CHEMICAL ENGINEERING TRANSACTIONS

VOL. 71, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871193

Architecture of Indoor Air Volatile Organic Compounds Testing System Based on Wireless Sensor Networks

Huabao Chen

School of Physics and Electronic Electrical Engineering, Huaiyin Normal University, Huaian 223300, China
huabaochen@163.com

Today, as people's living standard grows better and better, the people’s indoor living environment is also demanding higher and higher. In particular, the concentration of indoor air VOCs is of even greater concern. Given that the traditional system developed for testing indoor air quality has some defects such as monomer node, single detection target and high user threshold, this paper applies wireless sensor network to the test system for indoor air VOCs. The results show that users can easily access the detection results via the Web, and the whole system features wireless, networking, multiple nodes, simple operation and low cost. The holistic equipment works in good condition and never fails. In a specific environment, compared with the traditional wireless sensor network, the detection control system devised herein reaches a constant value in a shorter time. With the test of the system functions, it is proved that the system can work in a truly and stably manner and has a high detection precision.

1. Introduction

Today, with the rapid growth of the socioeconomic sphere, China has witnessed an unprecedented increase of people’s concern about air quality. However unfortunately, the high-profile air quality indoors is still a blind spot the public data about it covers (Ahn et al., 2017). General social surveys recently conducted show that air pollution has a significantly negative impact on people's well-being, and people have high requirements and expectations for indoor air quality (Abraham and Li, 2016). By far, spiraling incidence of certain diseases such as respiratory diseases and cardiovascular and cerebrovascular diseases caused by indoor air pollution has entailed huge economic losses. The majority of human life, exceeding 80%, is spent in the houses, so that how good the indoor air quality is having direct bearing on the human life (Yu et al., 2013). The VOCs from interior decorations and furniture, for example, are the principal pollutants in indoor air since they always jeopardize human health. After testing and determining, the concentration of VOCs increases over time in the first year after interior finish. It is thus visible that the VOCs will indeed have an enduring hazard to the human body (Abraham and Li, 2014).

Commonly used air quality test methods include spot and online tests. The special test is expensive, inconvenient, and lacks function, so that it cannot be oriented to the consumer market (Liu et al., 2013). Indoor air quality test equipment can timely collect, observe and record data about indoor air quality at a target point to provide user with indoor environment data (Maruo and Nakamura, 2011). The current air quality test system is currently developed towards the trend of simplified interaction and operation, multi-nodes, networking, wireless and intelligent modes. Via a rapidly developed sensor network, it outputs physical, chemical and biological information in the space as electrical signals under certain rules (Thevenet et al., 2018). Based on wireless sensor network technology, this paper devises and implements a set of test system for controlling the VOCs in indoor air. Users can timely acquire accurate and efficient air quality relevant information indoors with simple tools such as cellphones.

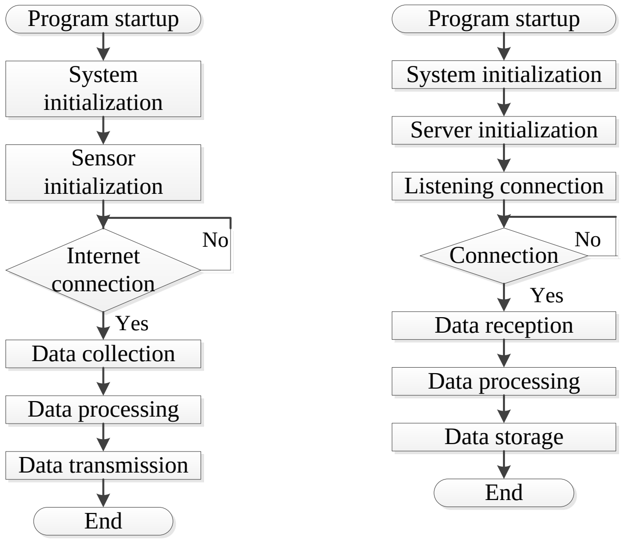
2. Overall design program

2.1 Overall design and technology prototype

The whole test system for indoor air VOCs integrates a series of functions including VOC concentration

Please cite this article as: Chen H., 2018, Architecture of indoor air volatile organic compounds testing system based on wireless sensor networks, Chemical Engineering Transactions, 71, 1153-1158 DOI:10.3303/CET1871193

acquisition, wireless sensor transmission, treatment and storage, display and management, etc. (Zhou and Chang, 2012). Wireless sensor network features scale-up, (Li and Shi, 2018) network self-configuration, non-fixability, and data-centricity (Caron et al., 2016). The system includes the master and child node devices. Among them, the master node, as the core of the entire test system for VOCs, integrates and stores data from the child nodes. There are commonly used master nodes including PCs, router, and embedded devices, etc. The software flow diagram of the child and master nodes is shown in Fig.1. After the program boots, it enters the system and sensor initializations. When the networking succeeds, the child node will collect, process and send data, and the master node timely receives, processes and stores data.



(a) Child node software flow chart (b) Master node software flow chart

Figure 1: Child node and master node software flow chart

2.2 Key technologies of system

Now the security of wireless LAN technology has aroused a common concern. It has become more and more important issue. Common wireless sensor encryption algorithms include WEP and WPA. Embedded technology is a common application type for sensor since it features small volume, low power consumption and high availability. Database and Web are the core technologies for wireless sensor networks, as commonly used computer-aided data management mode, while the commonly used data application models include the hierarchical, network and relational types. Web server-side technology mainly includes PHP, ASP, .NET and JavaEE technologies.

3. Design and implementation of system hardware

3.1 Indoor Air VOCs information web service architecture

With the advent of dynamic Web services architecture, various Web application architectures have emerged, among which, the MVC (model-view-control architecture) is the most widely applied. The schematic diagram of the MVC architecture is shown in Fig. 2, it effectively achieves the separation of the front and back ends. The Web architecture enabled with front- and back-end separation can be developed and maintained on its own sense, thus greatly reducing the coupling between the frontend and the backend. Currently, such types of Web service architectures include the BSS built by NodeJS technology and the SPA-based Web services architecture where the SPA is lightweight and does not increase extra workload. This paper incorporates the advantages of the two types of architecture to design a Webpage application service architecture, which can improve the availability and stability of the pages on the premise of template reuse and front- and back-end separation. A communication model for the indoor air VOC test system based on the architecture is shown in Fig. 3, where the wireless module and the terminal test device are connected via a wireless coordinator. A hardware structure of a terminal device is shown in Fig. 4. It consists of the core board, power, signal conversion and signal sensing modules, and its main function is to transmit the detected data information.

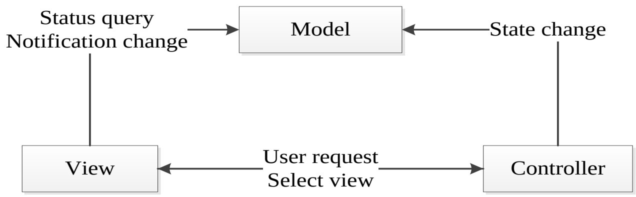


Figure 2: MVC architecture diagram

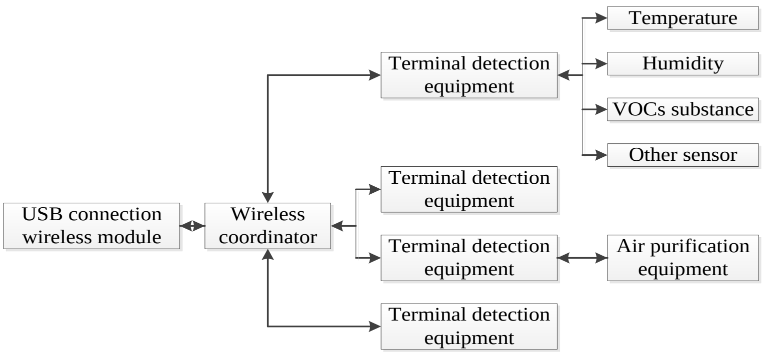


Figure 3: Indoor air VOCs monitoring system communication model

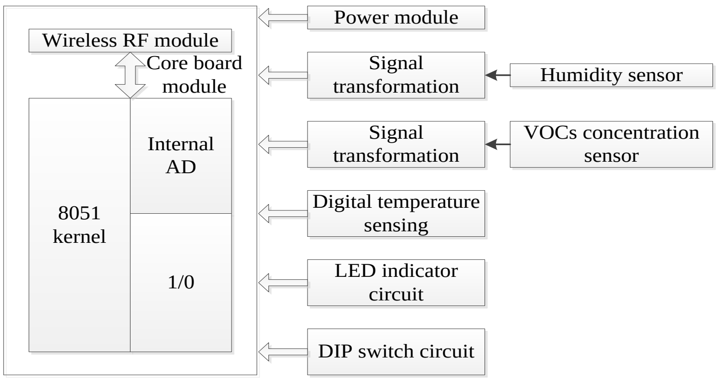


Figure 4: Terminal equipment hardware structure

3.2 Building air quality collection sub-node sensor

Table 1: DHT91 sensor accuracy table

Function	Measuring range	Precision	Response time	Resolution
Humidity	0%-100%	±3%	5s	0.01%
Temperature	-50 ºC-125 ºC	±0.5 ºC	5s-10s	0.01 ºC

The data sources for testing indoor air VOCs are collected by a plurality of sub-nodes sensors. The acquisition of indoor air VOCs covers various spaces in the houses, and data communication between sub-node and the main node sensors can be achieved via WLAN. The schematic diagram of a child node sensor device is shown in Fig. 5. The child node sensor includes the smoke sensor, the particulate matter sensor, the temperature sensor, and the humidity sensor, among which, the temperature and humidity sensors use the DHT91 module. The precision of DHT91 sensor is shown in Table 1. A Sharp particle sensor for testing the VOCs is used here, which is an optical particle matter sensor with a dust range of 25-1000μg/m^3. See Fig. 6 for the architecture of master node device. The master node device has functions such as providing WLAN service for the management child node sensor, managing the child node device, and receiving data sent by the child node device to the database.

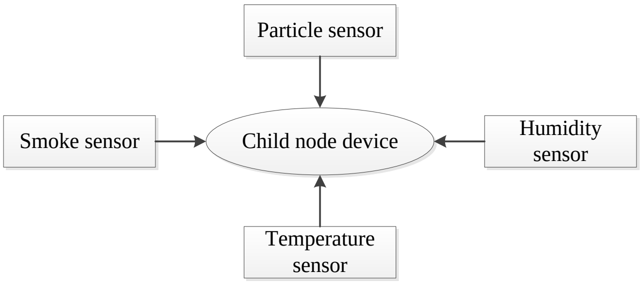


Figure 5: Subnode sensor device schematic

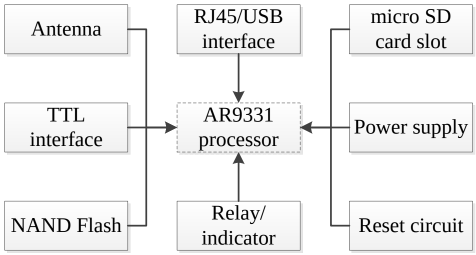


Figure 6: Master node device schematic

4. Design and implementation of system software

4.1 Main node software

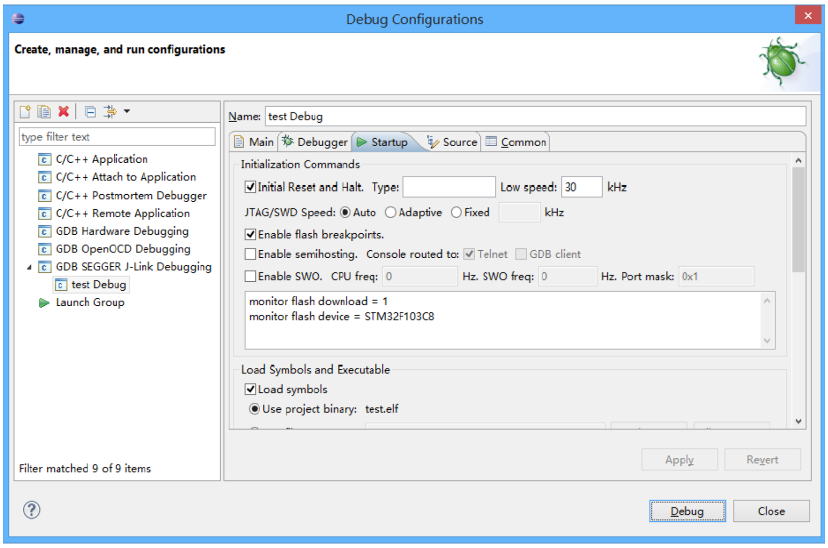


Figure 7: J-Link emulator configured in Eclipse CDT

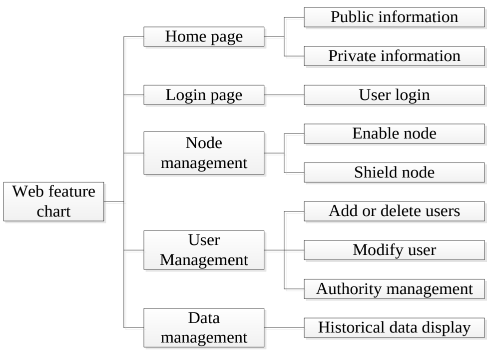


Figure 8: Web page function structure diagram

The test system Software for indoor air VOCs includes data collection child node, main test node and Web service platform. The data acquisition child node software is designed depending on the STM32 development environment where there are the Eclipse CDT integrated development platform and the J-Link download emulator, as shown in Fig. 7, configured in the Eclipse CDT. After the driver is installed, the Eclipse CDT is configured properly. Create a new debug in the *Debug Configuration*. Configure the chip model information in the *Startup*. As data collected varies from sub-node to sub-node in the indoor layout, the data information of the VOCs is transmitted and tested in the JSON data format. For the design of master node software system, it is required to establish Linux host and cross-compilation environments, and build a database using SQLite. For Web page function structure, see Fig. 8, there are the home page, login page, node management, user management, and data management.

4.2 System test

The system in this paper should be tested for functions, performance and stability when using for indoor air VOCs. The whole debugging operation process is divided into two modules: the master node and the child node. In order to accurately test the data acquisition and transmission functions of the child nodes, a PC is used to simulate the master node to receive data from child node. The master node is connected to the wireless network for the test via the mobile phone. Data management displays historical data of the indoor air VOCs in the form of a broken line graph.

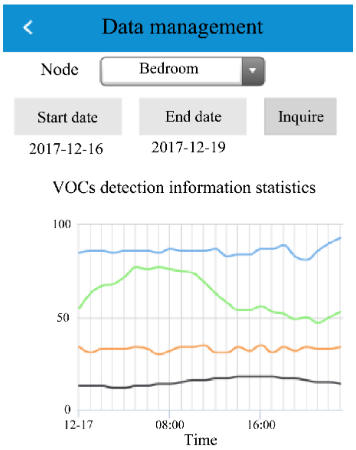


Figure 9: Historical data interface

Fig. 9 is the historical data interface. According to the debugging, it is found that the master node can complete the collection of data from the child node and store them in the database, in order to achieve the functions in the target. In this paper, 10 houses newly renovated are performed with a field test using the Web platform. See table 2 for the test results of the Web service platform. It can be seen that the loading time of the service platform is less than 5s, and the probability of no-response rate is low. The test results of the test system for indoor air VOCs are given in Table 3. It is obvious that the whole equipment runs in good operating condition and there is no error. As shown in Table 4, the concentration of VOCs in the tested room is tested. Under the specific detection environment, the test control system designed herein can reach a constant value within ten minutes, much shorter than the traditional wireless sensor network.

Table 2: Web service platform test

Page	First load completion time	Load completion time	50 times within 10 seconds without response rate
Home page	3.68s	2.67s	0.0%
Login page	3.62s	1.82s	0.0%
Node management page	3.72s	2.54s	0.5%
User management page	3.69s	2.94s	0.0%
Add user page	3.68s	2.17s	1.0%
Historical data page	4.21s	3.12s	0%

Table 3: Indoor air VOCs monitoring system test results

Test items	Child node running status	Data transmission	Data storage	Master node running status
Error number	12	5	1	0
Average hourly error rate	6.6%	2.4%	0.1%	0.05%
Average error-free running time	18.9h	21.7h	23.6h	24h

Table 4: VOCs concentration monitoring in the tested room

Time/min	Wireless sensor detects VOCs concentration	Traditional sensor detects VOCs concentration
0	1.032	1.032
5	1.034	1.038
10	1.035	1.041
15	1.035	1.039
20	1.035	1.038
25	1.035	1.036
30	1.035	1.036

5. Conclusion

Based on wireless sensor network technology, this paper devises and implements the test system for indoor air VOCs. The specific conclusions are derived as follows:

(1) Wireless sensor network features scale expansion, network self-convergence, non-fixability and data-centric mode. With an integrated design, the system includes the master node and the child node devices.

(2) The particulate matter sensor for testing the VOCs uses Sharp particle sensor. The master node device includes functions to provide the management child node sensor with WLAN service, manage the child node device and receive data sent by the child node device to the database.

(3) After the system debugging, the whole equipment of the test system for indoor air VOCs works in good conditions, no error occurs. In the specific environment, compared with the traditional wireless sensor network, the test system designed herein can reaches a constant value in a shorter time.

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