = \begin{bmatrix} 0.3889 \\ 0.2068 \\ 0.0882 \\ 0.0778 \\ 0.1774 \\ 0.0609 \end{bmatrix} \tag{4}$$

Calculate the maximum characteristic root of the judgment matrix

$$\lambda_{\max} = \sum_{i=1}^{n} \left[(XW)_i / nW_i \right] =$$

$$\frac{1}{6} \begin{bmatrix} 2.5204 \\ 1.3163 \\ 0.5545 \\ 0.4845 \\ 1.1336 \\ 0.3760 \end{bmatrix} \div \begin{bmatrix} 0.3889 \\ 0.2068 \\ 0.0882 \\ 0.0778 \\ 0.1774 \\ 0.0609 \end{bmatrix} = 6.3207 \tag{5}$$

The consistency index of the judgment matrix:

$$CI = (\lambda_{\max} - n)/(n-1) = 0.3207 \tag{6}$$

Calculate the consistency ratio CR，simulate the analytic hierarchy above using Mat lab mathematical simulation. The sample capacity is calculated to be 1000. 1 ~ 10 order RIs are obtained as the following.

Table.2 RI order judgment matrix average random consistency index

rank	1	2	3	4	5
RI	0	0	0.5291	0.8180	1.0812
rank	6	7	8	9	10
RI	1.1344	1.2162	1.3247	1.3952	1.4105

$$CR = CI/RI = 0.0565 \tag{7}$$

CR<0.1, the consistency of the X is acceptable. Otherwise it needs to readjust the judgment matrix, until meets consistency check.

After all experts have made the evaluation of the mine gas explosion risk, the fuzzy relation matrix processed with the normalization will be obtained.

$$R = \begin{bmatrix} 0.5 & 0.3 & 0.2 \\ 0.6 & 0.3 & 0.1 \\ 0.6 & 0.2 & 0.2 \\ 0.4 & 0.3 & 0.3 \\ 0.5 & 0.4 & 0.1 \\ 0.4 & 0.4 & 0.2 \end{bmatrix}$$

Therefore, the $Q = W \bullet R$ draws the fuzzy evaluation matrix

$$Q = (0.5157，0.3150，0.1693)$$

Based on the fuzzy evaluation matrix Q and the parameters column vector u of the evaluation set, system comprehensive evaluation result Z will be obtained:

$$Z = Q \bullet u = 76.928 \tag{8}$$

According to the evaluation level regulation, 76.928 is in the possibly dangerous interval, and in line with the actual situation.

5. Conclusions

This system use ZigBee Pro wireless communication technology to be able to complete real-time vibration monitoring, alarming and other functions. Before underground pipeline facilities are destroyed it can predict the arrival of the risk, and notify the emergency maintenance personnel in time, giving them more time. It is found that the method can play the advantages of the multiple sensor information fusion by using the fuzzy data fusion method for the early warning research on coal mine gas after carrying the experiments on the method to be verified. To a certain extent, it can reduce not-reporting and misreporting for the limitations of single sensor information, and reduce the uncertainty, so as to improve the safety performance of the gas system. Therefore, ZigBee pro wireless communication technology and data fusion method used in coal mine gas warning study is feasible.

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References

[1] Haifeng Duan, Lijie Wang, and Quanzhong Jing. “Definition of Investment in Coal Mine Safety and Security Costs”, Journal of safety science of China，Vol. 16, No. 6, 2006, pp.65-70.

[2] Shuming Wang, and Xueqiu He, “Reflections on Enhancing the Strength of Coal Mine Safety investment strategy”, coal economic research, Vol. 4,2006,pp.85-86

[3] Yuanping Cheng, Lei Wang, Xiaolei Zhang, “Environmental impact of coal mine methane emissions and responding strategies in China”, International Journal of Greenhouse Gas Control, Vol. 5, NO. 1, 2011, pp. 157-166.

[4] J. Han, H. Lee, and K. Park. “Remote-Controllable and Energy-Saving Room Architecture based on ZigBee Communication”. IEEE Trans. On Consumer Electronics, Vol. 55, No. 1, 2009, pp. 264-268.

[5] Guangrong Wu, and Jianxiong Zhang, “Realization of Wireless Sensor Network Based on CC2430”, Modern Electronics Technique, Vol. 12,2008, pp.121-124

[6] K. Gill, S. Yang, F. Yao, and X. Lu. “A ZigBee-based Home Automation System”. Consumer Electronics, Vol. 55, No. 2, 2009, pp.422-430.

[7] C.C. Shen, C. Srisathapornphat, C., R. Liu, Z.C. Huang, C. Jaikaeo, C., E.L. Lloyd, “CLTC: a cluseter-based topology control framework for ad hoc networks”, Mobile Computing, IEEE Transactions on . Vol. 3, No. 1, 2004, pp.18–32.

[8] Quan Zhou, Zhushi Yang, Weigen Chen, Jian Li, Xiaomin Ma. “Design of Conductor Galloping Multi-points Monitoring System Using ZigBee PRO Wireless Network Technology”. High Voltage Engineering, Vol. 37, No. 8, 2011, pp.1967-1969.

[9] Li Zheng, “Zigbee Wireless Sensor Network in Industrial Applications”, Proceedings of International Conference on Computer International Joint Conference SICE-ICASE，Oct，2006，pp. 1067- 1070.

[10] Tiejun Li, Dali Guo, Yujun Gong, Zhihao Tang and Kequan Chen, “A Research of Fuzzy Comprehensive Evaluation on Carbonate Reservoir”, Advances in Intelligent and Soft Computing, Vol. 147, 2012, pp. 331-337.

[11] Jiedi Sun, and Jiangtao Wen, "Research on Monitoring and Pre-warning System for Security of Pipelines Based on Multi-Seismic Sensors," Proceedings of International Conference on International Conference on Electronic Measurement & Instruments (ICEMI) 2009, pp. 1689-1693.

[12] Blanco A, Delgado M, Martín- Ramos JM, and Polo MP. "AIEIA: software for fuzzy environmental impact assessment". Expert Syst Appl, Vol. 36, No. 91, 2009, pp.35-49.

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