Research on Adaptive Fault Diagnosis Control System of Audio Management Component Environment of Airborne Electronic Equipment

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Abstract

The system adopts adaptive control, and the controller of audio management component is directly applied to the controlled object. Through online calculation, the model is identified online by using the dynamic characteristics of the object, and the relationship between input and output variables is expressed. It can be corrected by entering and leaving data, which is actually to correct the controller. The initial rules of the controller are composed of default models. Through continuous self-reasoning learning, the controller is optimized to achieve data tracking, fast convergence, strong anti-interference ability and excellent performance. Combining intelligent control with adaptive technology not only expands the scope of adaptive system, but also provides an effective way for intelligent control. The environmental adaptive diagnostic control system uses adaptive technology to adjust the parameters, data and knowledge base of the controller. The system detects IO signal,

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AD signal and the status data sent by the sub-unit through the internal CAN bus according to the power-on self-check of the unit, and at the same time, it monitors all the status data in real time during the operation, judges the operation of each sub-component, gives an alarm in time and carries out protection control. Through the design of integrated detection module, the overall installation space of detection sensors is reduced, signal interfaces and connecting cables are reduced, and the overall adaptive diagnosis effect can be improved. Through the data recording and storage function, the system stores the operation information of each subunit, compares it with the built-in health data table, and prompts the maintenance information in time.

Keywords: Adaptive control, intelligent control, adaptive diagnostic control system.

1 Introduction

The environmental adaptive diagnosis system of the audio management component of airborne electronic equipment is mainly used for comprehensive detection of the environment inside and outside the cabin, which mainly includes the module for detecting the environment outside the cabin, the module for detecting the environment inside the cabin and the data acquisition unit [1–9]. The integrated environment detection module in the cabin is used to detect the temperature, relative humidity, overpressure inside and outside the cabin, harmful gas concentration, oxygen concentration and so on. The extravehicular environment detection unit can detect the data of extravehicular temperature, relative humidity and electromagnetic radiation in real time [10–16]. Among them, the cabin environment detection unit includes temperature and humidity sensors, various gas sensors, dust sensors, differential pressure sensors, etc., which can monitor the concentrations of CO, CO_2, NO_2, VOC, smoke and dust, O_2, temperature and humidity in the cabin, overpressure in the cabin and other data in real time. Firstly, according to the overall demand, the selected research method has carried out relevant technical research and practical application investigation at home and abroad, and analyzed the equipment status, development trend and technical development and application in the field of audio management component environmental control system in detail. Based on the basic principles of advanced performance and mature technology, the technical route selection and overall scheme design optimization were carried out. The data acquisition unit receives signals from sensors and alarms, processes the signals, uploads

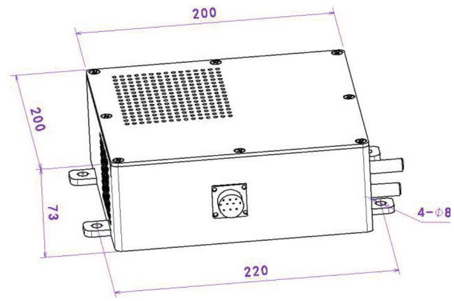

Figure 1 Outline drawing of environmental detection module of audio management component.

the collected environmental parameters in real time, and receives instructions such as self-inspection of electromagnetic radiation alarms [17–19]. Among them, the temperature and humidity adjustment module is widely used and has many faults. The module is mainly used for cabin temperature and humidity adjustment and has the functions of refrigeration, heating and dehumidification. It mainly includes electric scroll compressor, condenser, condensing fan, liquid storage dryer, expansion valve, evaporator, drainage pump, drainage solenoid valve, electric heater, etc. The appearance of the environmental detection module of the audio management component is shown in Figure 1.

2 Structural Strength Check Analysis of Audio Management Component

2.1 Mechanical Modeling Analysis

In order to ensure that the structural strength design of the environmental control system of audio management components conforms to the relevant national regulations and meets the requirements of environmental adaptability indexes related to vibration and shock, ANSYS workbench is used for mechanical simulation calculation. The mechanical simulation model of the environmental control host is shown in Figure 2.

The stress and deformation nephogram of the mechanical simulation of the environmental control host is shown in Figures 3 and 4.

The results of mechanical simulation show that the maximum displacement deformation of the environmental control host is 0.0003 mm, the maximum stress value is 39.8 MPa, and the yield limit of the materials used meets the strength design requirements.

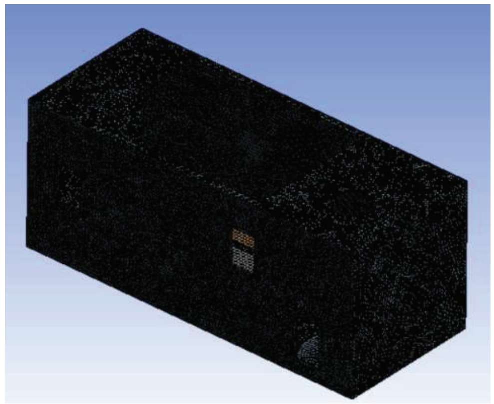

Figure 2 Mechanical simulation model of environmental control host.

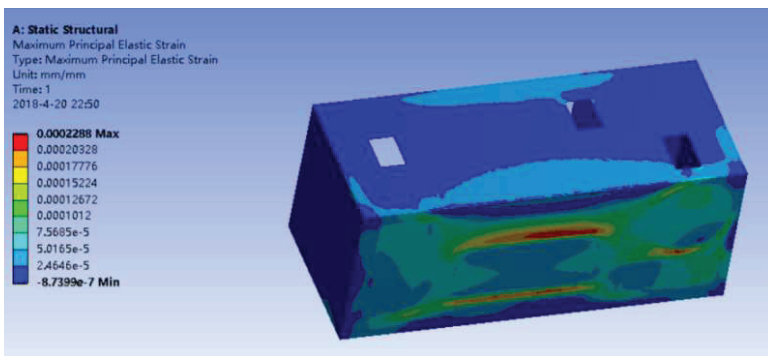

Figure 3 Deformation nephogram of environmental control host.

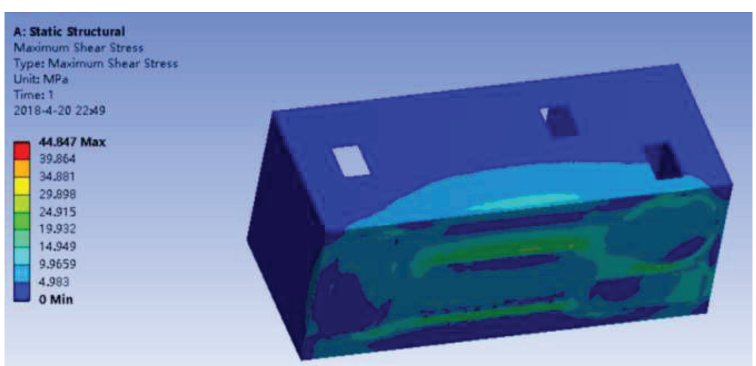

Figure 4 Cloud diagram of stress analysis of environmental control host.

2.2 Mechanical Strength Calculation

Check and calculate the main stress parts of the audio management component environmental control host. In the process of vibration and impact, the M12 bolts used in the four mounting feet are subjected to large shear force, so the shear force of the M12 bolts used in the installation is now checked. The impact acceleration is 40 g, the mass of environmental control device is m = 100 kg, and the number of screws is n = 4.

$$\mathrm{F} = \mathrm{m} \times \mathrm{a} = 100 \times 40 \times 10 = 40000\mathrm{N}$$

$$\tau = \frac{\mathrm{F}}{\pi \left(\frac{\mathrm{d}_0}{2}\right)^2 \mathrm{n}} = \frac{40000}{3.14 \times \left(\frac{0.012}{2}\right)^2 \times 4} = 88.5\ \mathrm{MPa}$$

The bolt material is A2-70, $\delta\mathrm{s} = 700$ MPa, and the safety factor S = 3.0. According to the third strength theory, $[\tau] = \delta\mathrm{S}/2\mathrm{S} = 700/10 = 117$ MPa, $\tau < [\tau]$, and the shear force meets the use requirements.

3 Reliability Modeling Analysis of Environmental Adaptive Fault Diagnosis System

The reliability model of airborne electronic equipment shows the relationship between system reliability and component unit reliability, which is expressed in mathematical analytical form and called reliability mathematical model [20]. This relationship is expressed in graphic form and is called reliability block diagram. The purpose of establishing reliability model is to allocate, predict and evaluate the reliability of the system. According to the information of reliability model, working cycle and task time, mathematical expressions or computer programs are drawn up. Using these expressions and programs and the corresponding data of failure rate and success probability, basic reliability and task reliability can be allocated, predicted and evaluated. According to the Reliability Prediction Manual of Electronic Equipment (GJB/Z299C), the distribution and frequency of mechanical parts faults and previous design experience, and based on the reliability test of audio management module, the reliability calculation is carried out. From the calculation results of electrical control failure of audio management module, it can be seen that the mean time between failure MTBF of this diagnostic control system is 1203 h, which is greater than the overall requirement of 1000 h. Meet the requirements of reliability index. The reliability model should include a reliability block diagram and a reliability mathematical model, so

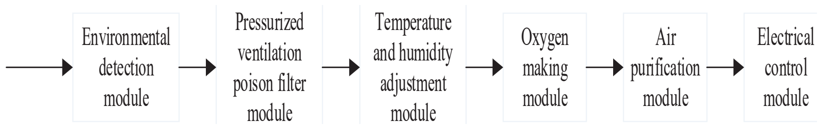

Figure 5 Basic reliability block diagram.

as to express the reliability logical relationship and quantitative relationship between the environmental adaptive system and the constituent units. The basic reliability block diagram is shown in Figure 5.

The basic reliability is a series model, and the mathematical expression of reliability is:

$$R_s(t) = \prod_{i=1}^{n} R_i(t) \tag{1}$$

Where:

$R_s(t)$ – System reliability.
$R_i(t)$ – Reliability of i(i = 1,2...n) th subsystem.

When the life distribution of each subsystem is exponential, that is $R_i(t) = e^{-\lambda_i t}$, then

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \tag{2}$$

Where:

λ_s – System failure rate.
λ_i – Failure rate of each subsystem.

Mean time between failure MFBF of the system is:

$$MTBF_s = 1/\lambda_s \tag{3}$$

3.1 Maintainability Modeling

Maintainability model is a physical model and a mathematical model established by analyzing and evaluating system maintainability. In the stage of engineering development, the maintainability model is established by using the block diagram method of system function hierarchy in physical model. The adaptive fault test of audio management component can automatically test the main performance of equipment according to the programmed program, and can also be manually operated if necessary. When the self-test system fails, it will not affect the normal operation of the equipment. For example, in the electrical design, the possible faults of the equipment are

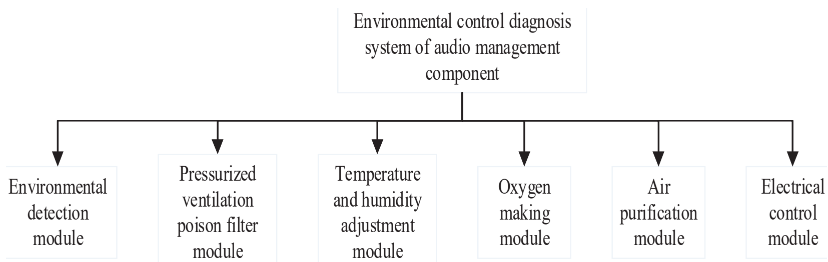

Figure 6 MTTR allocation model.

analyzed, and fault prompts and fault alarms are provided. When the system fails, the equipment can automatically detect the failed parts and display them. The audio management component adaptive diagnosis system needs a certain average system repair time. Used to check whether the working state of the component units is normal at the beginning of unit power-on; It is used to periodically and continuously carry out condition monitoring and fault diagnosis of the unit during the execution of the task; It is used for the maintenance inspection of the unit when it is not working, to check and confirm the faults in the work, and to further isolate the faults.

The audio management component environment adaptive fault diagnosis system allocates MTTR indicators according to each module, and the MTTR allocation model is shown in Figure 6.

3.2 Maintainability Prediction

The required average repair time of the system is 1h. The failure rate of each module of the equipment can be predicted from the reliability, and the maintainability of the equipment system can be predicted from the Mcti(min) of each module and the distribution of the average maintenance time as shown in Table 1.

If the system consists of n subsystems, and the failure rate and mean time to repair (MTTR) of each repairable subsystem are known, the mean time to repair of the system is:

$$\overline{M_{ct}} = \frac{\sum_{i=1}^{n} \lambda_i \overline{M_{cti}}}{\sum_{i=1}^{n} \lambda_i} \tag{4}$$

Where:

λ_i – Failure rate of I-th subsystem.
Mcti – Average repair time of I-th subsystem.
Mct – Mean time to repair system.

Table 1 Maintainability prediction

Functional Module	λi 10^{-6}/h	Operation Time of Subsystem Maintenance Activities (min)					Mcti (min)	Mcti $\times\lambda i$
		Position	Isolation	Resolve	Replace	Test		
Environmental monitoring module	254	2	2	10	10	2	39	9906
Ventilation and pressurization poison filter module	135	2	2	10	10	3	50	6750
Temperature and humidity adjustment module	165	2	2	10	10	3	62	10230
Oxygen making module	87	2	2	5	10	3	40	3480
Air purification module	50	1	2	4	5	2	27	1350
Electrical control module	140	3	2	3	5	2	25	3500
Total	831						42.4	35216

The predicted value of instruction system and average repair time is 42.4 min, and the predicted value of average repair time is less than the index value of 60 min.

According to the actual performance requirements of airborne electronic equipment, it is stipulated that the average repair time of audio management components at the grass-roots level is not more than 60 min, and the device has the ability to quickly repair faults at the component level. Through BITE and airborne test instruments, the component-level rapid diagnosis is completed, the LRU is located, and the faulty LRU is replaced to complete the component-level maintenance. The electromechanical LRU (repairable) replaced at the component level is sent to the relay level, and the LRU sent for repair is further diagnosed, and the fault is isolated to the SRU and replaced. If the reliability is not considered, the repair time will be further shortened to less than 30 min, and further attempts can be made in this respect in the later stage.

4 Adaptive Detection and Analysis of Audio Management Component Environment

In-cabin environment detection of audio management module adopts online real-time sampling detection, and the sampling interval is 5 s. Among them, according to the relevant provisions of the national standard, according to the

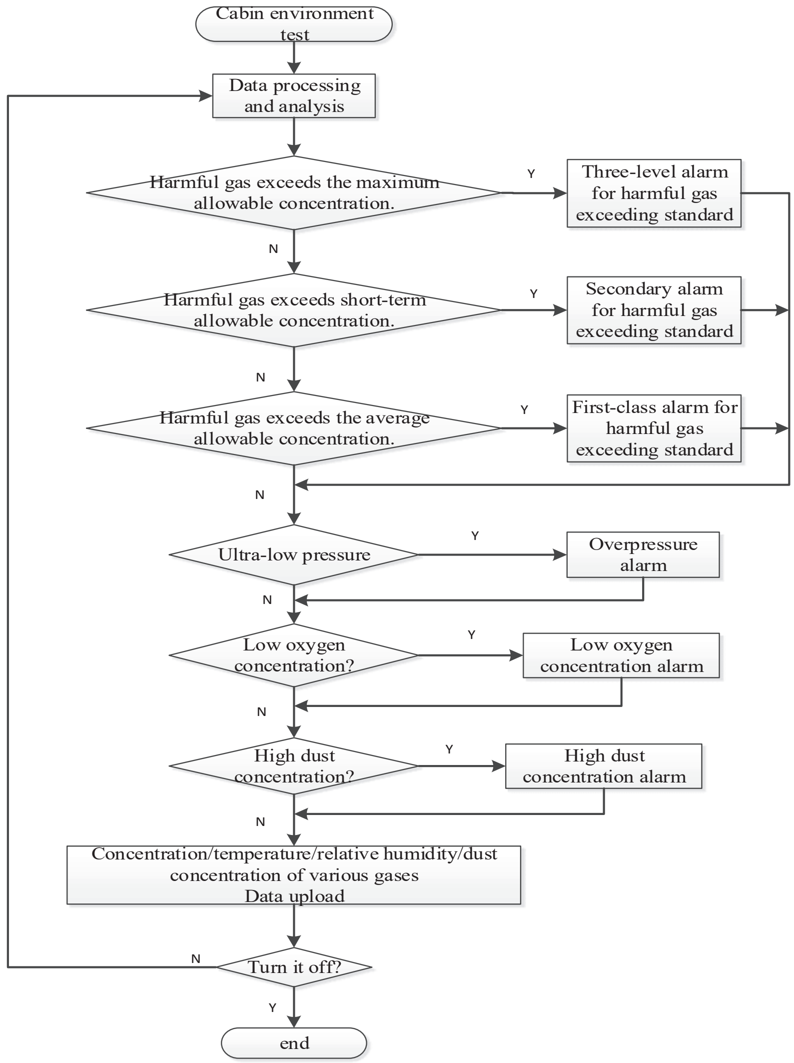

Figure 7 Flow chart of on-line real-time sampling detection for cabin environment detection.

time-weighted average allowable concentration, short-time contact allowable concentration and maximum allowable concentration, the alarm levels are divided into primary alarm, secondary alarm and tertiary alarm in turn. The flow chart of on-line real-time sampling detection for cabin environment detection is shown in Figure 7.

4.1 Temperature and Humidity Detection

According to the general requirements, the system should have the ability to detect temperature and humidity inside and outside the cabin [21]. The integrated temperature and humidity sensor is selected, and its sensor parameters are shown in Table 2. Among them, the results of the temperature and humidity measurement error range of the system are shown in Figures 8 and 9. The error range of relative humidity measurement error results at different temperatures is shown in Figure 10.

Table 2 Temperature and humidity sensor parameters

Sensor Name	Detection Parameter	Detection Principle	Measuring Range	Standard Error	Maximum Error
Humiture	Temperature	Platinum resistor	$-60°C \sim 120°C$	$\pm 1°C$	$\pm 1.5°C$
sensor	Relative humidity	Aluminium oxide	$0 \sim 100\%$	$\pm 3\%$	$\pm 5\%$

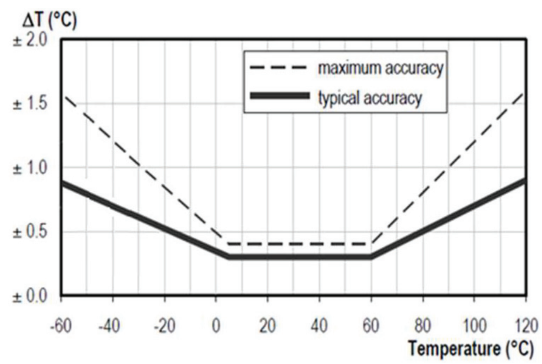

Figure 8 Error range of cabin temperature measurement.

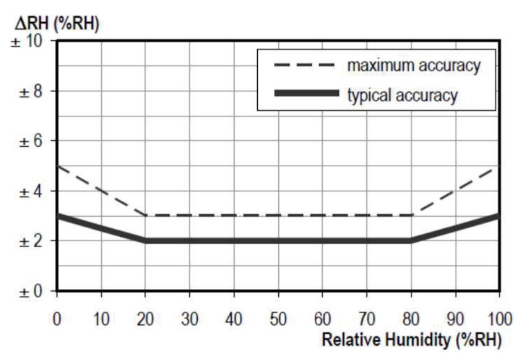

Figure 9 Error range of relative humidity measurement.

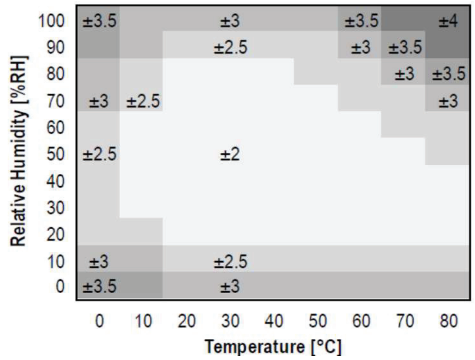

Figure 10 Error range of relative humidity measurement at different temperatures.

4.2 Electromagnetic Radiation Monitoring and Alarm

Electromagnetic radiation detection adopts "single GM counter time to count wide range radiation detection method". The GM drive module is realized by hardware, which will drive the GM counter to work according to the specified time sequence and output the measurement results under the control of the single chip microcomputer, and the single chip microcomputer can calculate the dose rate through appropriate processing. When particles are incident, ionization occurs in the GM tube. Under the action of high voltage, the ionized positive and negative particles drift to the two poles of the GM tube and produce avalanche discharge. After the detection circuit of the driving module detects the discharge, the high voltage of the GM tube is immediately reduced, and the GM tube stops discharging. The generated particles drift to the two poles at a lower voltage until they are completely absorbed. The driving module reduces the high voltage of GM tube, records the waiting time before the particle incident, and makes corresponding treatment. When the particles produced by the GM tube are completely absorbed, the driving module immediately raises the working voltage of the GM tube, and the GM tube resumes its detection function.

4.3 Selection of Gas Sensor and Design of Signal Processing Circuit

Based on the overall technical requirements and the limit standard of harmful gas concentration in the cabin, the integrated environmental detection module in the cabin adopts an integrated structure [22–24]. In order to meet the requirements of miniaturization, high sensitivity, fast response, low power

Table 3 Sensor selection

Sensor Category		Detection Principle	Measuring Range	Resolution Ratio
Carbon monoxide sensor		Electro-chemistry	$0 \sim 500$ppm	0.5 ppm
Oxygen sensor		Zirconium oxide	$0 \sim 100\%$	0.1%FS
Carbon dioxide sensor		Infrared	$0 \sim 20000$ ppm	10 ppm
Temperature and humidity sensor	Temperature	RTD	$-60°C \sim 120°C$	$\pm 1°C$
	Humidity	Aluminium oxide	$0 \sim 100\%$	$\pm 3\%$FS
Nitrogen dioxide sensor		Electro-chemistry	$0 \sim 100$ ppm	± 0.1 ppm
Ammonia sensor		Electro-chemistry	$0 \sim 100$ ppm	± 0.1 ppm
Hydrogen sulfide sensor		Electro-chemistry	$0 \sim 200$ ppm	± 0.1 ppm
Sulfur dioxide sensor		Electro-chemistry	$0 \sim 100$ ppm	± 0.1 ppm
VOC sensor		Photoion	$0 \sim 500$ ppm	± 1 ppm
Dust sensor		Optical densimeter	$0.01 \sim 2$ mg/m^3	± 0.01 mg/m^3
Differential pressure sensor		Strain type	$0 \sim 1000$ Pa	$\pm 1\%$FS

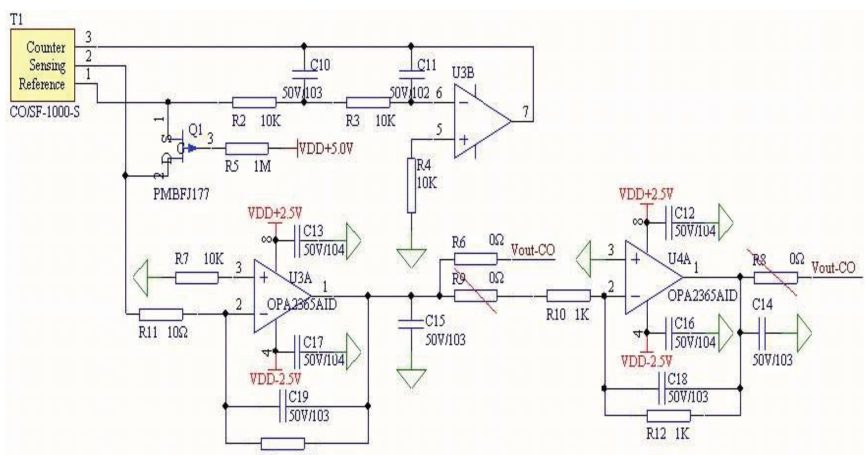

Figure 11 Circuit diagram of different CO detection signal processing.

consumption and wide temperature working range of sensors in the integrated diagnostic system for environmental control of audio management components of airborne electronic equipment, the design requirements of sensors in the integrated system are shown in Table 3. The CO detection signal processing circuit is shown in Figure 11. The NO_2 detection signal processing

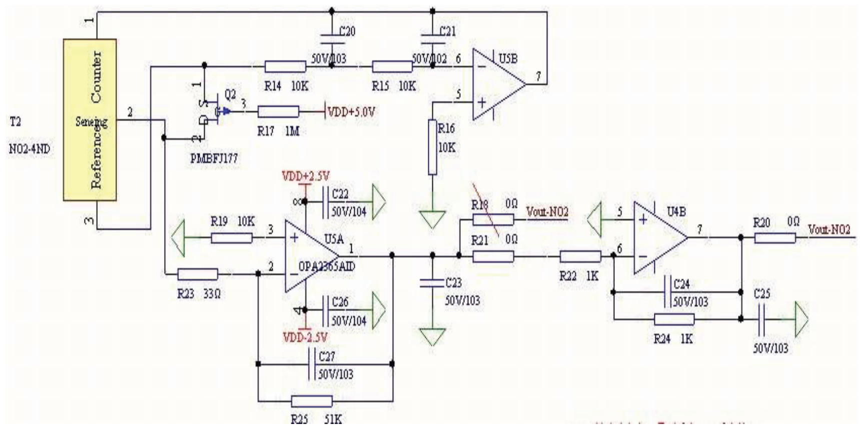

Figure 12 Different NO_2 detection signal processing circuits.

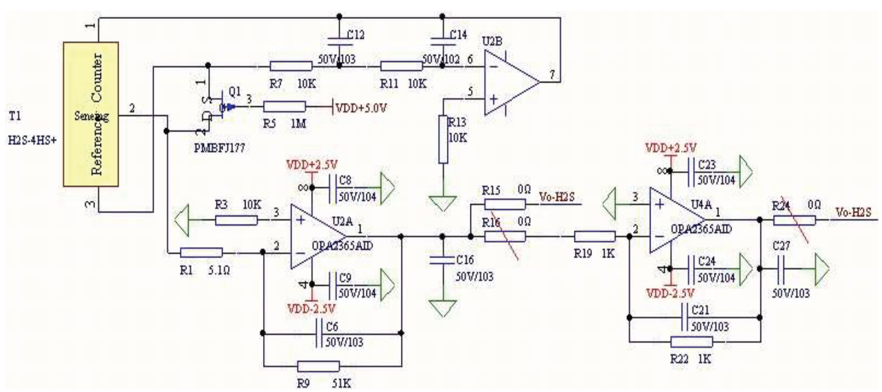

Figure 13 Different H_2S detection signal processing circuits.

circuit is shown in Figure 12. The H_2S detection signal processing circuit is shown in Figure 13; The SO_2 detection signal processing circuit is shown in Figure 14.

In order to avoid the zero drift and extreme temperature drift of the sensor, a balanced bridge circuit with "in-bridge compensation method" is designed. At the same time, the sensitivity compensation is realized by using the negative temperature characteristics of diodes and adding multiple semiconductor diodes. The nonlinearity is compensated for the second time in software processing, so that the accuracy and sensitivity of the sensor in detecting the whole temperature range are realized. The hardware design block diagram of sensor temperature compensation is shown in Figure 15.

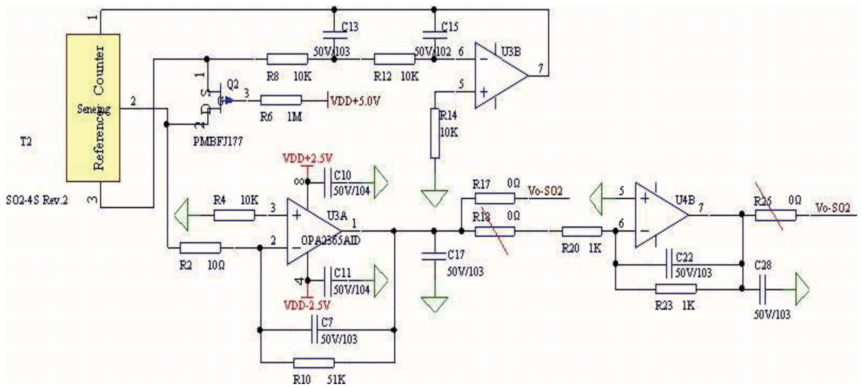

Figure 14 Different SO_2 detection signal processing circuits.

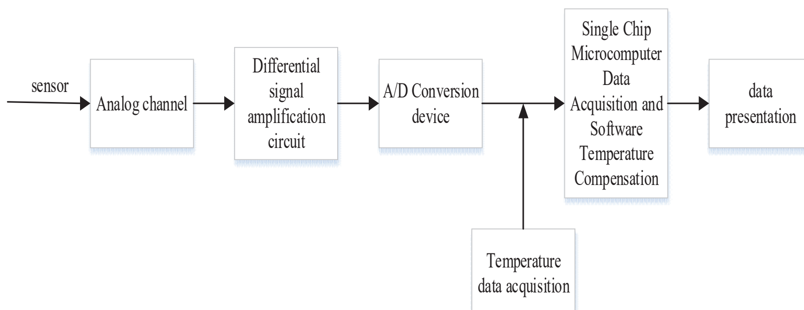

Figure 15 Hardware design block diagram of temperature compensation for different sensors.

4.4 Results Analysis of Environmental Adaptive Gas Purification System

Aiming at the shortage of air purification in the cabin by ventilation in the audio management module of airborne electronic equipment at present, this system studies the addition of internal circulation air purification function on the basis of ventilation and ventilation function to remove harmful gases in the cabin, and the purification system can be effectively regenerated and used for a long time.

During the internal circulation adsorption purification, the air in the cabin is sucked by the fan, and the dust and large-particle impurities in the air are pretreated by the primary filter, and then the harmful gas is filtered by the regenerative purification filter element, and the harmful gas concentration in the cabin is reduced to the required range through continuous circulation

Table 4 Sensor oxygen concentration limit

Altitude/m	Lower Limit of Oxygen Concentration/%	Upper Limit Value of Oxygen Concentration/%
0	19	23
1000	22	26
2000	25	29
3000	29	33
4000	34	38
5000	39	43
6000	45	55
7000	56	62
8000	68	78
9000	85	86
10000	96	97

filtration. Regenerative purification filter element adopts the principle of temperature change adsorption/desorption, and the special adsorbent contained in it can adsorb and remove carbon dioxide, carbon monoxide, nitrogen dioxide, ammonia, hydrogen sulfide, sulfur dioxide, VOC and other harmful gases at room temperature. When the filter element is saturated, it can be regenerated by regeneration function. During regeneration, it is heated by built-in microwave heating, and harmful substances are desorbed at high temperature, and then pumped out of the cabin by vacuum pump. The adsorption capacity of the purification filter element is restored.

The lower limit value of oxygen concentration is determined according to the altitude. When the cabin concentration is lower than the lower limit value, an alarm will be given, and when the oxygen concentration is higher than the upper limit value, the alarm will be lifted. The specific research results are shown in Table 4.

For the cockpit of airborne electronic equipment, a new type of special adsorbent is used for circulating purification and filtration in the air purification system. The cabin is designed with a space of 4 m^3, and the calculation requirements of adsorbent loading are shown in Table 5.

The adsorption capacity of adsorbent is about 3%, so the total adsorbent loading is:

$$(16.8 + 0.08 + 0.08 + 0.012 + 0.02 + 0.02 + 0.08)/0.03 = 570 \text{ (g)}$$

The more adsorbent loading, the more harmful substances can be absorbed by the purification filter element at a time, and the longer the

Table 5 Calculation of adsorbent loading

Harmful Substance	Initial Concentration (mg/m^3)	Purification Target Concentration (mg/m^3)	Required Adsorption Capacity (mg/m^3)	Adsorption Capacity of 4 m^3 Cabin Space(g)
CO_2	4500	300	4200	16.8
CO	20	0	20	0.08
NH_3	20	0	20	0.08
NO_2	3	0	3	0.012
SO_2	5	0	5	0.02
H_2S	5	0	5	0.02
VOC	20	0	20	0.08

Table 6 Purification performance of absorption and purification system for harmful substances

Harmful Substance	Initial Concentration (mg/m^3)	Concentration After 30 min Natural Attenuation (mg/m^3)	30 min Natural Attenuation Rate %	Start the Purification System and Control the Concentration Within 30 min (mg/m^3)	Purification Efficiency %
CO_2	4500	4430	1.56%	300	93.23%
CO	20	19.6	2.00%	1.8	90.82%
NH_3	20	19.3	3.50%	1.6	91.71%
NO_2	3	2.9	3.33%	0.2	93.10%
SO_2	5	4.8	4.00%	0.3	93.75%
H_2S	5	3.2	36.00%	0.3	90.63%

continuous purification time of the filter element at a time. Considering the design margin and the installation space, the adsorbent loading of the purification filter element is designed to be 1000 g.

If the completion time of single purification is designed as 10 min, the required air volume for purification cycle is:

$$\mathrm{Qj} = 4 \times 60/10 = 24\mathrm{m}^3/\mathrm{h}$$

The designed purified circulating air volume is 30 m^3/h.

The experimental simulation shows that the purification efficiency of the air purification system for harmful gases within 30 min minutes is greater than 93%. Design and calculation of purification system are as follows:

The purification capacity test of the purification system for different harmful substances is shown in Table 6, in which the initial concentration of harmful substances refers to the time-weighted average allowable concentration limit in the harmful gas concentration limit in the cabin of airborne electronic equipment.

5 Conclusion

The design idea of integrated design and modular construction is adopted in the interior environment control system. In this paper, the adaptive fault diagnosis control system is used to deeply analyze the functions of each module, the performance of each component, the structural characteristics and the relationship between them. Through the integration of functions and structures, the overall integrated design of the cabin environmental control system is realized, which reduces the volume and weight of the system and improves the comprehensive efficiency of the system. Compared with traditional methods, such as expert system and fuzzy C clustering, it has higher reliability and security. According to the architecture and technical system of the vehicle integrated electronic system, the functional units of the interior environment control system, such as environmental detection module, electrical control module and execution module (pressurization and ventilation, anti-virus filtration, temperature and humidity adjustment, oxygen generation and air purification), are integrated into an integrated system through the in-vehicle bus, and the system function integration and information sharing are realized. It can detect the indoor environment temperature and humidity, harmful gases, smoke/dust, and the outdoor environment temperature and humidity, nuclear, chemical and biological weapons, and realize the functions of refrigeration, heating, dehumidification, purification, ventilation, pressurization and poison filtration, oxygen generation, differential pressure inside and outside the cabin, etc. At the same time, it has the ability of electromagnetic radiation protection.

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