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Solution of false alarm and slow response in flame detector

Song Wengang[1,2] Zhang Lijun[1] Zheng Zhanqi[1] Wang Guanying[1] Zhang Jianming[3]

([1] Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, China)
([2] School of Microelectronics, University of Chinese Academy of Sciences, Beijing 100190, China)
([3] Wuhan Binhu Electronic Limited Liability Company, Wuhan 430205, China)

Abstract: A new flame detector with one ultraviolet and two infrared detectors is designed. The ultraviolet detector is of rapid response ($\leqslant 10$ μs) while the two infrared detectors usually have a response time of more than 5 ms. The ultraviolet detector is applied to deal with the flame of large scales. When facing the flame of mid or small scales, the three detectors cooperate. Employing the high-order derivatives of the sample data of the infrared circuits to improve the sensitivity, the response speed is greatly improved. The data of the temperature sensor is used to adjust circuit parameters in real time, thus reducing the effect of temperature drift. The flame detectors are tested at different distances and the response time is as rapid as 0.65 ms. The test results show that the new flame detector has the characteristics of high speed and a low rate of false alarms.

Key words: flame detector; rapid response; low false alarm rate; derivative

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With the benefits of long-term stability, reliability, environmental adaptability, and the possibility of being operated away from the flame in a less harsh environment, flame detectors are widely used to detect the radiation of an open fire, especially in places such as gas stations, armored vehicles and chemical plants, etc. The question is how to extract flame signals from background noises.

The main method to distinguish flame signals from interference sources relies on the analysis of the signal spectrum. The flicker frequency of the flame is approximately 13 to 17 Hz[1]. Thuillard[2] analyzed the spectral components of different combustion conditions and utilized his findings to design flame detectors. Another method is to optimize the hardware design. Pauchard et al.[3] proposed a novel compensation loop for spark rejection.

However, for rapid response and low false alarm rate, the methods mentioned above do not work as expected. According to Ref. [4], composite high-speed flame detectors usually have a response time of about 5 ms. If efforts are made to improve the response time, it usually means a high rate of false alarms.

There are two reasons leading to this contradiction. The first reason is that the spectral components of flame interact with those of interference sources, such as sunlight, flash lamps, arc lights and so on. The second reason is that infrared detectors generally have a response delay time (for resistance to reduce 5%) that is greater than several milliseconds[5]. The larger the distance from flame, the longer the response time.

In this paper, a novel method is presented to solve the contradiction between false alarms and rapid response in flame detectors. This method involves one ultraviolet (UV) and two infrared (IR) detectors. The rapid-response UV detector monitors a large flame and all three detectors extract the weak signals of a small combustion. In addition, the high-order derivatives from sample data of the IR detectors are used to improve speed performance. The results show that our method can effectively reduce the rate of false alarms and response time simultaneously.

1 Principles of the New Flame Detector

When an object is burning, the rays of certain wavelengths are emitted. According to Ref. [6], the typical flame spectrum is shown in Fig. 1. By monitoring the rays in the air, the flame detector determines whether there is flame or not. However, it is obvious that the spectrum of flame overlaps with sunlight. Moreover, some other sources of interference also affect the signal quality.

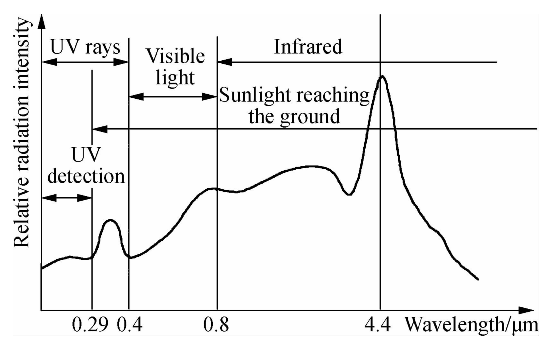

Fig. 1 Typical flame spectrum from ultraviolet to infrared

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Biographies: Song Wengang (1996—), male, Ph. D. candidate; Zhang Lijun (corresponding author), male, professor, zhanglijun@ime.ac.cn.

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We reduce the risks of being disturbed by interference sources via combined ray detectors. The UV radiation of the flame mainly comes from the electron transitions of the metallic elements and NO molecule. The UV wavelength of the flame is less than 400 nm. According to Fig. 1, only the rays with wavelengths larger than 290 nm can reach the ground. We adopt a vacuum UV detector and the responsive wavelength is 185 to 260 nm. The UV detector has a response time of less than 10 μs[7].

The products of steady combustion become excited under high temperatures and they radiate mostly IR rays. Hot CO_2 is the main IR source and it has two peak radiation bands, namely 4.3 and 2.7 μm. We adopt two IR detectors to monitor the two bands. The wavelengths are 2.5 to 3.0 μm (IR1) and 3.85 to 4.85 μm (IR2), respectively.

1.1 Hardware design of the system

Fig. 2 shows the system framework. There are two IR detectors, one UV detector, one micro control unit (MCU), one temperature sensor, and other necessary parts. The supply voltage is direct current (DC) 24 V and power management chips generate other voltages.

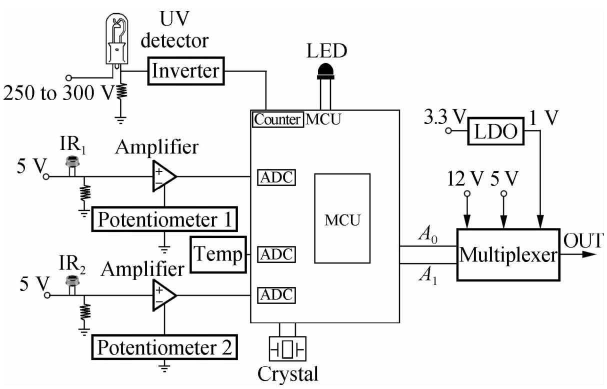

Fig. 2 Hardware framework of the flame detector

The resistance of the two IR detectors will be reduced when exposed to IR rays, which are detected by two divider resistors. The voltages of the resistors are amplified by two amplifiers and then sampled by the MCU.

The vacuum UV detector has an operating voltage within 250 to 300 V. In this system, we utilize the MCU to generate two pulse width modulation (PWM) signals, which are used to control a transformer to produce an alternating current (AC) high voltage. A single-phase bridge rectifier converts the AC voltage to the direct current.

Fig. 3 shows the schematic diagram of the UV detection circuit. The UV detector uses the theories of the photoelectric effect and current multiplication effect. When UV light shines on the detector between its cathode and anode, a photoelectric effect occurs and causes a gas discharge and numerous electronic streams in the tube[7]. Then capacitor E1 discharges itself through R5 and R6. In this way, we obtain a pulse signal for R6 and limit the pulse voltage to below 3.6 V by using a Zener diode D2. One inverter achieves pulse shaping by changing exponential waveforms to rectangular waveforms. Finally, the MCU counts the number of pulses in a certain period of time, such as 1 or 2 ms.

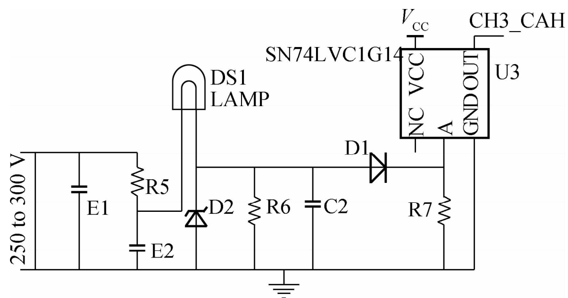

Fig. 3 Schematic diagram of UV detection circuit

Moreover, the MCU obtains the temperature through the temperature sensor and automatically adjusts the parameters of the circuits of IR and UV detectors in real time to compensate for temperature variations.

1.2 Software design of the system

The software system includes the initialization module and alarm-monitoring module. Fig. 4 shows the design block diagram.

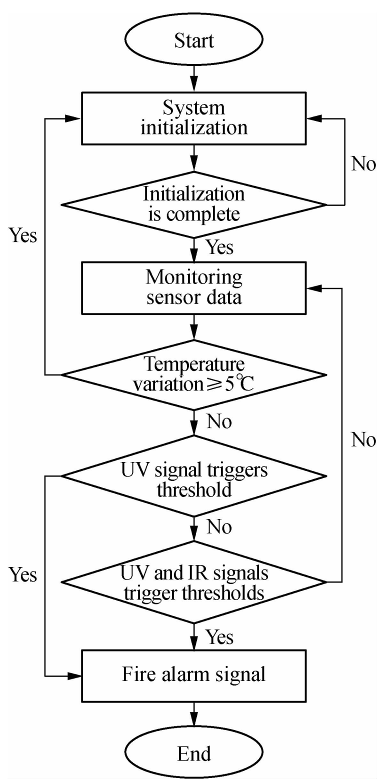

Fig. 4 The block diagram of the software system

Once the power is on, the system initialization module starts working. The MCU samples the output voltage of the temperature sensor and converts it to the corresponding temperature. Then, the MCU will automatically adjust the reference voltages of the signal amplification circuits of the IR detectors, ensuring that the static output voltages remain within the scope of 1 to 3 V. Moreover, the MCU calibrates the working voltage of the UV detector by adjusting the width of PWM signals.

With initialization complete, the alarm-monitoring module comes into its effect. The MCU processes the data acquired from the temperature sensor, IR and UV detectors. The first step is to determine whether the temperature changes exceed 5 ℃ since the last system initialization. If it is greater than 5 °C, the system restarts the initialization.

Alarm condition 1 If the temperature change is less than 5 ℃, the MCU will implement real-time monitoring of the counters of UV signal. This alarm condition generally applies to a flame of large or near combustion. Under such circumstances, the numbers of the counters far exceed the numbers resulting from optical noises.

The pulse counters and their thresholds are listed in Tab. 1. P_1, P_2, and P_3 represent the numbers of pulses in three continuous time windows and Fig. 5 shows the time windows. There are four groups of thresholds. If the pulse numbers are larger than the thresholds of any group, the alarm signal is triggered. The time length τ of these windows can be determined according to the required response time.

Tab. 1 UV pulse counters and thresholds in alarm condition one

Groups of thresholds	P_1	P_2	P_3
Ⅰ	> cnt_1		
Ⅱ	> cnt_2	> cnt_3	
Ⅲ	> cnt_4		> cnt_5
Ⅳ	> cnt_6	> cnt_7	> cnt_8

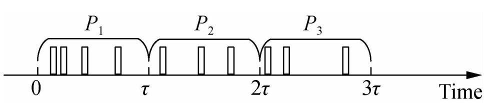

Fig. 5 Three time windows and their pulse numbers

To determine these thresholds, we place the flame detectors under the environments of the large fire and interference sources, respectively. Acquiring the law of signal pulses of the UV detector, we set these thresholds under the condition that the flame detectors would not respond to these interference sources.

Alarm condition 2 When the combustion is far or small, we exploit all three detectors to distinguish the weak flame signals from background noises. Considering that the response time of the IR detectors is slow, we propose a new method of employing high-order derivatives of the data acquired from the IR detectors.

In Tab. 2, we present the monitoring signals and their thresholds. If the signals satisfy the thresholds of any group, the alarm signal is triggered.

In Tab. 2, P_{tot} is the total pulse number in three time windows; IR1 and IR2 are the current samples of IR detectors and their thresholds are $A*$IR1_1 and $B*$IR2_1,

Tab. 2 The signals and thresholds in alarm condition 2

Groups of thresholds	P_{tot}	IR1	IR2	IR1′	IR2′	IR1″	IR2″
Ⅴ	> CNT	< $A*$IR1_1	< $B*$IR2_1				
Ⅵ	> CNT			< C	< D		
Ⅶ	> CNT					< E	< F

respectively; IR1_1 and IR2_1 are the samples several seconds before; A and B are two coefficients with the value range of 0 to 1; IR1′ and IR2′ are the first derivatives of IR1 and IR2, respectively; IR1″ and IR2″ are the second derivatives of IR1 and IR2, respectively. Thresholds CNT, C, D, E and F are acquired by the experiments.

Using the finite difference method[8], we calculate the derivatives of the samples of the IR detectors. The formulae for the first- and second-order derivatives are presented as follows:

$$f'(x_i) = \left(\frac{\partial f}{\partial x}\right)_{x_i} \approx \frac{f(x_i + h) - f(x_i - h)}{2h} \quad (1)$$

$$f''(x_i) = \left(\frac{\partial^2 f}{\partial x^2}\right)_{x_i} \approx \frac{f(x_i + h) + f(x_i - h) - 2f(x_i)}{h^2} \quad (2)$$

The three curves in Fig. 6, from top to bottom, are the original sampling data, the first and second derivatives of IR1. When using IR1, IR1′ and IR1″ to trigger the alarm, the response times are 91, 40 and 24 ms, respectively. So, high-order derivatives are effective for reducing response time. The greater the distance from the flame, the greater the improvement. In our design, the data related to the IR detectors are the average values of multiple samplings.

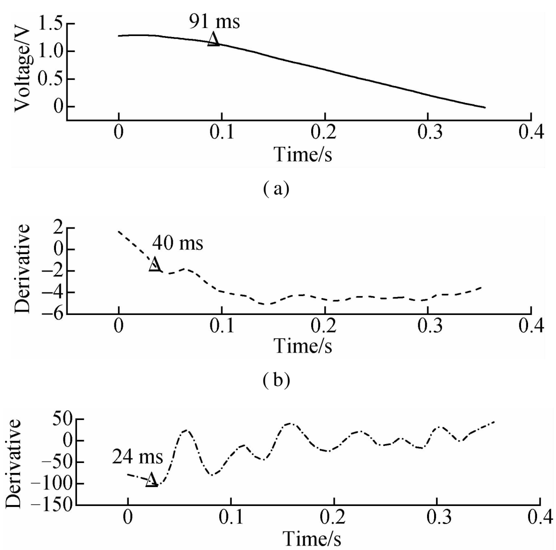

Fig. 6 Changes in signals when exposed to IR rays. (a) Original sampling data IR1; (b) The first derivative IR1′; (c) The second derivative IR1″

Combining alarm conditions 1 and 2, the flame detector is able to detect flames of varying degrees. On the one hand, alarm condition 1 has the characteristic of rapid response and it is very useful for detecting a sudden large combustion, of which the response time is of the utmost importance. On the other hand, alarm condition 2 has the characteristics of high sensitivity and a low rate of false alarms.

2 Test Results

Based on the theories described above, three working prototypes are designed. Fig. 7 shows the three prototypes and the test system[9]. According to the application requirements, we test two items, i. e., the response time and the rate of false alarms.

(a)

(b)

Fig. 7 Pictures of real objects. (a) Three working prototypes of flame detectors; (b) The test system of response time and false alarm rate

2.1 Response time

We test the response time of the three prototypes at different distances of 0.4, 1.2 and 3 m. At each distance, three prototypes are tested for 100 times respectively and we calculate the mean values of the test results, which are listed in Tab. 3. The flame size is 10 cm × 10 cm. It should be noted that no missing alarm occurs in this test.

Tab. 3 Response time measurements

Test distance/m	Response time/ms			Mean value/ms
	Prototype 1	Prototype 2	Prototype 3	
0.4	0.60	0.66	0.70	0.65
1.2	106	98	103	102.3
3.0	129	125	131	128.3

2.2 False alarm under interference sources

We test the false alarm rate of the three prototypes under direct sunlight, infrared spotlight, LED, car headlight, incandescent lamp, camera flash light and air heater. The detailed test conditions and results are shown in Tab. 4.

Tab. 4 The times of false alarm in a fixed time under interference sources

Interference sources	Test conditions	Times of false alarm
Direct sunlight	Facing the sun for 30 min, using the chopper in front of the detector to modulate the sunlight at the frequency of 1Hz	0
200 W infrared spotlight	At the distance of 60 cm, illuminating for 3 min and using the chopper to modulate at the frequency of 1Hz	0
10 W red and white LED	At the distance of 30 cm, illuminating for 3 min, respectively, and using the chopper to modulate at the frequency of 1Hz	0
80 W car headlight	At the distance of 40 cm, illuminating for 3 min and using the chopper to modulate at the frequency of 1Hz	0
80 W 15 Hz, 38 Hz, 58 Hz incandescent lamp	At the distance of 40 cm, illuminating for 3 min, respectively	0
Camera flash light	At the distance of 30 cm, shining for 30 times	0
450 W air heater	At the distance of 55 cm, irradiating for 3 min and using the chopper to modulate at the frequency of 1Hz	0

Designing flame detectors with flicker frequency detection has the possibility to achieve a good false alarm rate[2]. However, considering that the flicker frequency of the flame is only about 13 to 17 Hz, the response time cannot be less than $1/f$, where f is the flicker frequency. Liu[10] established a specific mathematical relationship between four IR spectral characteristics. This method achieved a high sensitivity, but the response time was too slow.

Based on the test results and comparison presented above, it is obvious that the new flame detectors have the advantages of a low false alarm rate and rapid response. Especially when dealing with large (or near) combustions, the flame detectors realize an average response time of 0.65 ms. Furthermore, the flame detector has the characteristics of a large viewing angle (120°), a wide working temperature range (−40 to 105 °C) and strong shock resistance ability (the final peak saw tooth shock pulse with the peak acceleration $20g$).

3 Conclusion

This paper proposes a novel method to achieve the rapid response and low false alarm rate of flame detectors. This method involves one UV and two IR detectors. We exploit the fast response of the UV detector to monitor large (or near) combustions and three detectors to distinguish the weak flame signals from background noises. Moreover, the high-order derivatives of the IR detectors are applied to improve the response time. Test results show that the flame detectors are extremely fast and have a good effect on the false alarm rate. However, as the distance from the flame core increases, the response time increases significantly. In the following research, a composite algorithm, which contains our algorithm, flicker frequency detection or fuzzy logic, might be helpful to improve the sensitivity and response speed when dealing with mid or far flame.

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火焰探测器中虚警和慢响应的问题解决

宋文刚[1,2]　张立军[1]　郑占旗[1]　王冠鹰[1]　张建明[3]

([1]中国科学院微电子研究所, 北京 100029)

([2]中国科学院大学微电子学院, 北京 100190)

([3]武汉滨湖电子有限责任公司, 武汉 430205)

摘要:提出了一种带有 1 个紫外探测器和 2 个红外探测器的新型火焰探测器,紫外探测器的响应时间快(≤ 10 μs),而 2 个红外探测器的响应时间通常大于 5 ms. 用紫外探测器对大面积的火焰进行判别;对于中小型火焰,3 个探测器共同作用. 同时,利用对红外电路采样数据求导的方法来提升火焰探测器灵敏度,改善中小型火焰条件下的响应速度. 根据温度传感器的数值实时调整电路参数,减小温度漂移的影响. 在不同距离对火焰探测器进行测试,响应时间最快可达 0.65 ms,测试结果表明新型火焰探测器具有高速响应和低误报率的特点.

关键词:火焰探测器; 高速响应; 低误报; 求导

中图分类号:TP212.1; TP212.9