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RESEARCH ON ACTIVE DISTRIBUTED INTELLIGENT FIRE ALARM SYSTEM BASED ON INTERNET OF THINGS

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Abstract. In response to the problems of low response efficiency and poor accuracy of existing passive detection system, we have developed an active distributed intelligent fire alarm system based on the Internet of Things (IoT). This article introduces the overall design and control system structure of a new active distributed intelligent fire alarm system, the structural design of the active intelligent fire alarm unit, the working principle of the active intelligent fire alarm unit, and the application steps of the active distributed intelligent fire alarm system based on the Internet of Things. This new type of intelligent fire alarm system can actively, real-time, and continuously detect fires, detect them at the first time, and extinguish them autonomously. It can eliminate fires in their early stages and minimize losses to the greatest extent possible.

Key words: *intelligent fire alarm system; passive detection system; active detection system; Internet of Thing.*

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ИССЛЕДОВАНИЕ АКТИВНОЙ РАСПРЕДЕЛЕННОЙ ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМЫ ПОЖАРНОЙ СИГНАЛИЗАЦИИ НА ОСНОВЕ ИНТЕРНЕТА ВЕЩЕЙ

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Аннотация. Чтобы решить проблему низкой эффективности и точности реагирования существующих систем пассивного обнаружения пожаров, разработана активная распределенная интеллектуальная система пожарной сигнализации на основе Интернета вещей. В статье представлена общая структура системы проектирования и управления новой активной распределенной интеллектуальной системой пожарной сигнализации, структура активного интеллектуального блока пожарной сигнализации, принцип работы активного интеллектуального блока пожарной сигнализации и шаги по применению активной распределенной интеллектуальной системы пожарной сигнализации на основе Интернета вещей. Новый тип интеллектуальной системы пожарной сигнализации может в режиме реального времени непрерывно выявлять пожары, обнаруживать их с первого раза и тушить автономно. Это позволяет ликвидировать пожары на ранней стадии и минимизировать потери.

Ключевые слова: *система пожарной сигнализации; пассивные системы обнаружения; системы активного обнаружения; Интернет вещей.*

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Introduction

In today's social life, various factors that affect fire safety are constantly emerging, especially the occurrence of fire accidents that pose great harm to human life and property safety. Fire is a sudden and highly destructive disaster. In order to detect the fire situation in a timely manner, various fire alarm systems have been developed [1, 2]; With the emergence and development of IoT technology, more and more people are applying IoT to the field of fire safety, warning of fire hazards, preventing tragic fire accidents, and safeguarding human life and property safety [3, 4, 5, 6].

The fire alarm systems currently in circulation on the market belong to passive detection systems (each fire detector includes an independent smoke sensor and alarm), which means that after a fire occurs, the smoke particles generated freely diffuse into the detection range of the fire detector, and the fire detector can detect the fire information [7, 8, 9]. Although these devices can detect the occurrence of fires to a certain extent, their response efficiency and accuracy are often limited by open spaces and indoor and outdoor environments [10, 11]. Meanwhile, due to the limitations of monitoring technology principles, each room needs to be equipped with different numbers of fire detectors, resulting in a low utilization rate of fire detectors. Therefore, there is an urgent need to develop an active distributed intelligent fire alarm system based on the Internet of Things.

In recent years, with the development of IoT technology and the increasing improvement of fire safety, more and more people have begun to study IoT active fire safety systems. The active fire safety system of the Internet of Things collects the operation status of fire protection facilities and fire safety management information through information sensing devices, and realizes the collection, transmission, processing, and storage of data. The system connects various intelligent devices such as fire-fighting equipment, sensors, and monitors through IoT technology to achieve real-time monitoring and early warning of data [12].

At present, there are three main types of IoT active fire safety systems: 1) intelligent smoke detection system; 2) IoT combustible gas monitoring and automatic cut-off system; 3) Fire warning system based on video analysis. The working principle of the intelligent smoke detection system is to monitor environmental parameters in real time through photoelectric/ion smoke sensors. When the smoke concentration or temperature exceeds the threshold, the data is transmitted to the cloud platform through the gateway, triggering an audible and visual alarm, and linking the sprinkler system or smoke exhaust equipment [13]. The working principle of the IoT combustible gas

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monitoring and automatic cut-off system is to use semiconductor or catalytic combustion gas sensors (such as methane detectors) to monitor the concentration of combustible gases in real time. When the concentration exceeds the safety threshold, the system automatically closes the solenoid valve to cut off the gas source, starts the ventilation equipment, and sends an alarm message through the cloud platform [14]. The working principle of a fire warning system based on video analysis is to collect real-time video streams through cameras, and use computer vision and deep learning algorithms (such as YOLO object detection) to identify flame shapes and smoke dynamic features. After detecting abnormalities, sound and light alarms will be triggered, on-site screens will pop up, and fire extinguishing devices will be linked [15].

The intelligent smoke detection system achieves linkage control through multi-sensor fusion and wireless networking. The system is easy to install, does not require wiring, and has a lower false alarm rate than traditional smoke detectors. It can be widely used in residential areas, hotel rooms, factories (early fire warning), data centers (temperature sensitive areas), and shopping malls (linked smoke exhaust in densely populated areas). The IoT combustible gas monitoring and automatic cut-off system achieves rapid response through anti-interference design, multi-channel alarm, and active cut-off, and is suitable for flammable and explosive environments such as kitchens, gas pipeline rooms, chemical plants, gas stations (flammable gas storage areas), catering venues (liquefied gas use areas), and other fields. The fire warning system based on video analysis has good adaptability to complex environments through non-contact detection and dynamic recognition, and is suitable for large spaces such as forests, oil depots, warehouses, sports venues, etc.

Overall structure of an active distributed intelligent fire alarm system based on the Internet of Things

The developed active distributed intelligent fire alarm system based on the Internet of Things is shown in Figure 1, including the core control system, fire equipment sensor module, automatic fire equipment module, and user's mobile terminal. The core control system includes a fire cloud platform and a data processing module installed inside the building; The fire cloud platform includes MQTT message servers, business servers, and enterprise databases. The business servers are connected to the mobile terminal network for communication; The data processing module includes a core processor CPU, alarm speaker, wireless communication module, and network communication module. The wireless communication module, alarm speaker, and network communication module are all electrically connected to the core processor CPU; The data processing module communicates with the fire cloud platform network through the network communication module. The wireless communication module, network communication module, and alarm speaker are all electrically connected to the core processor CPU; Fire equipment sensors include temperature sensors, smoke sensors, and toxic gas detectors; Automatic fire protection equipment includes exhaust fans, electric window openers, and fire sprinklers.

The fire equipment sensor module and automatic fire equipment module are installed inside the house, forming an active distributed intelligent fire alarm system unit. Each unit is connected to the wireless communication module of the data sensor through wireless communication, and multiple units are connected to the core control system through the Internet of Things, forming a complete active distributed intelligent fire alarm system based on the Internet of Things.

In order to achieve long-distance and clear signal device information communication, wireless network communication adopts LORA wireless transmission method, and the wireless communication module is LORA wireless transceiver module. In order to ensure reliable communication between the local data processing module and the home fire cloud platform, and to avoid network failures in the event of a fire, the network communication module includes WIFI network module, 5G module, 4G module, and 3G module. In order to ensure the reliability of the data processing module, a power module is installed inside the data processing module to supply power to the module. The automatic fire protection equipment also includes an intelligent power

switch. In order to facilitate user operation and system viewing, the data processing module is also connected to a LCD touch screen module for displaying device information and interacting with users inside the house.

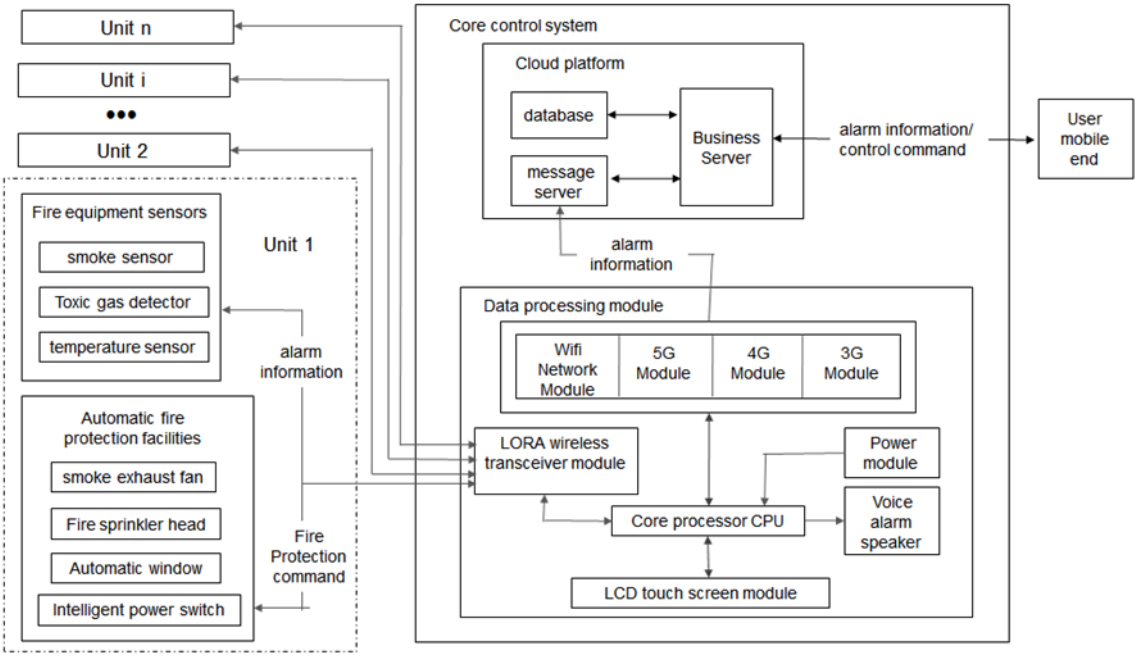


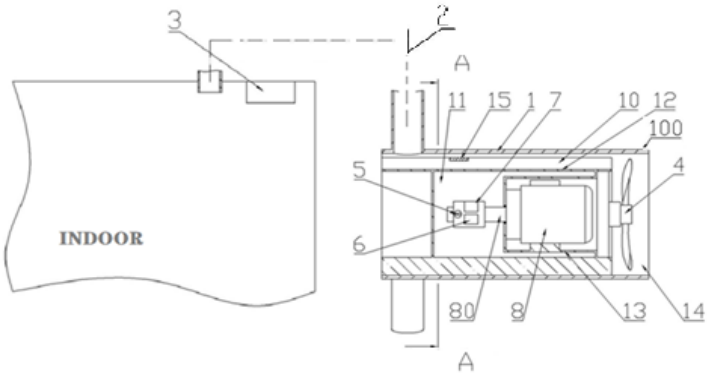
Fig. 1 - Overall structure of an active distributed intelligent fire alarm system based on the Internet of Things

Structural Design of Active Distributed Intelligent Fire Alarm System Unit

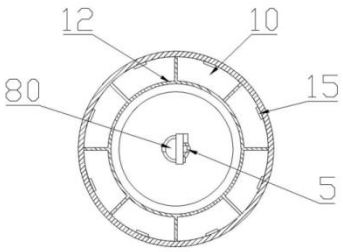
The intelligent fire IoT consists of multiple active distributed intelligent fire alarm system units, including gas gathering pipelines, detection systems, alarm systems, and aerodynamic devices. There is a transparent isolation layer between the gas flow channel and the equipment room. The working principle is to continuously draw indoor air into the air collection pipeline, use a detection system for real-time detection, and immediately control the alarm when smoke is detected. The detailed introduction is as follows:

As shown in Figure 2 (a), the active distributed intelligent fire alarm system unit includes a gas collection pipeline 100, a detection system, an alarm system, and an aerodynamic device 4. The gas collection pipeline 100 includes a main flue 1 and multiple branch flue 2 connected to the main flue 1. In order to facilitate installation and save materials, as shown in Figure 2 (b), the main flue 1 has a concentric sleeve structure, and the equipment room 11 is located in the center of the main flue 1. The transparent isolation layer 12 is a cylindrical pipeline, and the gas flow channel 10 is distributed in a circular shape around the outer circumference of the equipment room 11. One end of different gas flow channels 10 is connected to different branch flues 2, while the other end is connected to the outlet 14 of the main flue 1. The detection system is installed inside the gas collection pipeline 100 and includes sensors, a processor CPU 6, and a wireless communication device 7 that are electrically connected to each other. The sensors include a main infrared smoke sensor 5 and a reflector 15, which is installed on the gas collection pipeline 100. The alarm system includes a wireless communication device 7 and a wireless communication alarm 3; In practical use, the gas collection pipeline 100 connects the air inside the house.

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(a)



(b)

Fig. 2 - Structural Design of Active Distributed Intelligent Fire Alarm System Unit

In order to improve the efficiency of sensor usage and save costs, the equipment room 11 is equipped with a motor 8, and the active infrared smoke sensor 5 is connected and fixed to the output shaft 80 of the motor 8 instead of being installed in each gas flow channel 10. Equipment room 11 is a closed transparent cylinder, and a support column 13 extends from one end of the transparent cylinder facing the outlet 14 of the main flue 1 to the inside of the cylinder. The support column 13 is hollow inside, and its end facing the outlet 14 of the main flue 1 is connected to the outlet 14 of the main flue 1. The motor 8 is set in the support column 13, and the output shaft 80 of the motor 8 is coaxial with the cylinder and extends into the equipment room 11 through the support column 13. The output shaft 80 and the support column 13 can rotate relative to each other in a sealed fit, which can effectively dissipate heat from the motor. Multiple reflectors 15 (mirrors) are fixed on the inner walls of different gas channels 10. When the output shaft 80 rotates with the active infrared smoke sensor 5, the infrared rays emitted by the active infrared smoke sensor 5 pass through the transparent isolation layer 12 and shine on the reflectors 15 in different gas channels 10. The reflectors 15 reflect the infrared rays back to the receiver of the active infrared smoke sensor 5 to obtain the detection results.

Operation of Active Distributed Intelligent Fire Alarm System Unit

As shown in Figure 3, the developed active distributed intelligent fire alarm method mainly includes the following steps:

a. The aerodynamic device 4 draws indoor air into the air collection pipeline 100;

b. In order to locate the gas flow channels where smoke appears, it is necessary to sequentially number the N isolated gas flow channels surrounding the equipment room in advance.

b. 1. Motor 8 rotates at an angular velocity ω, driving the active infrared smoke sensor 5 to rotate. At the beginning of rotation, the gas channel number aligned with the active infrared smoke sensor 5 is the starting value n_0 of all gas channel numbers;

b. 2. active infrared smoke sensors 5 sequentially detect the presence of smoke in each gas flow channel during rotation, and send the detection data to the processor CPU 6;

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b. 3. The CPU 6 of processor records the time of receiving data and calculates the position information of the corresponding gas flow channel according to the formula based on the transmission time T of the detection data:

$$n = \left[\frac{\omega NT}{2\pi}\right] + n_0$$

Among them, n represents the number of the gas channel where smoke is detected, and represents the rounding symbol downwards.

In the actual working process, users can set the angular velocity ω of motor 8 to meet the detection requirements of different numbers of gas flow channels 10 and different sizes of main flue 1.

c. After obtaining detection data and calculating the number of the gas flow channel 10, the processor CPU6 controls the wireless communication device 7 to send alarm instructions to the alarm 3 corresponding to the branch flue 2 connected to the gas flow channel 10.

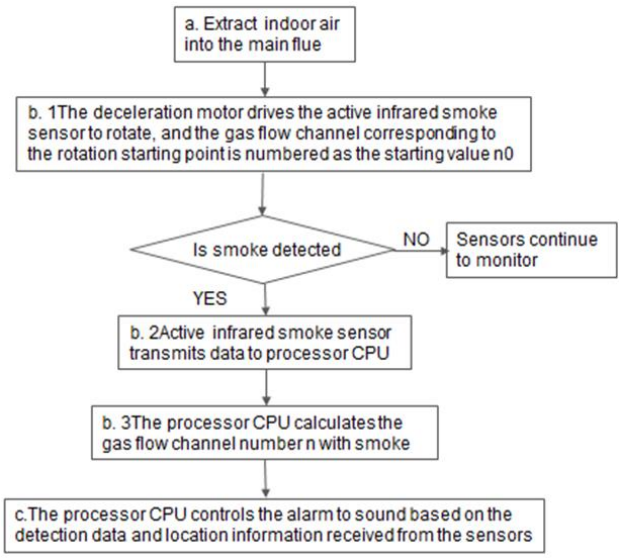


Fig. 3 - Process diagram of active distributed intelligent fire alarm system unit

Taking the design in Figure 2 as an example, there are N=8 gas flow channels surrounding the equipment room 11 of the main flue 1. The rotation direction of the output shaft 80 of the motor 8 is counterclockwise in Figure 2. In steps b.1-b.3, the gas flow channel 10 in the two o'clock direction in the figure is numbered n_0=1, and other gas flow channels 10 are numbered 2-8 in sequence. In step b.3, taking the speed $\omega = \pi/8(\mathrm{rad}\cdot s^{-1})$ as an example, if T=3s, then n=2, smoke is detected in the gas flow channel 10 with the number 2.

The developed active distributed intelligent fire alarm system adopts the form of motor 8 driving the active infrared smoke sensor 5 to rotate, so that the infrared emitted by the sensor circulates through the various gas flow channels 10 surrounding the equipment room 11, thereby periodically detecting whether there is smoke in the gas flow channels 10, achieving the effect of an active infrared smoke sensor 5 detecting all gas flow channels 10. On the premise of ensuring reliable detection, it greatly reduces the installation and maintenance costs of the sensor and reduces the waste of sensors.

Real time operation of the active distributed intelligent fire alarm system based on the Internet of Things

The method of using the active distributed intelligent fire alarm system based on the Internet of Things developed above, as shown in Figure 4, mainly includes the following steps:

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a. Multiple interconnected fire equipment sensors distributed in various locations actively monitor the indoor environment in real-time and send alarm information to the data processing module in case of a fire; The alarm information includes the fire equipment sensor's own number, the indoor temperature of the building where the fire occurred, the smoke concentration in the air, and the parameters of toxic gases present in the air.

b. The data processing module controls the alarm speaker to sound an alarm based on the received alarm information. At the same time, the data processing module sends corresponding firefighting instructions to the automatic firefighting equipment through the wireless communication module.

c. After receiving the fire command, the automatic fire-fighting equipment carries out indoor fire-fighting operations, including starting the fire sprinkler to extinguish the indoor fire source according to the fire command, starting the exhaust fan, and opening the window with an electric window opener to discharge indoor smoke and toxic gas; In order to reduce the danger caused by a fire, the intelligent power switch receives a fire command and cuts off the power supply to the indoor area where the fire occurred.

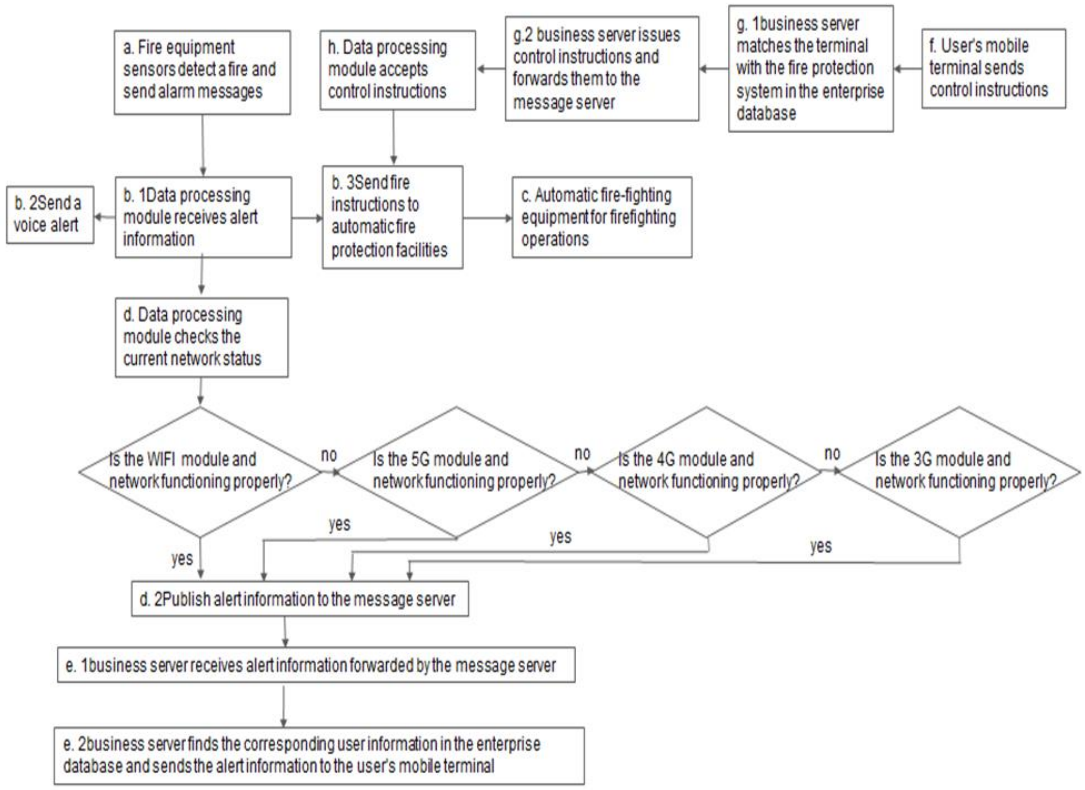


Fig. 4 - Real time operation flowchart of an active distributed intelligent fire alarm system based on the Internet of Things

d. During steps b and c, the data processing module issues alert information through the network communication module, and the MQTT message server receives and pushes the alert information to the business server; In order to ensure communication efficiency, when the data processing module issues alarm information to the MQTT message server, it first checks the connection status of the network communication module and prioritizes using the WIFI network module for communication. When the WIFI network cannot be used, the startup priority of other modules in the network communication module is in descending order of 5G module, 4G module, and 3G module.

e. After receiving the alert information pushed by the MQTT message server, the business server first searches for the corresponding house address and user contact information in the

enterprise database according to the number of the fire equipment sensor, and then sends the alert information to the user's mobile terminal according to the user's contact information.

In order to facilitate remote control of firefighting by users, they can control firefighting equipment through mobile terminals, specifically:

f. Users send control instructions to the business server through mobile terminals;

g. The business server searches for user data corresponding to the mobile terminal in the enterprise database, and publishes control instructions and user data, which are received by the MQTT message server and pushed to the corresponding data processing module through the network;

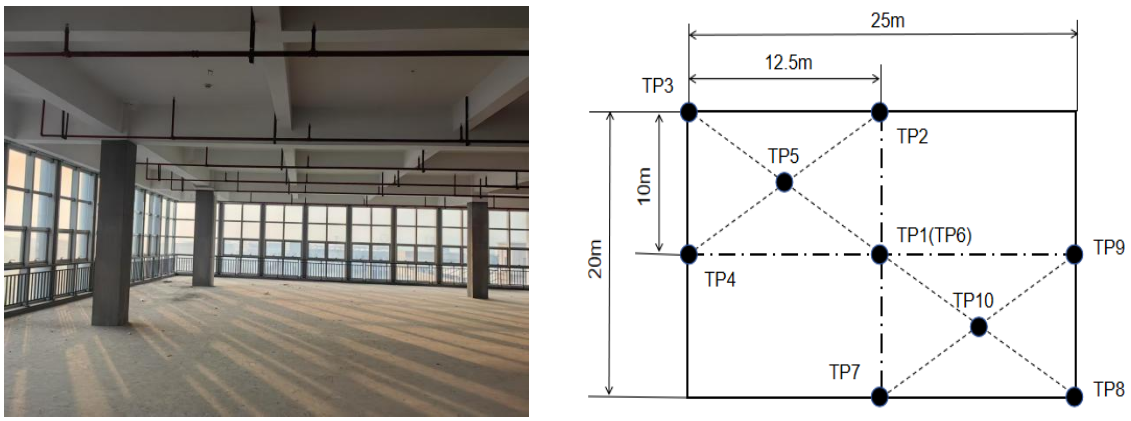
h. The data processing module sends corresponding firefighting instructions to the automatic firefighting equipment according to the control instructions, and the automatic firefighting equipment performs corresponding firefighting operations based on the firefighting instructions.

Test of activation time

A typical fire can be divided into four stages: pre ignition stage, visible smoke combustion stage, flame combustion stage, and intense combustion stage[16]. In the pre ignition stage, there is no obvious visible smoke formation, and any traditional fire detector cannot detect potential fire threats. However, our developed active suction smoke fire detector can already identify the decomposition particles of ignition materials that are invisible to the naked eye in the air and issue warning signals.

The sensitivity of traditional fire detectors is generally 5% -15% obs/m [17], while the sensitivity of active suction smoke fire detectors is 0.05% -20% obs/m, with the highest sensitivity being 100 times that of ordinary smoke detectors. Ensure the timeliness of alarm issuance, so that the fire can be eliminated in its early stages.

The detection time and alarm speed of smoke detectors are important indicators that users are concerned about. Therefore, we conducted a series of experiments to test the alarm time of active inhalation smoke fire detectors, ionization alarms, and photoelectric alarms. The experiment was conducted in a 500 square meters empty factory building, which is 25 meters wide, 20 meters wide, and 4 meters high; The doors and windows are closed, and the room temperature is 16 degrees Celsius; Various types of alarms are installed on the ceiling in the middle of the factory building; The active aspirated fire alarm system has 4 sampling tubes, each 25 meters long, with 5 evenly distributed sampling holes on each tube. The inner diameter of the sampling tube is 20mm, and the diameter of the sampling holes is 5mm; Two series of experiments were conducted: smoldering wood and flaming wood; The ignition source is placed in 10 different positions, as shown in the Figure 5.



(a) Test factory building (b) Test positions

Fig. 5 - Positions of the ignition source

Table 1 - Activation Time for photoelectric alarm,ionization alarm and active distributed intelligent fire alarm system

Test	Description	Photoelectric Alarm	Ionization Alarm	Active Distributed Intelligent Fire Alarm System
TP1	Smoldering wood	116	125	12
TP2		122	138	23
TP3		139	145	45
TP4		128	133	32
TP5		125	129	28
TP6	Flaming Wood	95	87	9
TP7		102	93	13
TP8		124	115	36
TP9		113	102	27
TP10		106	98	20

As shown in Table 1, in the smoldering wood test, the alarm time of our new developed system is 12-45 seconds, with an average alarm time of 28 seconds; The average alarm time of traditional photoelectric alarm is 124 seconds, while the average alarm time of ionization alarm is 133 seconds. In the flaming wood test, the alarm time of our new developed system is 9-36 seconds, with an average time of 21 seconds: while the average alarm time of traditional photoelectric alarms is 108 seconds, and the average alarm time of ionization alarms is 99 seconds.

Conclusion

This article studies an active distributed intelligent smoke alarm system and method. Through an aerodynamic device, the air in each room of the house is actively collected, and an active infrared smoke sensor installed in the flue is used for detection. Compared with traditional passive alarm methods, it can issue alarms faster, thereby reducing the losses caused by fires. At the same time, based on the alarm information transmitted from the fire sensor to the core control system, the location of the fire source can be confirmed in a timely manner according to the sensor number, which is helpful for extinguishing fires and identifying fire accidents afterwards.

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