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Internet of Things-driven intelligent ventilation system for buildings in humanized designs

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Abstract

This paper focuses on designing a personalized intelligent ventilation system based on the Internet of Things (IoT), which consists of a three-layer structure of workstations, network controllers and field controllers. The indoor environmental data is preprocessed using the Grubbs criterion, while the node data collected by multiple sensors are then weighted and fused to obtain the optimal data values. Through the fuzzy controller, the concentration deviation and dust concentration deviation are used as input quantities, and the final output of the fan on time under different environments. The simulation results of the experimental scenarios show that the stability test success rate of the system in this paper are more than 95%, and the degree of stability is very high. Compared with the conventional PID control, the steady state error of the fuzzy PID control is only 2%. The simulation experiment tested three functional rooms: bedroom, living room and kitchen. When the CO₂ concentration in the bedroom, PM_{2.5} concentration in the living room and PM_{2.5} concentration in the kitchen exceeded the standard, the system in this paper can monitor and turn on the ventilation system in time to improve the indoor air quality. It also has the warning function of dangerous gas.

Keywords: Internet of things; Intelligent ventilation system; Sensor; Fuzzy control; Weighted fusion.

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1 Introduction

With the continuous progress of science and technology, intelligent technology has been widely used in various fields, one of which is the intelligent ventilation system of buildings. The appearance of intelligent ventilation system not only makes the ventilation effect of the building more excellent, but also helps to improve the energy utilization efficiency of the building [1-4]. Building intelligent ventilation system has the design principles of intelligence, energy saving and efficiency, safety and reliability as well as humanization, and in the gradual generalization of this system, its humanized design has gradually been emphasized [5-7].

In modern society, buildings are not only to meet the basic needs of living and working, but more importantly, how to create a comfortable, convenient and humanized space [8-9]. Humanized design refers to the architects and designers in the design of buildings, give full consideration to people's needs, habits, comfort and psychological factors, in order to improve the quality of life and enhance people's sense of well-being. Humanized design is a very important part of architecture [10-13]. Through the consideration of ventilation and lighting, barrier-free design, comfortable indoor environment, rational planning of spatial layout, aesthetic design and safety design, a comfortable, convenient and beautiful architectural space that meets people's needs can be created [14-17]. These designs not only improve the quality of life, but also increase people's sense of well-being and work efficiency. Therefore, humanized design should receive more attention and application in building design, especially in building intelligent ventilation system [18-21].

To address the individual needs of the ventilation system, the software architecture of the IoT-driven intelligent ventilation system for buildings is designed by applying IoT technology to the building ventilation system based on its excellent performance. The indoor environment is sensed by IoT sensors, data are collected and transmitted, and the acquired information is stored in a database and preprocessed by applying the Grubbs criterion to remove gross errors. And then the node data is collected by multi-sensor fusion algorithm for weighted fusion to get the best data value. In order to accurately control the opening and closing of the ventilation system, a fuzzy controller is designed. The concentration deviation and dust concentration deviation are used as inputs to output the fan on time in different environments. The environmental data of a family over a period of time is used as a research sample, and scenarios of its living room air quality, kitchen air quality and dangerous gases are simulated to discuss the reliability of the intelligent ventilation system in this paper.

2 Internet of Things technology

2.1 Overview of the Internet of Things

The concept of the Internet of Things was first proposed by scholars at MIT in 1999, that is, the Internet of Things is a network that uses radio frequency identification technology and sensing devices to connect all items to the Internet for intelligent identification and management. In 2005, the ITU proposed in its annual report that “by embedding short-range mobile transceivers into a variety of accessories and everyday items, a new mode of communication between people, people and things, and things and things has been formed, i.e., real-time interactions can be realized at any time and any place.” In 2008, IBM formally put forward the idea and concept of Smart Earth, namely “Internet of Things + Internet = Smart Earth”. In this regard, the Internet of Things has further become an important innovative weapon needed by countries around the world to face the financial crisis, leading to a third revolution in the field of information technology. In 2009, the European Union's Strategic Roadmap for IoT Research also stipulated the concept of IoT. In the

same year, Chinese Premier Wen Jiabao also put forward the concept of “Sensing China”, a concept related to the Internet of Things. Nowadays, the development of Internet of Things (IoT) has entered China's emerging strategic industry planning map, becoming an important strategy for the development of national information industry.

The conceptual model of the Internet of Things (IoT) is shown in Figure 1, which cannot be separated from the traditional Internet and has the following characteristics: first, it is a kind of ubiquitous network based on the Internet. The Internet of Things is the integration and expansion of the Internet with various networks, while the Internet remains the important foundation and core of the Internet of Things technology. Meanwhile, in the process of transmitting massive information, IoT supports various protocols and heterogeneous networks in order to meet various requirements for data. Secondly, it is an extended application of various sensing technologies. A huge number and variety of sensors are deployed on the IoT, where each sensor is a source of information collection, which can collect various specific information according to a specified frequency and periodicity, and these data are extremely real-time. What's more, IoT realizes intelligent processing on the basis of sensor connectivity itself. The Internet of Things realizes intelligent data processing on sensors and utilizes various intelligent technologies, giving it the ability to control objects and the environment intelligently, while expanding both width and depth in the field of application.

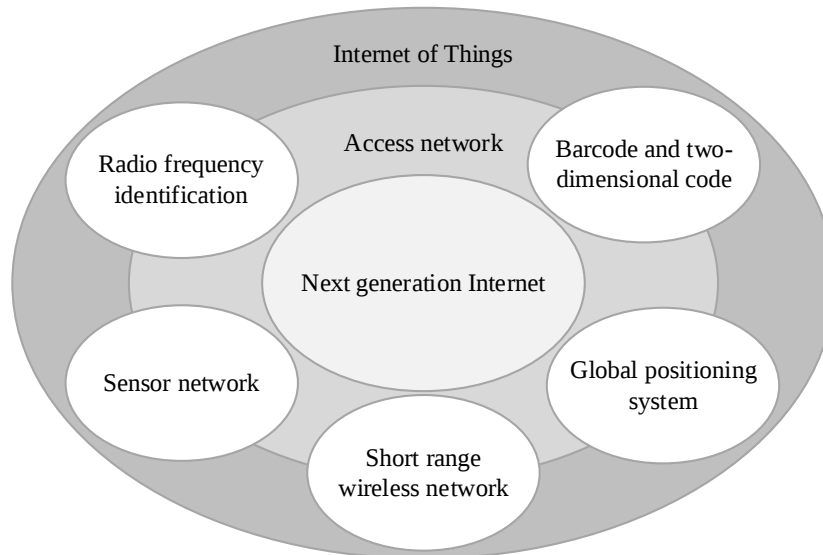


Figure 1. Conceptual model of iot

2.2 Technical framework for the Internet of Things

- 1) Perception layer: mainly responsible for environmental information acquisition, the technology of information acquisition includes sensors, barcode and two-dimensional code, gas concentration sensors, humidity sensors, temperature sensors and other perception terminals. Perception layer is the core of making IOT with comprehensive perception ability, and the key to the development of perception layer technology lies in how to have more accurate and comprehensive perception ability.
- 2) Network layer: It is responsible for encoding, authenticating and transmitting the information data obtained from the perception layer using wireless and wired networks. Due to the wide coverage of existing mobile communication networks, the network layer is the most practical part of the three-layer architecture of IoT, and the future development focuses

on how to further optimize and improve the characteristics of IoT applications, and ultimately build a huge network with collaborative sensing.

- 3) Application layer: it is the fundamental goal of IoT development, providing a large number of intelligent applications based on IoT. It is the interface between users and IoT, creating a large number of high-quality intelligent application solutions based on IoT technology and specific needs.

3 Personalized design of home ventilation systems based on the Internet of Things (IoT)

The IoT ventilation system issues remote control commands to the fan through real-time monitoring and early warning to change the underground air volume, air pressure and air flow to improve air quality.

With the development of IoT and the continuous progress of network technology, at present, many subsystems of power equipment in buildings have quasi-IoT form or are already in IoT form. IoT consists of a standard three-layer structure (perception layer, network layer, application layer), and its structural characteristics determine that IoT should have the ability to comprehensively perceive, reliably transmit, and intelligently process, while intelligent processing requires the analysis and processing of massive amounts of data, and ultimately realizes the intelligent control of equipment.

Intelligent Building Technology Key Laboratory intelligent integrated system of air conditioning and ventilation system using the U.S. Alerton (Aiden) company's BACNet products, air conditioning and ventilation system consists of fresh air units, fixed-air volume combined air conditioning units and air conditioning cold and heat source system, the system to achieve a constant temperature and humidity comfortable environment, air conditioning and ventilation system network structure shown in Figure 2. The whole air-conditioning and ventilation system consists of a three-layer structure of workstations, network controllers and field controllers, which can automatically regulate all relevant actuators in the system to meet the control requirements of the system. The AlertonVLC series of field DDC controllers ensures fast, accurate, flexible and reliable operation. The VLC utilizes industry-standard inputs to support access to sensors (CO2 sensors, PM2.5 sensors, temperature sensors, humidity sensors, etc.) and transmitters of various signal types. The monitoring and control workstation for the air conditioning and ventilation system is located in XX308. The BACNet protocol is used between the network controller and the underlying DDC controller, and the host computer is connected to the network controller via TCP/IP. The monitoring workstation of the air conditioning and ventilation system is installed with ENVISIONfor BACTalk software, which can visualize various parameters of the on-site fresh air units and fixed-air-volume air conditioning units through the graphical settings of the graphical workstation. As the cloud platform of building equipment IoT information system needs to obtain the field data of air conditioning and ventilation system, in order to realize the data integration, we consider expanding the network switching ability of monitoring workstation by adding an Ethernet card, which can also function as a gateway, the system follows the distributed characteristics in general, and finally forms the interconnection and mutual access network with the integration platform. In addition, in addition to the need for a smooth network conditions, the monitoring workstation needs to run an interface program based on OPC technology, here proclaimed the use of third-party integrator KPWARE KPWAREServerEX software package, which supports the BACNet communication protocol, can communicate directly with the air conditioning and ventilation system's network controllers, and in the form of OPC Server to the outside to provide access to the interface of the data.

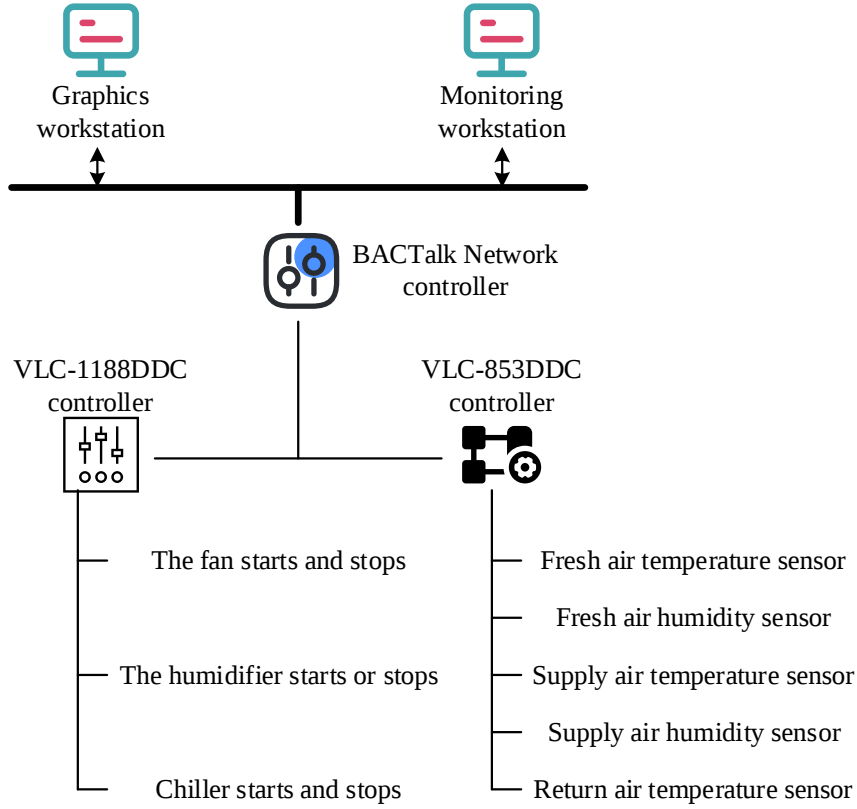


Figure 2. Network structure diagram of air conditioning and ventilation system

4 Data collection and analysis for the Internet of Things

4.1 Sensor data preprocessing

The range of data that can be captured by a single sensor is very limited, and multiple and multiple types of sensors must be used to obtain relatively accurate as well as wide coverage data. Multi-sensor data fusion, sometimes referred to as multi-sensor information fusion or multi-sensor data fusion, is used to integrate and fuse multiple data from different sensors, devices, or algorithms to obtain more comprehensive and reliable information.

Grubbshuaize is particularly applicable in measurement scenarios where the amount of data is between 3 and 50, especially when individual outliers need to be identified and ruled out. This method is not only effective, but also simple and easy to implement. It is important to note that when the significance level is set at 0.1, the number of measurements performed must exceed 10 to ensure the accuracy of the criterion.

The environmental data obtained from measurements in one cycle were sorted in order from smallest to largest. Equations (1), (2) and (3) were utilized to calculate the arithmetic mean and standard deviation of these measurements:

$$\bar{x}_i = \frac{1}{m} \sum_{m=1}^m x_{im} \quad (1)$$

$$\varepsilon_{im} = x_{im} - \bar{x}_i \quad (2)$$

$$\sigma_i = \sqrt{\sum_{m=1}^m \varepsilon_{im}^2} \quad (3)$$

From the Grubbs criterion, the Grubbs of the home's indoor internal environmental data is shown in equation (4):

$$g_{im} = \frac{x_{im} - \bar{x}_i}{\sigma_i} \quad (4)$$

Let y be the value of the significant level parameter, which can usually be taken as 0.05 or 0.01. When $g_{ij} \geq g_{i0}(m, y)$ holds, it means that the data contains gross errors and should be removed. In addition, the Grubbs Criterion $g_{i0}(m, y)$ can be determined by looking up the table.

The Grubbs Criterion input measurements are also measured home indoor environmental data over a period of time, and then this sequence is ordered to find its semi-mean and variance. Determine the exact distribution of the Grubbs statistic and compare the magnitude of g_{ij} and $g_{i0}(m, y)$. If yes, the data contains gross errors and should be eliminated, then calculate the next data and compare again. If no, the data is normal and should be retained, then calculate the next data.

4.2 Multi-sensor fusion algorithm

The environmental data in the home interior collected by the environmental collection node within the home interior for a period of time, after preprocessing by the previous Grubbs criterion, the environmental data in the home interior collected by the terminal i of a certain collection node during this period of time is regarded as an array Q and divided into 3 groups. Each group can be represented as a sequence, and each sequence has its own corresponding mean and variance, as shown in equations (5) and (6). It is assumed here that there are 12 preprocessed data, so the 3 groups are 4 data in each group, and the first group can be represented as $X_1 = \{X_{11}, X_{12}, X_{13}, X_{14}\}$, the second group as $X_2 = \{X_{21}, X_{22}, X_{23}, X_{24}\}$, and the third group as $X_3 = \{X_{31}, X_{32}, X_{33}, X_{34}\}$, where the m th group is represented as $X_m = \{X_{m1}, X_{m2}, \dots, X_{mn}\}$:

$$\bar{X}_m = \frac{1}{n} \sum_{mn}^n X_{mn} \quad (5)$$

$$\sigma_m^2 = \frac{1}{n-1} \sum (X_{mn} - \bar{X}_m)^2 \quad (6)$$

The mean and variance of each of the three groups of data divided by Eq. (5) and Eq. (6) are obtained, and the following intra-group fusion is carried out, and through this computational process of Eq. (7), the mean and variance are utilized to compute the new fused value, i.e., the optimal ambient value of the environmental data acquired by the collection node terminals within the interior of the home within the period of time:

$$X = \frac{\sigma_1^2 \bar{X}_1 + \sigma_2^2 \bar{X}_2 + \sigma_3^2 \bar{X}_3}{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} \quad (7)$$

The previous equation obtains the optimal environmental values of the collection node terminals inside the home interior during a certain period of time, in addition, the total variance of the environmental data collected by the collection node terminals inside the home after fusion can be obtained based on the variance of each group σ^2 , and the calculation process is shown in Equation (8):

$$\sigma^2 = \frac{\sigma_1^2 \sigma_2^2 \sigma_3^2}{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} \quad (8)$$

Adaptive weighted fusion algorithms are commonly used for multi-sensor data fusion, where the data collected from different sensors are weighted according to their reliability and accuracy, and then the weighted data are fused to obtain the final result. In order to get the values that can more accurately reflect the environmental information inside the home, add weight values to each sequence of environmental data from each acquisition node, multiply each sequence with its weight, and finally add them to get the final environmental values. For example, now there are two collection nodes, it should be the environmental data collected by the two collection nodes by intra-group fusion and then weighted fusion.

Next, the weighted fused values of the environmental data inside the home are calculated, now assuming that n acquisition node is arranged inside the home, then there are the same number and type of sensors. The optimal fusion value and the overall total variance of each collection node sensor inside the home interior can be calculated using equation (7) and equation (8) above. Here, the weights of n identical sensors are set to be $\omega_1, \omega_2, \dots, \omega_n$ respectively, that is, weights are assigned to each acquisition node sensor. Assuming that the overall total mean square deviation of the data after fusion of each acquisition node sensor inside the home interior is σ^2 and the measurement result is X , the calculation formula can be obtained as shown in equation (9) below:

$$\begin{cases} X = \sum_{i=1}^n \omega_i X_i \\ \sum_{i=1}^n \omega_i = 1 \\ \sigma^2 = \sum_{i=1}^n \omega_i^2 \sigma_i^2 \end{cases} \quad (9)$$

The above equation (9) is three separate equations, which are combined below to obtain the functional representation. The formula for the functional representation obtained from equation (9) is shown in equation (10) below:

$$f(\omega_1, \omega_2, \dots, \omega_n) = \sigma^2 = \sum_{i=1}^n \omega_i^2 \sigma_i^2 \quad (10)$$

In order to obtain the optimal weights, the key is to solve the minimal value of equation (10). The specific formula is shown in equation (11) below:

$$\omega_i = \frac{1}{\sigma_i^2 \sum_{i=1}^n \frac{1}{\sigma_i^2}} \quad (11)$$

From Eq. (11), the weight value of the environmental data collected by a particular sensor is ω_i . Substituting this weight value into Eq. (9) yields the optimal value of the fused environmental data within the home interior, which is calculated as shown in Eq. (12):

$$X = \sum_{i=1}^n \omega_i X_i \quad (12)$$

4.3 Basic theory of fuzzy control (PID)

Under the premise of ensuring the safety and comfort of the residential environment, in order to make the ventilation operating costs as small as possible, it is necessary to use appropriate control strategies to control the fan on. The ventilation system is a nonlinear, large time lag system, ordinary control strategies are difficult to meet the requirements. The fuzzy control method is a good choice for ventilation control because of its small dependence on the mathematical model of the system and good robustness.

Fuzzy control systems for a variety of control objects were also successfully developed. In the next few decades, fuzzy control theory has been developed tremendously, and it has become the most active control method in the field of intelligent control. Its characteristics are as follows:

- 1) Although the fuzzy engineering calculation method utilizes the fuzzy set theory for fuzzy calculation, the results obtained are deterministic conditional statements.
- 2) Compared with traditional control methods, fuzzy control methods rely on fuzzy rule bases, which are rules expressed in the natural language of human beings and are close to human thinking habits, so they are easy for operators to understand and use.
- 3) There is no need to establish the mathematical model of the system, only need to set the fuzzy control rules based on experience, so the fuzzy control is suitable for those objects whose mathematical model is difficult to establish and whose dynamic characteristics are not easy to grasp.
- 4) Fuzzy control system is robust, interference and parameter changes have little effect on the control effect, especially suitable for nonlinear, large time lag system.
- 5) The fuzzy control table obtained at the end of fuzzy control is actually a computer program composed of many conditional statements, which is easy to design.

Fuzzy, rule, inference, and de-fuzzy together constitute a fuzzy controller, which combines the actual situation of home indoor environment monitoring system, and automatically adjusts the fan turn-on time according to the collected environmental data using fuzzy inference. Inputting CO2 concentration deviation and dust concentration deviation into the fuzzy controller starts fuzzification, enters the inference machine, and then defuzzifies to get the clear value which is the fan on time. After performing the whole process go back to start the cycle next time.

5 Application of IoT smart ventilation systems

5.1 System Performance Testing

After the introduction of the previous section, to complete the construction of the entire intelligent Internet of Things home ventilation system and the laboratory of the function of each part of the relevant test, the test results show that the realization of the function of each part of the expected goal. But a successful system in addition to ensure that the functions to be realized, a very important point is the stability of the system indicators meet the requirements, when the stability of the system indicators meet the requirements, it shows that the system designed to meet the requirements. Based on the requirements of system stability, so the overall function of the system to do the stability test, the test mode through a number of measurements to observe the success rate to see whether it can meet the requirements, the test results shown in Table 1.

Through the above test data, it can be seen that the stability of the various parts of the entire system function is very high, the success rate are more than 95%, to meet the requirements of the system's normal operation of the reliability of the system can meet the requirements of the system design, the completion of the design of the laboratory system to meet the expected goals.

Table 1. System test table

Name	Content	Test frequency	Success number
PC client	Power control	120	115
	Fault alarm	120	115
	Data display	120	120
	Equipment control	120	115

The comparison results are shown in Table 2, and it can be seen that the fuzzy inference-based PID controller has a steady state error of only 2% compared with the conventional PID controller. The fuzzy PID controller integrates the advantages of PID control and fuzzy control, thus completing the dynamic adjustment of the PID control parameters, the system's dynamic response curve is good, the response time is short, the overshooting amount is small, the steady state accuracy is high, and it can realize the automatic adjustment of the ventilation volume according to the change of the environment in time to ensure the safe, reliable and stable operation of the ventilation system. Using computer simulation software, the designed conventional PID controller and fuzzy PID controller comparison simulation experiments, compared with the conventional PID control, fuzzy PID control has a better control performance, but also for the design and debugging of the actual integrated ventilation system to provide a practical significance and theoretical basis.

Table 2. Conventional control and fuzzy control comparison

Control method	Hypermodulation (%)	Rise time (s)	Adjust time(s)	Steady state error(%)
Conventional control	30	0.09	0.63	3
Fuzzy control	10	0.06	0.42	2

5.2 Experimental Scenario Simulation

In this paper, the environmental data (including temperature, carbon monoxide, oxygen, hydrogen sulfide, etc.) of a family for a period of time were collected, with a total of 90 sets of experimental data. The same environmental parameter is taken to be averaged after repeated measurements for

many times to get the optimal value after the fusion of the environmental data within the family room, and it is taken as the real value with high reliability. Some of the environmental data collected are shown in Table 3.

Table 3. Part of the collection of sample Numbers

Group number	Carbon monoxide (ppm)	Oxygen (vol.)	Temperature (°C)
1	60.5	21.97	25.2
2	47.2	21.74	26.1
3	41.1	21.55	26.6
4	36.9	20.96	27.5
5	33.7	20.37	27.4
6	30.8	20.02	28.2
7	28.6	20.19	29.6
8	22.2	19.46	30.8
9	16.7	19.37	31.2
10	58.3	18.22	31.5
11	69.7	19.32	30.6
12	79.2	20.03	29.2
13	81.1	20.27	28.6
14	83.3	20.68	27.9
15	84.7	21.14	27.4
.....			

5.2.1 Analysis of indoor air quality monitoring

In this test experimental scenario, due to the indoor equipment to realize the complete networking. During the experimental test, the monitoring and reporting function of each indoor environmental parameter is realized by each monitor, and the ventilation system is turned on and off, so as to verify the effectiveness of the IoT ventilation system.

The single-day CO₂ concentration change curve in the living room-bedroom is shown in Figure 3, and the single-day PM_{2.5} concentration change curve in the living room-living room. During the night rest period (00:00-8:00), the CO₂ concentration in the bedroom is above and below 800-2000 ppm, and some instantaneous values can exceed 2000 ppm, and the bedroom is closed at this time with the inner door and outer window closed. At around 8:00 a.m., the experimenter woke up and got up (point 1), at this time, the platform opened the ventilation system. 8:10 a.m., at this time, the indoor CO₂ concentration of 1380 ppm, 10 minutes later, the indoor CO₂ concentration dropped to about 900 ppm. At this time, the experimenter closed the outside window of the bedroom and opened the inside door of the bedroom, and the indoor CO₂ concentration dropped to 785 ppm at 8:36 p.m. Subsequently, until the experimenter returned home at 2:40 p.m., the indoor area was unoccupied (the outside window of the bedroom was closed), and the CO₂ concentration of the bedroom was maintained at about 400-500 ppm.

The experimenter returned home at 2:40 p.m. and entered the bedroom (point 3), where he was working on his writing at the bedroom desk, and there was a sustained increase in the indoor CO₂ concentration, as shown in points 3-4, during which there was an instantaneous value of 1,381 ppm.

The platform turned on the ventilation system after noticing the exceedance of the standard, and the indoor CO₂ concentration dropped rapidly at 4:30 p.m. (point 4), falling to 510 ppm at 4:43 p.m. The graphs show that the indoor CO₂ concentration dropped to 510 ppm. Points 5 and 6 in the figure show the rapid decrease of indoor CO₂ concentration as a result of the platform's operation to turn on the ventilation system. All of the above shows that the CO₂ concentration in the bedroom can be reduced to below the safe level or even lower by turning on the ventilation system and reminding operation of the platform.

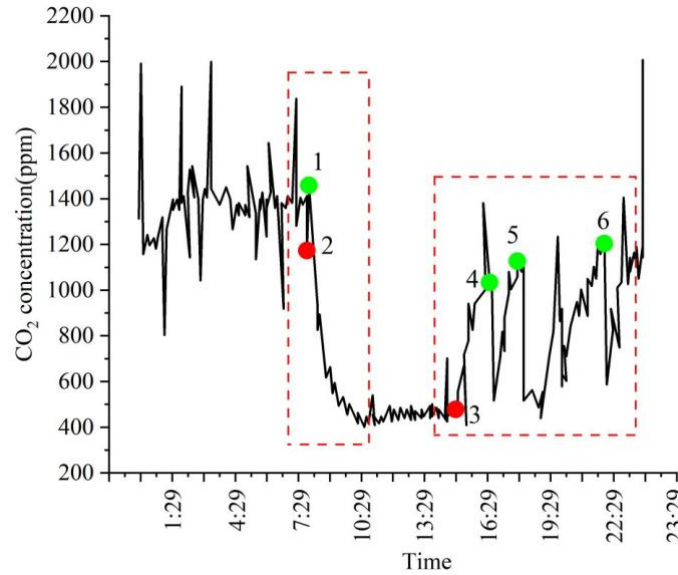


Figure 3. Variation curve of single-day CO₂ concentration in bedroom

The pollutant situation in the living room is shown in Figure 4, where the PM_{2.5} concentration is mainly influenced by the behavioral activities of the experimenter. For example, during the rest period (00:00-8:00) the PM_{2.5} concentration in the living room was maintained above and below 50 $\mu\text{g}/\text{m}^3$, and rarely exceeded 50 $\mu\text{g}/\text{m}^3$. During the evening break, the outdoor windows in the living room were closed and the kitchen window was open. On the day of the test, the outdoor AQI was 42, excellent. The experimenter woke up at 8-9 a.m. and moved around the living room, and the experimenter smoked inside the living room, and the PM_{2.5} concentration rose rapidly due to smoking at point 1-point 2 in the figure, and the PM_{2.5} concentration rose from 42 $\mu\text{g}/\text{m}^3$ to about 200 $\mu\text{g}/\text{m}^3$. The platform reminds the real and turns on the ventilation system. PM_{2.5} concentrations dropped to 35 $\mu\text{g}/\text{m}^3$ after a period of climbing. All the experimenters ate in the living room around 11:30 p.m. (point 3) and turned on the natural gas heating stove, at which time the PM_{2.5} concentration in the living room due to the increased human activities welcomed a climb, as shown in point 3-point 4, from 53 $\mu\text{g}/\text{m}^3$ to about 140 $\mu\text{g}/\text{m}^3$ and reached the highest value of 150 $\mu\text{g}/\text{m}^3$ in point 4. The platform turned on the ventilation system and the PM_{2.5} concentration was decreasing to about 50 $\mu\text{g}/\text{m}^3$. The same is true for points 5-6, where PM_{2.5} concentrations were exceeded due to behavioral activities such as heating and smoking in the room by the experimenter. As can be seen from the above, when there is no activity in the living room, the PM_{2.5} concentration can be maintained at a low level range (around 50 $\mu\text{g}/\text{m}^3$), and once there is activity (especially smoking) there is a spike in the PM_{2.5} concentration, but after the operation of turning on the ventilation system as prompted by the platform, a short period of significant decline can be found.

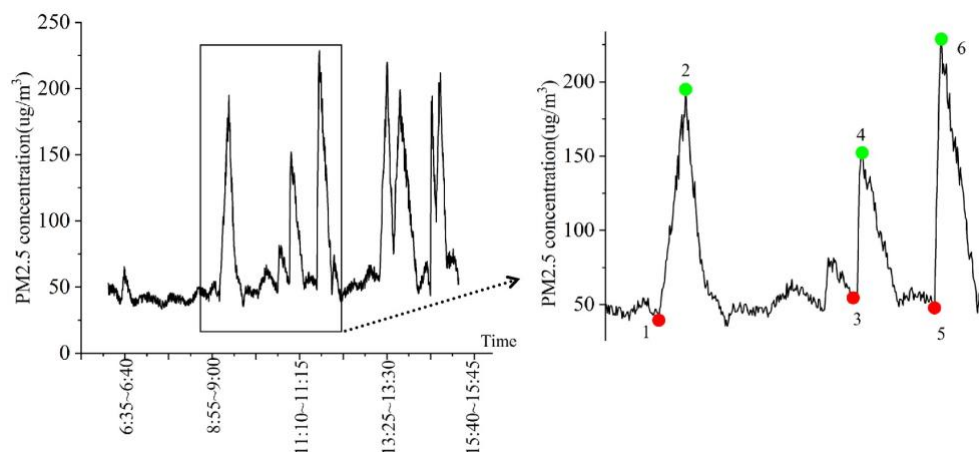


Figure 4. Variation curve of single-day PM2.5 concentration in living room

5.2.2 Analysis of kitchen air quality and hazardous gas monitoring

The pattern of change of pollutants in the kitchen is also very obvious, the pollutants monitored in the kitchen are CO₂ and PM_{2.5} concentration, but only PM_{2.5} concentration is used as a control object. PM_{2.5} is the main source of cooking activities in the kitchen, and the change curve of PM_{2.5} concentration in the kitchen in a single day is shown in Figure 5. Area 1, Area 2, and Area 3 show the changes of pollutants during cooking time for breakfast, lunch, and dinner, respectively.

During the breakfast cooking time, its PM_{2.5} concentration reached a maximum of 225 $\mu\text{g}/\text{m}^3$ because the fan was not activated. During the lunch cooking time, the production started at 11:45 a.m. (point 1) An extremely rapid increase in PM_{2.5} concentration then occurred. The platform issued a recommendation to then turn on the fan in the kitchen for exhaust ventilation (point 2). The PM_{2.5} concentration in the kitchen dropped from 80.4 $\mu\text{g}/\text{m}^3$ to 46 $\mu\text{g}/\text{m}^3$ in 10 minutes. When the experimenter was stir-frying a dish, the PM_{2.5} concentration reached 101.4 $\mu\text{g}/\text{m}^3$, but it was able to fall to 71.6 $\mu\text{g}/\text{m}^3$ in 5 minutes without the fan operating and continuing to rise. The platform turned on the fan during the dinner cooking time, but the experimenter turned it off. During the cooking period, the PM_{2.5} concentration increased from 44.4 $\mu\text{g}/\text{m}^3$ to 152.2 $\mu\text{g}/\text{m}^3$ (point 4 - point 5). Points 6 - 7, where the experimenter boiled water in the kitchen and did not turn on the fan, revealed that the PM_{2.5} concentration significantly exceeded the standard (up to 115.8 $\mu\text{g}/\text{m}^3$).

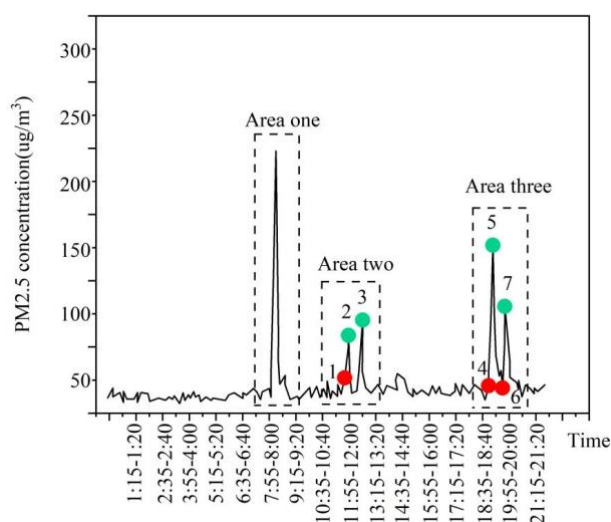


Figure 5. Variation curve of single-day pollutant concentration in kitchen

The hazardous gas alarm thresholds are shown in Figure 6. In addition to the pollutant monitoring function in the kitchen space, the hazardous gas alarm function is implemented and provides for an immediate alarm when the collected voltage value is greater than or equal to approximately 0.6.

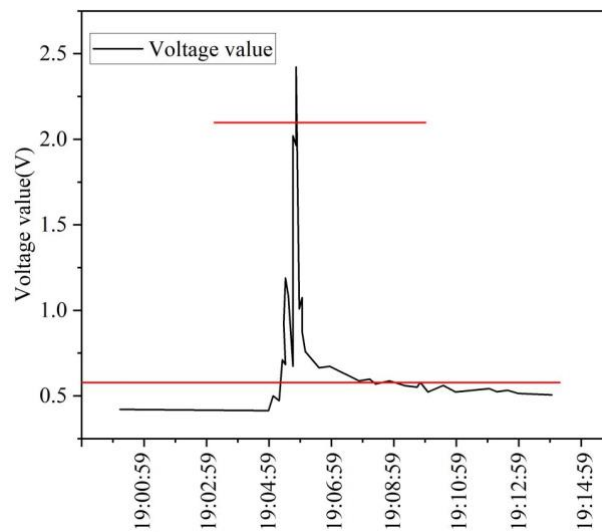


Figure 6. Dangerous gas alarm threshold

6 Conclusion

According to the building ventilation mechanism, combined with the Internet of Things (IoT) technology, this paper proposes a personalized intelligent ventilation system based on IoT architecture. And it utilizes the multi-sensor fusion algorithm and fuzzy controller to collect environmental data in real time and issue regulation commands to the fan to improve the indoor air quality. The results of the test and analysis show that the success rate of the tests of the intelligent ventilation system in this paper are more than 95%, and each part has strong stability and small error, which can meet the reliability requirements of the normal operation of the system. The intelligent ventilation system formulated in this study is in line with real-life scenarios, and verifies the feasibility of the platform function constructed in the study, the interaction function of module data and the control strategy of indoor air parameters.

References

- [1] Cao, S. J., Yu, C. W., & Luo, X. (2020). New and emerging building ventilation technologies. *Indoor and Built Environment*, 29(4), 483-484.
- [2] Hati, A. S. (2021). A comprehensive review of energy-efficiency of ventilation system using Artificial Intelligence. *Renewable and Sustainable Energy Reviews*, 146, 111153.
- [3] Lachhab, F., Bakhouya, M., Ouladsine, R., & Essaaidi, M. (2018). Towards an intelligent approach for ventilation systems control using IoT and big data technologies. *Procedia computer science*, 130, 926-931.
- [4] Liu, Z., & Jiang, G. (2021). Optimization of intelligent heating ventilation air conditioning system in urban building based on BIM and artificial intelligence technology. *Computer Science and Information Systems*, 18(4), 1379-1394.
- [5] Saber, E. M., Chaer, I., Gillich, A., & Ekperti, B. G. (2021). Review of intelligent control systems for natural ventilation as passive cooling strategy for UK buildings and similar climatic conditions. *Energies*, 14(15), 4388.

- [6] Mofidi, F., & Akbari, H. (2020). Intelligent buildings: An overview. *Energy and Buildings*, 223, 110192.
- [7] Zeng, W. (2024, July). Research on Intelligent Ventilation System Based on Digital Twins. In 2024 IEEE 3rd World Conference on Applied Intelligence and Computing (AIC) (pp. 1064-1069). IEEE
- [8] Chiu, C., Zhong, J., Gao, S., Luo, Z., He, Y., Liu, C., & Guan, P. (2024). Designing Sustainable Buildings for Personalized Participatory Space Teaching Buildings. In *E3S Web of Conferences* (Vol. 565, p. 03019). EDP Sciences.
- [9] Aboud, Z., & Abbas, S. S. (2023, September). Personalization of the interior space of dwelling unit. In *AIP Conference Proceedings* (Vol. 2806, No. 1). AIP Publishing.
- [10] Cooke, S. (2019). 3D turntables: humanizing architectural technology through hip-hop. *Technology|Architecture+ Design*, 3(2), 190-199.
- [11] Yamaletdinov, S. F. (2012). Ensemble of the main square in Krasnoyarsk-26: humanized space of totalitarian architecture. *Journal of Siberian Federal University. Humanities & Social Sciences*, 5(5), 742-755.
- [12] Wang, X., & Zhang, Z. F. (2013). Research on the restaurant space humanized design. *Advanced Materials Research*, 651, 579-583.
- [13] Fang, N. (2018). Research on humanization design of green building based on big data. In *E3S Web of Conferences* (Vol. 53, p. 04046). EDP Sciences.
- [14] Zhou, R. (2023). Exploration of interior design using humanistic design. *Frontiers in Art Research*, 5(4).
- [15] Gan, L. (2022). Analysis of humanized treatment of interior environment art design. *International Journal of Education and Teaching Research*, 3(4).
- [16] Jiang, H. (2023). The Combination of Architectural Art and Humanization. *Studies in Art and Architecture*, 2(4), 34-38.
- [17] Laboy, M. (2021). Humanizing Architecture. *The Architecture of Persistence: Designing for Future Use*.
- [18] Dagdanova, T. B., & Khadeev, M. B. (2021, April). Humanization of Living Environment Quality is Indicator of Quality Life (modern Danish architecture example). In *IOP Conference Series: Earth and Environmental Science* (Vol. 751, No. 1, p. 012024). IOP Publishing.
- [19] Wang, Q. (2024). The Application of Intelligent Architectural Design in Energy Saving and Sustainable Development. *Transactions on Social Science, Education and Humanities Research*, 7, 279-284.
- [20] Qiao, M., Shang, Y., & Lv, Y. (2023). Research on the Space Design Strategy of Pension Buildings Based on the Internet of Things Technology. *Journal of Civil Engineering and Urban Planning*, 5(8), 75-80.
- [21] Vijayan, D. S., Rose, A. L., Arvindan, S., Revathy, J., & Amuthadevi, C. (2020). Automation systems in smart buildings: a review. *Journal of Ambient Intelligence and Humanized Computing*, 1-13.

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