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Design and Availability Research of a Flammable and Explosive Volatiles Monitoring and Early Warning System (FEVMEW) for the Bus Crowded Places

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Abstract

In order to reduce the arson or accidental fire losses, we developed a gas sensitive detector used for the rapid detection and early warning of flammables in crowded places such as buses. A MEMS (Micro-Electro-Mechanical System) based thin film semiconductor was fabricated as the gas sensor. To obtain the target gas selective response, the surface of the sensitive film was modified with highly active metal catalytic nano-particles. Thus the anti-interference ability was improved and the false alarm rate was effectively reduced. Furthermore, the modular embedded system for information acquisition and transmission was developed. Supported by the Airflow Precision control system (APs), the rapid warning of volatile gas of flammable substances was realized. Experiments showed that RAs has satisfied selectivity to volatiles of usual flammable liquid, such as the output voltage reaches 3 V (0 - 3.3 V). With simulation about the actual installation state in bus, MWs sounds an alarm at 2 minutes after splashing 50 mL 92# petrol to the floor. For the last two years, FEVMEW has been integrated into more than 4000 buses in Hefei. This design has been proved feasible according to the actual operation.

Keywords

Flammable and Explosive Volatiles, Monitoring and Early Warning, Bus Crowded Places, Gas Sensitive MEMS Chip, Airflow Regulating

1. Introduction

The intelligent monitoring technology of inflammable and explosive in public security is the key guarantee for national security, social stability and people's happiness. In the outline of "national medium & long term Sci. & Tech. development layout 2006-2020" [1], public safety is the tenth of the key areas and priority themes. Among them, the monitoring device is required for the themes (1) and (4), as the terminal of the emergency information platform. The early warning information can be collected and issued, and concurrently, prevention and rapid disposal can be easily implemented, to minimize the loss of life and property.

For the bus open environment, it is difficult to carry out security inspection on items carried by passengers. Thus, arson by inflammables or accidental fire can cause more casualties. The readily available inflammables are mainly liquid fuels, easy to flow and diffuse, such as petrol, 200# solvent oil, and banana oil. whereas, using conventional combustible gas alarm [2] [3] [4] to monitor the slight leakage or spillage, there are problems of long response time and small monitoring area.

A flammable gas detector based on MEMS semiconductor [5] [6] [7] gas sensor is developed to rapidly monitor the volatile gas of flammable liquid in the bus compartment, warning the driver and prompting the location. The response speed and coverage of the device are verified by experiments in simulated bus compartment environment.

2. The FEVMEW Configuration

The FEVMEW includes Master control Terminal (MT), multiple Air supply Terminals (AT) and Receiving Terminals (RT), shown in **Figure 1**. The RT includes a Sub-Controller (SC), the special Gas Sensor (GS) and Air Exchange device (AE). The AT includes a Sub-Controller (SC) and Air Exchange device (AE). The MT includes the Master-Controller (MC), Early Warning Expert System (EWES), Display and alarm Device (DD). The RT and AT are connected to the MT by bus interface or WiFi for power supply, data exchange, and control.

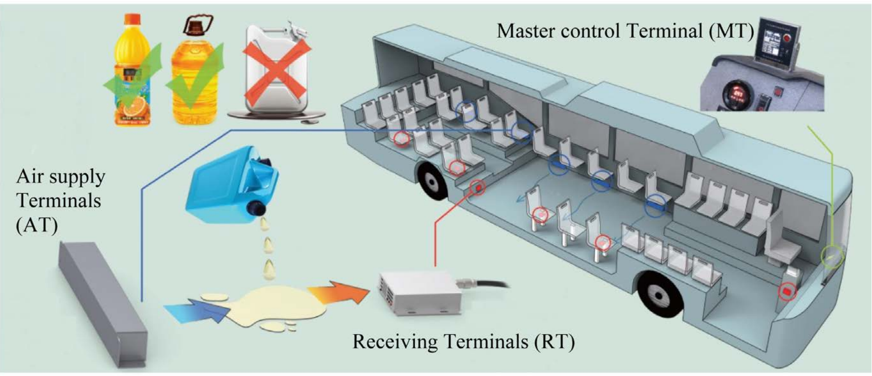


Figure 1. The FEVMEW configuration.

3. The Gas Sensor Design

3.1. Sensitive Unit Package Design

The semiconductor gas sensor microchip is fabricated by MEMS technology. It's composed of support bracket, silicon substrate with platinum pad and metal package, as in **Figure 2**. The micro-heater and interdigital electrode are integrated in the support bracket. After that, the bracket is fixed on the silicon substrate by a cantilever beam. The external cables of the micro heater and interdigital electrode are led out through the platinum pad welding wire.

The interdigital electrode is covered with metal oxide semiconductor nano films which are sensitive to target gas for flammable liquid detection. When the interdigital electrode had been heated to more than 200˚C by micro heater, the metal oxide semiconductor nano films could absorb target gas then their electronic conductivity of increased according to gas concentration. Gas sensor microchip is soldered to four gold wires by conductive silver paste so it can be hung up to avoid other components overheating and to reduce power consumption, as shown in **Figure 3(a)**. By using spot welding technology, the other ends of gold wires are soldered to metal rods on a pedestal, as shown in **Figure 3(b)**. The pedestal and an outer shell with air vent are fastened together to be a gas sensor, as shown in **Figure 3(c)**.

3.2. Signal Acquisition Circuit Design

Sensing & communication module provides power supply to the micro heater of gas sensor. The resistance variation of interdigital electrode is converted to voltage variation for Analog-to-Digital Converter (ADC) sampling by STM32F103.

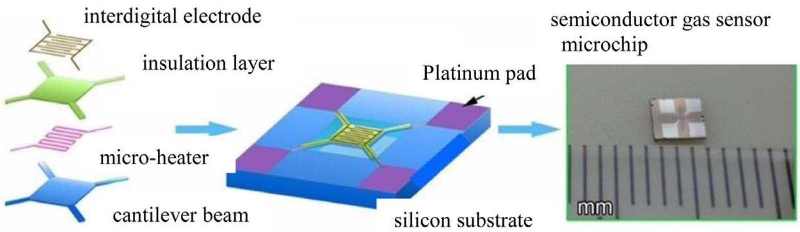
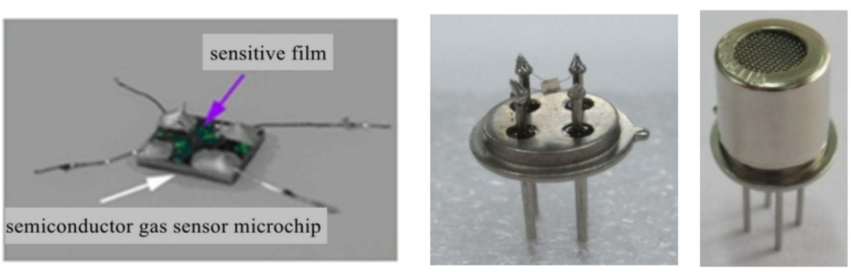


Figure 2. The gas sensitive chip formation.



(a) (b) (c)

Figure 3. The MEMS based gas sensor processing. (a) Lead process; (b) welding procedure; (c) sensor package.

Sampling results of several sensing & communication modules is send to display & alarm module through the wireless digital communication.

According to the gas sensor can carry out large range measurement, resistance sampling circuit consists of two parallel signal pathways, in **Figure 4**. Transformation coefficient K1 of first signal pathway to pin ADC1 is equal to 10, K2 of second signal pathway to pin ADC2 is equal to 1. When the concentration of trace flammable gases rise, ADC1 could detect it. Higher concentration of flammable gases will saturate ADC1, so that ADC2 is useful to bypass the alarm when decreasing concentration has been detected.

4. Distributed Embedded Systems Design

Aiming at the open environment on the bus etc., a distributed embedded system is adopted to build the whole FEVMEW. The FEVMEW mainly includes three major systems, as Receiving and Acquisition system (RAs), Master control and Warning system (MWs), and Airflow Precision control system (APs). Relying on the RT, the RAs is used for data collecting and exchanging data, and command receiving. Based on the MT, the MWs is used for arbitration, inference, master control and report. Depending on the MT, RT and AT, the APs is used for airflow microenvironment precision Regulating, to get reliable and fast alarm response.

4.1. Receiving and Acquisition System (RAs) Design

RAs is powered by 24 Vdc of vehicle battery. Power module generates 5 Vdc and 3.3 Vdc to supply gas sensor, signal processing circuit, MCU, airflow controller and wireless transmitting module. A/D converter of MCU samples output voltage of signal processing circuit. By adjusting PWM output of GPIO, MCU controls input power of airflow controller, whose rotation rate is detected by MCU for closed-loop control. MCU send gas concentration value via wireless transmitting module controlled by SPI interface, as shown in **Figure 5**.

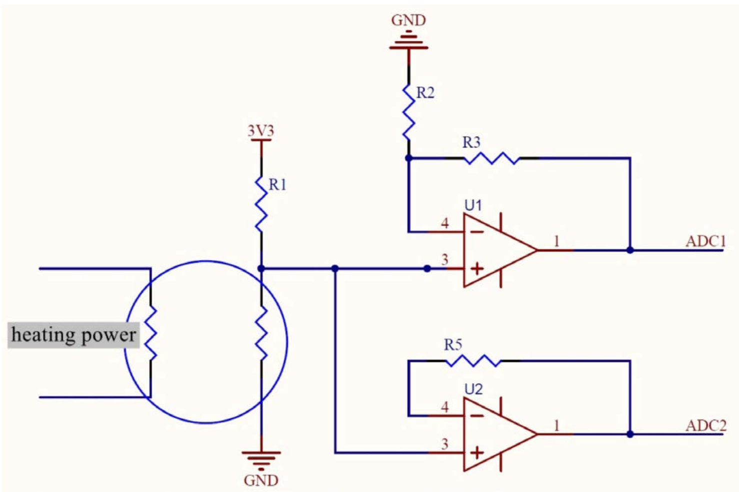


Figure 4. Signal acquisition circuit design.

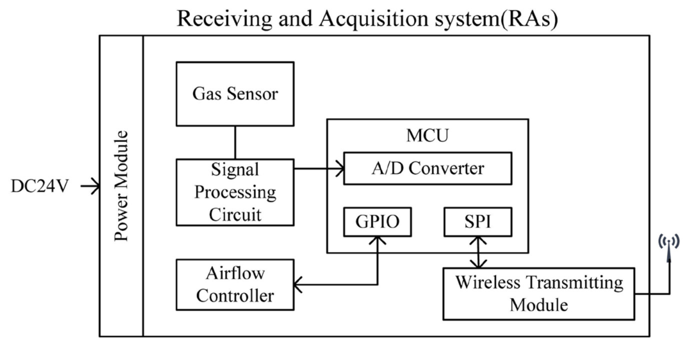


Figure 5. The RAs hardware framework.

4.2. Master Control and Warning System (MWs) Design

MWs is powered by 24 Vdc of vehicle battery. Power module generates 5 Vdc and 3.3 Vdc to supply color LCD, LCD driver, MCU, voice circuit, speaker, wireless transmitting module. MWs provide complete diagnostic and alarm for gas concentration values from multiple RAs. In the event of an alarm, color LCD prompts location and order of severity, at the same time speaker plays sound files, as shown in **Figure 6**.

4.3. Airflow Precision Control System (APs) Design

Due to the uncertain air flow and distribution of the bus open environment, we designed the APs to regulate the microenvironment, in **Figure 7**. The algorithm is coded on the MT for the AT and RT coordination, to realize the airflow precision control. The AE of the AT is used for air supply actively. The air inlet and outlet are fitted on the RT. The AE of the RT is used for negative pressure air supply, to maintain the steady airflow.

5. Experiment and Conclusion

In order to verify the effectiveness of airflow controller of RAs, the comparison experiment results obtained from trace gases concentration measurement in sealed box, in **Figure 8**. Flammable liquid is injected into the sealed box and then drips down onto electric heater. After rapid volatilization of flammable liquid, gases concentration in the sealed box is near a uniform distribution.

The response curves of RAs with and without airflow control is shown in **Figure 9**. Comparison experiment results show that RAs with airflow control responds more quickly. Measured values of RAs with airflow control rise rapidly after flammable liquid injection into the sealed box, reach alarm threshold within 2 seconds. RAs without airflow control need 10 seconds to trigger alarm under the same conditions, as shown in **Figure 9(a)**. RAs and cross flow fan are installed on opposite sides of the experimental bus. Cross flow fan generates air current near the floor to spread gas to RAs. RAs trigger an alarm in 3 seconds after splashing 50 mL 92# petrol to the floor, as shown in **Figure 9(b)**.

In **Table 1**, Floral water triggers an alarm because it contains alcohol. Similarly, shoe polish triggers an alarm that contains flammable organic solvents. But in

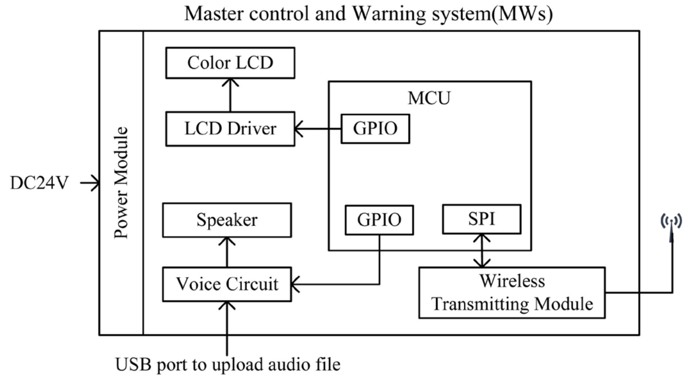


Figure 6. The MWs hardware framework.

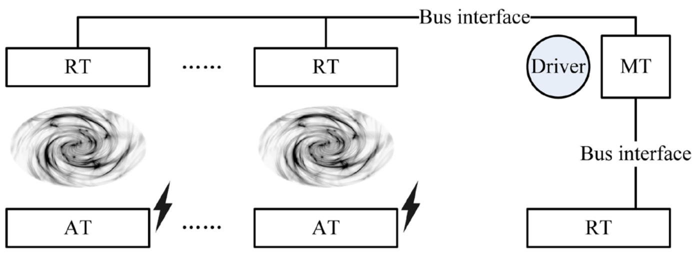


Figure 7. Embedded based APs system architecture.

Table 1. Anti interference experiments.

Test object	Output results		
	Type & Condition	Voltage (0 - 3.3 V)	Sensitivity
Soybean oil	interferences	0	No
Shower Gel	interferences	0	No
shampoo	interferences	0	No
orange juice	interferences	0	No
soy sauce	interferences	0	No
toilet water	alarm	1.2	Yes
toilet water	spread for a minute[a]	0.3	Minor
shoe polish	alarm	0.6	Yes
shoe polish	spread for a minute[a]	0.1	Minor
92# gasoline	flammables	3.0	Yes
75% medical alcohol	flammables	1.7	Yes
High-Flash Aromatic Naphtha	flammables	2.2	Yes
thinner of nitrocellulose lacquer	flammables	2.6	Yes

a: simulating the daily reality.

daily life situations, passengers use floral water and shoe polish at home. Alcohol and organic solvents are burned off on the way to bus station. One minute after floral water and shoe polish had been spread on test papers, sensor detected slight concentration rising which cannot trigger alarm.

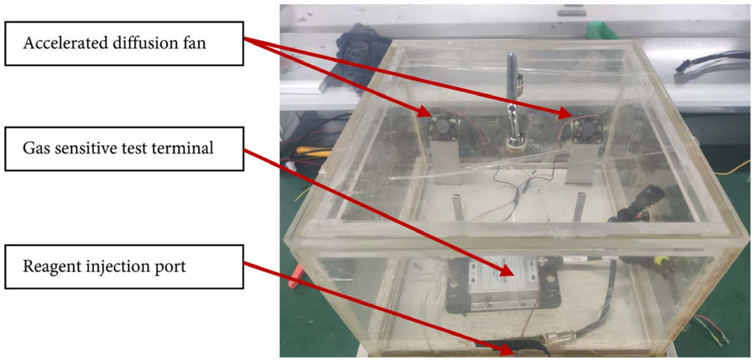
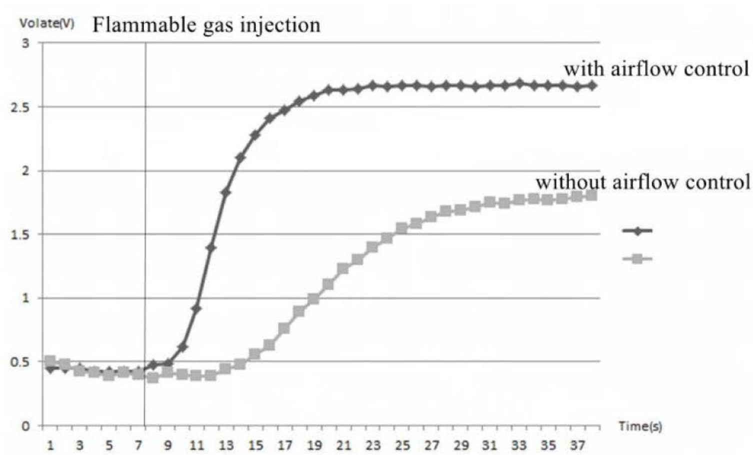
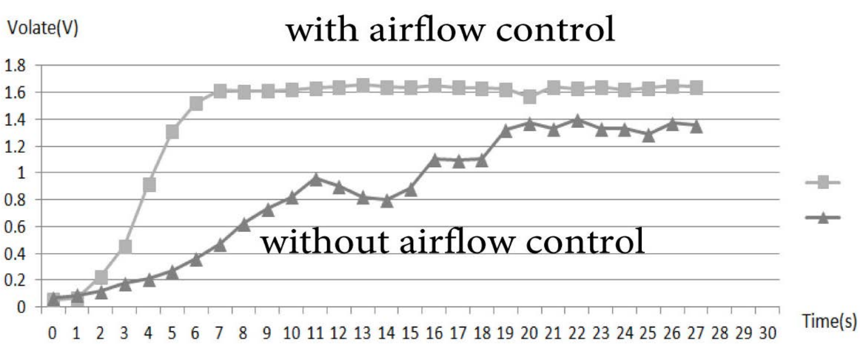


Figure 8. Response speed and sensitive selectivity experiments.



(a)



(b)

Figure 9. Simulation environmental test curve. (a) Response curves by airflow control; (b) Experiment on bus dimension.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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