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ZigBee-Based Wireless Sensor Network for Environment Monitoring ZigBee

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Abstract: ZigBee technology with the characteristics of low complexity, ad-hoc network, low cost, low power consumption and high security, is widely used for wireless sensing. Wireless sensor network is an interdisciplinary application between multi-sensor technology and wireless network, and has the broad application prospects in many fields such as intelligent agriculture and smart home. This paper designs and realizes an indoor environment monitoring system based on ZigBee and wireless sensor network. The system uses end-nodes to collect temperature, humidity, PM2.5 and other environmental parameters. The collected data is transmitted to the coordinator through wireless sensor network and finally to the monitoring system software by serial port protocol. The online monitoring platform with functions of real-time data display, storage and over-limit warning is developed by using the LabVIEW software. The test results show that the system is stable, easy to generate a network system, speedy and reliable to transmit data, and flexible to place nodes.

Keywords: ZigBee, Wireless sensor network, Environment monitoring, LabVIEW, Monitoring platform.

1. Introduction

Based on the characteristics of high information integration and multi-disciplinary intersection, Wireless Sensor Network (WSN) is concerned by various countries. SN involves embedded computer technology, communication technology, sensor technology and distributed information processing technology. It can collect various environmental parameters in the area covered by the wireless network, and process the information accordingly, and finally transmit them to the users who need the information [1]. At present, the network protocols applied to WSN mainly include Wireless Fidelity (WiFi), Bluetooth, General Packet Radio Service (GPRS), ZigBee, etc. Among them, ZigBee technology has the advantages of low complexity, self-organizing network, low cost, low power consumption and high security. It is widely used in smart agriculture [2-6], smart home [7-9], chemical detection [10-13], medical rehabilitation [14-17] and Smart factory [18-23].

In recent years, ZigBee technology, because of its superiority, has been used for environmental monitoring [2-23]. Zhang, *et al.* [5] designed an intelligent control system for the environmental monitoring in greenhouses. This system realizes the monitoring of environmental parameters in greenhouses, e.g., temperature and humidity. However, the type of sensors used is single and the number of nodes is too large; Gong, *et al.* [9] designed an environment monitoring system in smart home based on ZigBee. This system has the advantage of the real-time monitoring. However, the parameters monitored by the system are few and the software lacks the functions of data storage and over-limit warning. In addition, the package of nodes has not been designed; Ni, *et al.* [14] studied a telemedicine system based on ZigBee, EDGE, Ethernet and embedded LINUX system. This system realizes the functions of home self-care, remote diagnosis, etc., but the system is too complicated. Castro, *et al.* [18] described the development of an industrial automation system based on a ZigBee wireless sensor network, designed for the monitoring and control of multiple refrigeration equipment in an industrial area, replacing the existing cabled network, which was based on the LonWorks platform. However, the functionality of the system is relatively simple and the accuracy of the control is relatively low. At present, most researches on ZigBee technology are only applied to specific occasions, i.e., it is not universal.

This study aims to realize indoor environment monitoring with the characteristics of low complexity, ad-hoc network, low cost, low power consumption and high security. In order to avoid the problems of complicated wiring, poor mobility, high cost and energy loss caused by traditional optical fiber, coaxial cable and other wired monitoring, this study designed and built an environmental monitoring system based on ZigBee technology. The system can effectively reduce the number of nodes and improve the utilization of nodes. This paper developed a new type of terminal node package box to achieve waterproof and dustproof protection for node modules. The online monitoring platform for this system was developed by LabVIEW software to realize data display, storage and over-limit warning of the collected indoor environmental data.

2. Monitoring System Design

2.1. System Design

As shown in Fig. 1, the monitoring system is mainly composed of three parts: a terminal node, a coordinator and an online monitoring platform. All the sensors are installed on the terminal node. The acquired environmental data by the terminal node is wirelessly transmitted to the coordinator module and finally sent to the monitoring platform. If the distance between the terminal node and the coordinator is too far to achieve effective transmission, power amplifiers can be used to extend the transmission distance. The system layout is shown in Fig. 2. The coordinator is connected to the PC by a USB cable. In addition, the terminal node and coordinator are identical in hardware. They are only different in functions by burning different codes.

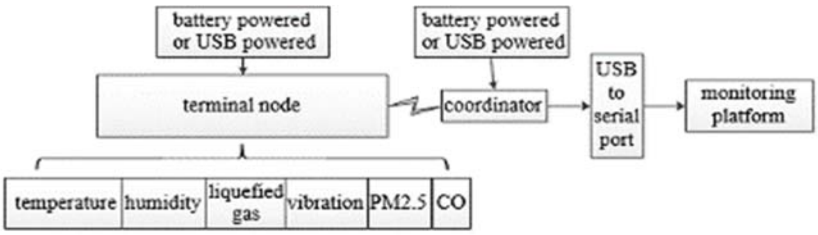

Fig. 1. System framework.

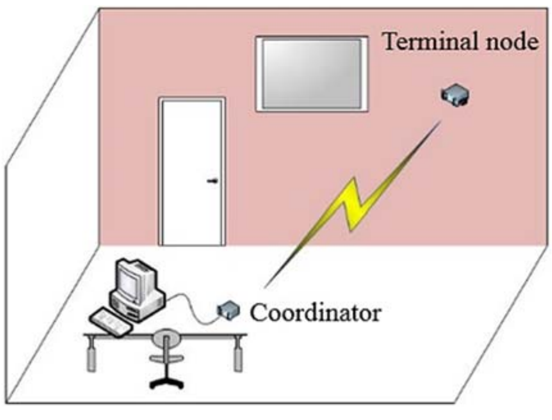

Fig. 2. System layout.

2.2. Network Topology and Sensor Parameters

In the ZigBee protocol specification, three network topologies are defined: star structure, tree structure and mesh structure. Among the three network topologies, the star structure is the simplest one. As shown in Fig. 3, there is no router in the star structure, only one coordinator and multiple terminal nodes, and all terminal nodes are required to be within the communication range of the coordinator. That is, the star structure is a radial system, and all devices communicate with the coordinator at the center. If any two terminal nodes need to communicate with each other, one of the nodes is required to send data to the coordinator, and then the coordinator forwards the data to another node. In this mode, the coordinator plays the role of information relay. In the entire star structure, the coordinator is usually powered by a continuous power system, while the other terminal nodes are powered by mobile batteries. The star structure is generally suitable for small-scale applications such as home automation and personal computer peripherals.

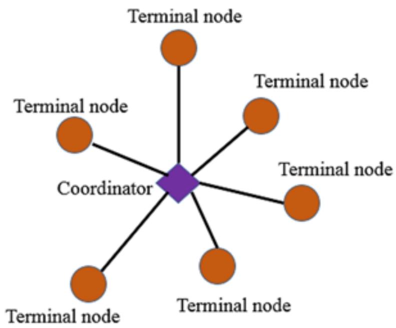

Fig. 3. The structure of star topology.

The environmental parameters monitored by the system are temperature, humidity, fine particles (PM2.5), carbon monoxide, liquefied gas and vibration, the parameters of each sensor used in this system are listed in Table 1. The sensor module is an integral part of the terminal node module in the system hardware platform. Among them, the liquefied gas sensor and the vibration sensor can only realize the function of over-limit warning. Besides, the liquefied gas is highly sensitive to hydrogen, methane, and propane. In addition, it can monitor a wide range of flammable gases for a variety of applications.

Table 1. The list of sensor parameters.

Name	Scope	Accuracy	Type
Temperature & humidity	0~50°C	±2°C	DHT11
	20~95 %	±5 %	
PM2.5	0~8000 pcs	±1 um	GP2Y1014 AU0F
Carbon monoxide	10-1000 ppm	±5 ppm	MQ-7
Liquefied gas	0/1		MQ-2
Vibration	0/1		SW-1801P

2.3. Package Design

The communication band (2.4 GHz) of the ZigBee network is an unlicensed free band in industrial, scientific and medical applications. Because the 2.4 GHz band is free, there are many other wireless sensor networks in this band, such as WiFi, Bluetooth, wireless USB and so on. These traditional wireless sensor networks have interfered with the communication of the zigbee network, which has been proven by many researchers [24-26].

ZigBee will be interfered by signals such as WiFi and Bluetooth in the environment during wireless communication. LQI (Link Quality Indicator) is an indication of link quality, which indicates the quality of the link between the current transceiver terminals. When there is interference in the channel, the packet loss rate will increase, and the LQI value calculated in the received packet will also decrease. Therefore, the LQI value can reflect the strength of the interference in the current channel, and the anti-interference design flow chart of the wireless sensor network is shown in Fig. 4.

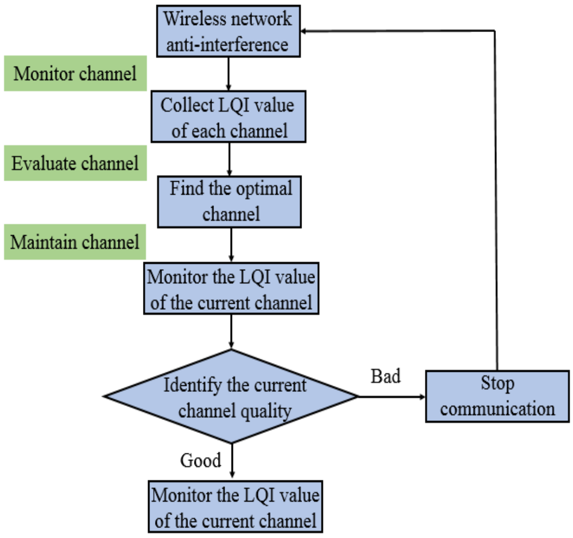

Fig. 4. The anti-interference design flow chart of wireless transmission network.

The node module package box of the system is made of acrylic sheet and is assembled by organic adhesive (acrylic glue), which has the advantages of simple design, simple assembly and low cost. By using the transparent acrylic sheet, the user can directly observe the condition of each sensor from the outside. The layered design inside the package box can isolate the node module from each sensor module, which can protect the node module from dust and water, and also make it easy to replace the sensor module directly. The node package box is shown in Fig. 5.

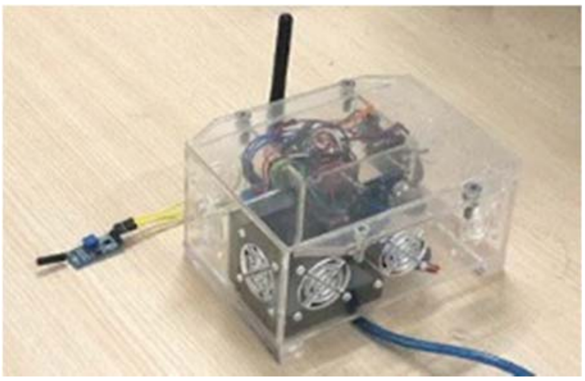

Fig. 5. Node package box.

2.4. Monitoring Platform

The user monitoring platform of this system is written by LabVIEW software. LabVIEW is a program-development environment developed by National Instruments (NI) and its program is written by graphical G language [27-29]. The login system of the system is shown in Fig. 6, the users enter the monitoring platform by the username and password set up by themselves. The user monitoring platform designed in the system is shown in Fig. 7. It has the functions of real-time display of indoor environmental parameters, e.g., temperature, humidity, PM2.5 and concentration of carbon monoxide. For indoor parameters of liquefied gas and vibration, the monitoring platform has only the function of over-limit warning because of sensor's performance limitations. According to the specific conditions of the monitored indoor environment, the upper limit and lower limit of the vibration and concentration of liquefied gas can be set as artificial values. In addition, the monitoring platform also has the function of data storage for each indoor environmental parameter, which can automatically generate a historical record of monitoring data in the background to facilitate data analysis and prediction.

Fig. 6. Login system.

Fig. 7. User monitoring platform.

3. Experimental Results and Analyses

The environmental parameters monitored by the terminal node module were temperature, humidity, PM2.5 concentration, carbon monoxide concentration, liquefied gas concentration and vibration. Among them, the monitoring form of liquefied gas and vibration is over-limit warning, while other environmental parameters can be detected to specific values. The environmental data is collected by the system for a duration of 24 hours in December in an indoor room in Xi'an, and the environmental changes are observed and analyzed from 6 am on the first day to 6 am on the next day.

The changes of temperature and humidity are shown in Fig. 8, the temperature in the room has three large changes in one day, which are 8 am-12 am, 14 pm-18 pm, and 21 pm-23 pm. This is basically consistent with the time of the switch of the air conditioner. Due to the dryness of the indoor environment, the humidity decreased with the rise of temperature. The changes of PM2.5 concentration and carbon monoxide concentration in the room are shown in Fig. 9 and Fig. 10, respectively. It can be seen that the changes of PM2.5 concentration and carbon monoxide concentration in one day are stable. The concentration of PM2.5 fluctuated around 75 μg/m^3, and the concentration of carbon monoxide was around 12 ppm.

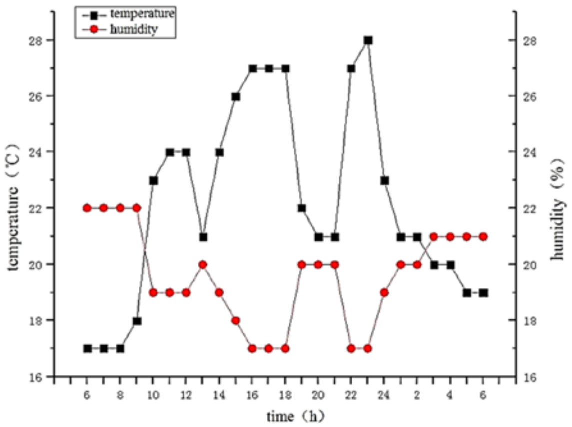

Fig. 8. Variation of temperature and humidity within 24 hours.

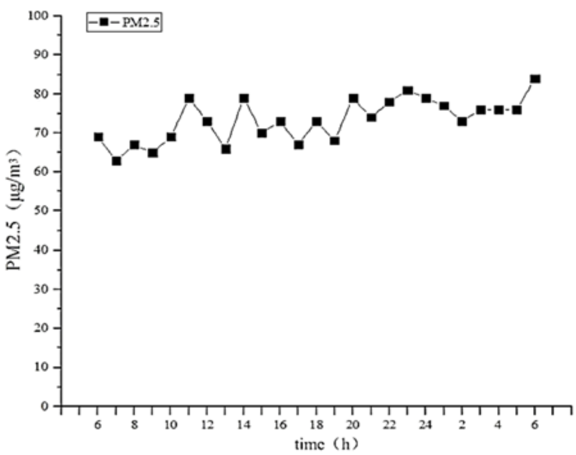

Fig. 9. Variation of PM2.5 within 24 hours.

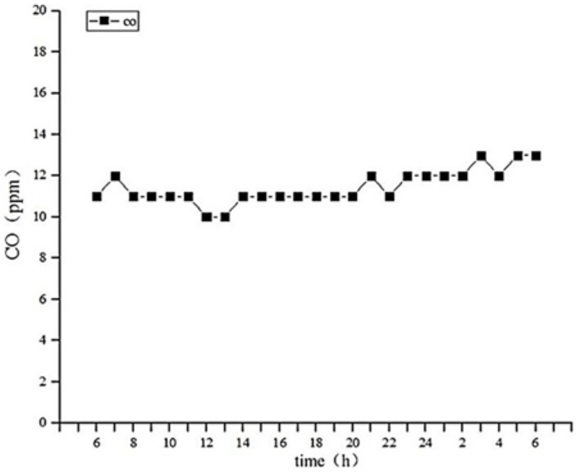

Fig. 10. Variation of carbon monoxide within 24 hours.

The measurement of liquefied gas and vibration used a mode of fixed-point warning. And the signals of the liquefied gas sensor and the vibration sensor are transmitted as switching signals. When the liquefied gas is detected, the liquefied gas sensor outputs the number "1", and when there is no liquefied gas, the number "0" is output. The setting of the vibration sensor is opposite to liquefied gas sensor. When there is vibration, the number "0" is output, and when there is no vibration, the number "1" is output. As can be seen from Fig. 11, the liquefied gas sensor outputs the number "0", and the vibration sensor outputs the number "1". This indicates that the liquefied gas and vibration signals were not detected, which was consistent with the actual situation.

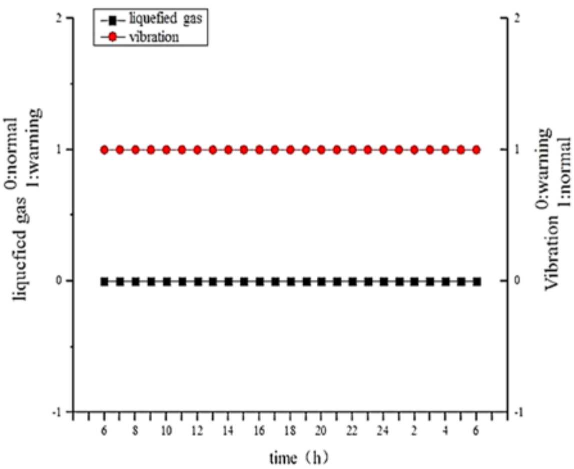

Fig. 11. Variation of liquefied gas and vibration within 24 hours.

4. Conclusions

This paper designs and builds an indoor environmental monitoring system based on ZigBee and wireless sensor network. The system has a simple structure, stable operation, low cost and high reliability. In this paper, a new type of node module based on CC2530 and its package box are designed and fabricated. The double-deck structure separated the node module and sensors to realize the dustproof and waterproof protection of the node module, which is convenient for operation and maintenance. The terminal node module is connected with many sensors, which can greatly reduce the number of terminal node modules. Based on LabVIEW software, the system's online monitoring platform was developed, which has realized the real-time display, storage and over-limit warning of environmental data.

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References

[1]. Laranjeira Luiz A., G. N. Rodrigues, Border effect analysis for reliability assurance and continuous connectivity of wireless sensor networks in the presence of sensor failures, *IEEE Transactions on Wireless Communications*, Vol. 13, Issue 8, 2014, pp. 4232-4246.

[2]. Krishnachaitanya N., G. Anand Kumar, P. Aruna Kumari, ZigBee based wireless sensing platform for monitoring agriculture environment, *International Journal of Computer Applications*, Vol. 83, Issue 11, 2013, pp. 9-12.

[3]. Sahitya G., N. Balaji, C. D. Naidu, Wireless sensor network for smart agriculture, in *Proceedings of the IEEE 2nd International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT)*, 2016, pp. 488-493.

[4]. Zhang Bowen, Z. Zhang, Y. University, Design of a smart agricultural system based on internet of things, *Journal of Yangtze University*, 2016.

[5]. Zhang Meng, J. Fang, Y. Han, Design on remote monitoring and control system for greenhouse group based on ZigBee and internet, *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 29, Issue 25, 2013, pp. 171-176.

[6]. Zhang Shuang De, J. H. Jiang, Design and Implementation of Watering Control System of

Flowers Based on ZigBee, *Hubei Agricultural Sciences*, 2014.
[7]. Jiang D., Yu L., Wang F., Xie X., Yu Y., Design of the smart home system based on the optimal routing algorithm and ZigBee network, *PLos One*, Vol. 12, Issue 11, 2017, e0188026.
[8]. Betzler A., Gomez C., Demirkol I., Paradells J., A holistic approach to ZigBee performance enhancement for home automation networks, *Sensors*, Vol. 14, Issue 8, 2014, pp. 14932-14970.
[9]. Gong Qingchao, G. Li, Y. Pang, Design and implementation of smart home system based on ZigBee technology, *Microcomputer Information*, 8, 6, 2012, pp. 143-156.
[10]. Zhu Bin, Tang Y., Tan Y., Xia K., Design of ZigBee-based data acquiring and transmission system in industrial control network, *Control and Instruments in Chemical Industry*, 2010.
[11]. Huang Jiao, H. R. Liu, Design of Intelligent pH Analyzer Based on ZigBee, *Control and Instruments in Chemical Industry*, 2011.
[12]. Chen Lei, S. Yang, Y. Xi., Based on ZigBee wireless sensor network the monitoring system design for chemical production process toxic and harmful gas, in *Proceedings of the International Conference on Computer, Mechatronics, Control and Electronic Engineering*, Vol. 4, 2010, pp. 425-428.
[13]. Zhao, Jian Jun, Y. Bai, R. S. Wang, Application of ZigBee technology in chemical water ultrafiltration system, *Advanced Materials Research*, Vol. 459, 2012, pp. 343-346.
[14]. Ni Yun Feng, J. Liu, Based on ZigBee technology remote health care system design and research, *Advanced Materials Research*, Vol. 433-440, 2012, pp. 3439-3444.
[15]. Khaliq Kishwer Abdul, Qayyum A., Pannek J., An emergency alert system for elderly/special people using VANET and WBAN, in *Proceedings of the IEEE 13th International Conference on Emerging Technologies (ICET)*, 2017.
[16]. Clarke M., Folter J. D, Verma V., Gokalp H., Interoperable end-to-end remote patient monitoring platform based on IEEE 11073 PHD and ZigBee health care profile, *IEEE Transactions on Biomedical Engineering*, Vol. 65, Issue 5, 2018.
[17]. Yu T., Dai Z., Li Y., Li Z., Tang L., The research on mine safety auxiliary system of wireless sensor networks, in *Proceedings of the IEEE 3rd International Conference on Instrumentation, Measurement, Computer, Communication and Control*, 2013, pp. 313-317.
[18]. Castro P., Afonso J. L., Afonso J. A., A Low-Cost ZigBee-Based Wireless Industrial Automation System, in *Proceedings of the Portuguese Conference on Automatic Control*, 2017.
[19]. Raza M., Aslam N., Le-Minh H., *et al*., A Critical Analysis of Research Potential, Challenges and Future Directives in Industrial Wireless Sensor Networks, *IEEE Communications Surveys & Tutorials*, Vol. 20, Issue 1, 2018, pp. 39-95.
[20]. Hang L., Savkin A. V., Wireless Sensor Network Based Navigation of Micro Flying Robots in the Industrial Internet of Things, *IEEE Transactions on Industrial Informatics*, Vol. 14, Issue 8, 2018.
[21]. Sahoo P. K., Pattanaik S. R., Wu S. L., A Reliable Data Transmission Model for IEEE 802.15.4e Enabled Wireless Sensor Network under WiFi Interference, *Sensors*, Vol. 17, Issue 6, 2017, 1320.
[22]. Su F. P., Chen Z. C., Zhou H. F., *et al*., A distributed monitoring system for photovoltaic arrays based on a two-level wireless sensor network, in *Proceedings of the IOP Conference Series: Earth and Environmental Science (EES),* Vol. 93, Issue 1, 2017, 012077.
[23]. Barankova I., Mikhailova U., Lukianov G., Automated control system of a factory railway transport based on ZigBee, in *Proceedings of the 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, 2017.
[24]. Firdaus, Nugroho E., Sahroni A., ZigBee and WiFi network interface on Wireless Sensor Networks, in *Proceedings of the Makassar International Conference on Electrical Engineering & Informatics (MICEEI)*, 2015.
[25]. Neumeier R., Ostermayer G., Analyzing Coexistence Issues in Wireless Radio Networks: Simulation of Bluetooth Interfered by Multiple WLANs, in *Proceedings of the 6th International Workshop on Multiple Access Communications (MACOM 2013)*, 2013, pp. 599-604.
[26]. Lv Y., Zhang W., Zhang D., *et al*., An Algorithm for Resisting WiFi Interference in ZigBee, in *Proceedings of the 4th International Conference on Information Science & Control Engineering*, 2017.
[27]. Blume Peter, The LabVIEW style book, *Pearson Education, Inc.,*, 2007.
[28]. Zhou Xiaoyi, Electrocardiogram system performance evaluation based on the LabVIEW virtual instruments development platform, in *Proceedings of the International Conference in Communications, Signal Processing, and Systems, Springer*, Singapore, 2017, pp. 1901-1908.
[29]. Ling-Li H. E., D. O. Imaging, Design of virtual ECG monitor system based on LabVIEW, *Chinese Medical Equipment Journal*, 2017.
