The Multifunctional Safety Helmet for Coal Miners of the Opto-Mechatronics

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Abstract:
The article introduced a multifunctional safety helmet for coal miners, which including protecting user's head, checking up the density of gas (give an alarm by the light when the density exceeds the allowed area), illuminating, adjusting the lights and so on. It uses the high efficient lithium battery as power source, the engineering plastic as the hat body which has high mechanical strength, the light which can conserve energy, the high accurate gas sensor, the light integration of machinery product taking monolithic integrated circuit AT89C2051 as the control core. It has following advantages: the energy conservation, the sensitive gas sensor, alarming by light (suit to the noisy situation), long action cycle and other characteristics. It also can be used in rescuing and providing disaster relief.

Keywords: Monolithic integrated circuit, Gas sensor, Illuminates, Adjust the lights, Alarm, Battery.

1. Introduction

Foreign countries began to research and develop gas sensors in the 1930s. In the past, gas sensors were mainly used for detection and alarm of gas, liquefied petroleum gas, natural gas and gas in mines [1-3]. At present, the types of gas to be detected have expanded from original reducing gas (H_2, C_4H_{10}, CH_4, etc.) to toxic gas (CO, NO_2, H_2S, NO, NH_3, PH_3, etc.). There are many kinds of gas sensors. According to the different gas sensing materials and characteristics, it can be divided into semiconductor type, solid electrolyte type, electrochemical type, contact combustion type, polymer type and so on [4].

At present, the development of gas sensing materials has greatly improved the sensitivity, performance, structure, volume and price of gas sensors, and improved the selectivity and sensitivity of sensors [5-6]. Most of the existing gas alarms use tin oxide plus noble metal catalyst gas sensors, but the selectivity is poor, and the accuracy of alarm is affected by catalyst poisoning. The sensitivity of semiconductor gas sensing materials to gas is related to temperature. The sensitivity is low at room temperature, as the temperature increases, the sensitivity increases and reaches the peak at a certain temperature [7-8]. Because these gas sensitive materials need to reach the best sensitivity at a higher temperature (generally greater than 100 ^oC), it will not only consume additional heating power, but also cause fire.

Since 1958, a graduate student from the University of California put forward the idea of lithium, sodium and other active metals as the negative electrode of battery, human began to study lithium battery [9-10]. In 1971, Yastaro Fukuda of Panasonic company of Japan invented lithium fluoride carbon battery and commercialized it. With its advantages of high specific energy, high battery voltage, wide operating temperature range and long storage life, lithium battery is widely used in small electrical appliances for military and civil purposes, such as mobile phones, portable computers, cameras, cameras, etc.

The research of lithium-ion battery began in 1980s. In 1990, Nagoura and others in Japan developed a lithium-ion battery with petroleum coke as the negative electrode and $LiCoO_2$ as the positive electrode: $LiC_6|LiClO_4$-PC + EC$|LiCoO_2$. Two battery companies, Moli and Sony, announced that they would launch lithium-ion batteries with carbon as the negative electrode [11-12]. In 1991, Sony energy Technology Company of Japan and battery department jointly developed a lithium-ion battery with glycan alcohol pyrolytic carbon (PFA) as the negative electrode [13]. In 1993, Bellcore (bell Telecom) first reported that polymer lithium-ion battery (PLIB) was manufactured by PVDF process.

The singlechip is a microcomputer that integrates the main computer functional components such as CPU, RAM, ROM and I/O into a single integrated circuit chip. This kind of micro-computer is called singlechip because it is made on a chip [14]. Single chip microcomputer is the product of the development of large scale integrated circuit technology. Single chip microcomputer has many outstanding advantages, such as high performance, fast speed, small size, low price, stability and reliability, wide application and strong universality. The design goal of single-chip microcomputer is to enhance the ability of "control" and meet the needs of real-time control (that is, fast response).

Therefore, it has its unique features in hardware structure, instruction system, I/O port, power consumption and reliability. One of its most significant features is its very effective control function [14-16]. Therefore, the single chip computer is often referred to as micro controller (MCU or μC).

The safety helmet for coal miners is used to protect the safety of the operator's head, which can protect the human head from external force injury, and also has the function of alarm.

2. Design requirements of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics"

2.1. The main functions of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics" are as follows:

(1) Dress code and head protection. The safety helmet of coal miners is the dress mark of coal miners, which should be beautiful and consistent. There should be enough mechanical strength to protect the head of the wearer, so the cap body is made of engineering plastic ABS by plastic mold injection molding. Different occasions are distinguished by the color of the hat body.

(2) Power and lighting functions. In order to make the working cycle longer after one charge, lithium battery with small volume, light weight and high efficiency and energy-saving luminescent body need to be used. Variable light illumination can be carried out through different combinations of luminescent body, which is also one of the energy-saving measures. Especially, other mine accidents are trapped underground, providing light support for the trapped for as long as possible. Therefore, it is necessary to use the field energy to charge the lithium battery in the mine. The power supply also needs to provide different working voltage according to the requirements of each component in the system. The system should have a high efficiency step-up and step-down circuit.

(3) Sensitive and stable gas sensor function. The gas sensor is the key to the environmental gas detection of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics". It should be sensitive, accurate, stable and reliable to detect the underground gas concentration. Once the gas concentration exceeds the standard, it will send out the alarm information accurately.

(4) Light alarm function. Due to the large noise in the coal mine, it is not suitable to use the sound alarm, and the energy consumed by the cap body vibration alarm is also large. The light alarm shall be selected. The light of lighting flashes according to different rules set, and the difference of flashing rules indicates the alarm of different faults.

2.2. Selection and principle analysis of LM339

Four independent voltage comparators are installed in the LM339 integrated block, which are characterized by: (1) Small offset voltage, typical value is 2mV, (2) Wide range of power supply voltage, 2-36V for single power supply and ±1V-± 18V for dual power supply, (3) The restriction of internal resistance to comparative signal source is wide, (4) The common mode range is very large, which is 0 ~ (Ucc-1.5V) Vo, (5) The differential input voltage range is large enough to be equal to the supply voltage, (6) the output potential can be selected flexibly and conveniently.

LM339 integrated block adopts C-14 package, and LM339 interface diagram is shown in Fig.1. Because LM339 is flexible and widely used, the world's major IC manufacturers and companies have launched their own four comparators, such as IR2339, ANI339, SF339, etc. whose parameters are basically the same and interchangeable.

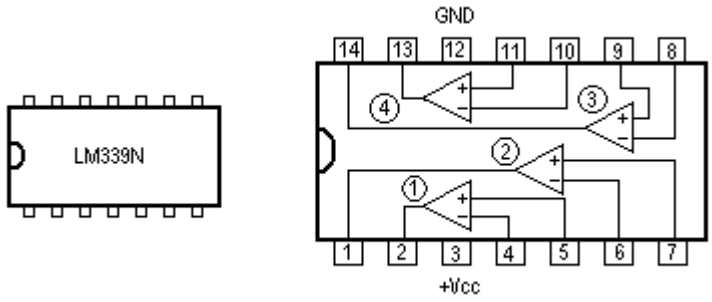

Fig.1. LM339 interface diagram

LM339 is similar to the operational amplifier with non adjustable gain. Each comparator has two inputs and one output. One of the two inputs is called in-phase input, which is indicated by "+", the other is called reverse input, which is indicated by "-". When comparing two voltages, add a fixed voltage to any input as reference voltage (also known as threshold level, which can select any point of LM339 input common mode range), and add a signal voltage to be compared to the other end. When the "+" terminal voltage is higher than the "-" terminal, the output tube is cut off, which is equivalent to an open circuit at the output terminal. When the voltage at the "-" terminal is higher than that at the "+" terminal, the output tube is saturated, which is equivalent to the low potential of the output terminal. The voltage difference between the two input terminals is greater than 10 mV, which can ensure that the output can be reliably transferred from one state to another. Therefore, LM339 is ideal for weak signal detection and other occasions. The output terminal of LM339 is equivalent to a transistor without collector resistance. In use, a resistance (called pull-up resistance, 3-15K) must be connected from the output terminal to the positive power supply. Selecting different values of pull-up resistance will affect the value of high potential at the output. When the output transistor is cut off, its collector voltage is basically determined by the pull-up resistance and load. In addition, the outputs of each comparator are allowed to be connected for use together.

2.3. Selection of single chip microcomputer

In this design project "the multifunctional safety helmet for coal miners of the Opto-Mechatronics", I choose the single chip computer PIC16F630. As shown in Fig.2, PIC16F630 not only meets the requirements, but also has simple command, no external crystal oscillator, strong anti-interference ability and 14 I/O interfaces.

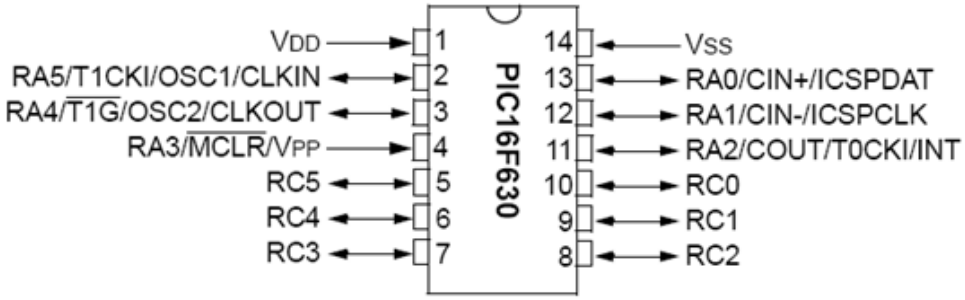

Fig.2. Chip interface

Pin description of PIC16F630 is shown in Table 1.

Table 1. Pin function of PIC16F630

Name	Function	Input type	type of output	Explain
RA0 /AN0 /CIN+ /ICSPDAT	RA0	TTL	CMOS	Bidirectional I/O with programmable pull-up and level change interrupt
	AN0	AN	/	A/D channel 0 input
	CIN+	AN		Comparator input
	ICSPDAT	TTL	COMS	Serial programming data I/O
RA1 /AN1 /CIN- /VREF /ICSPCLK	RA1	TTL	COMS	Bidirectional I/O with programmable pull-up and level change interrupt
	AN1	AN	/	A/D channel 1 input
	CIN-	AN	/	Comparator input
	VREF	AN	/	External voltage reference
	ICSPCLK	ST	/	Serial programming clock
RA2 /AN2 /COUT /T0CKI /INT	RA2	ST	COMS	Bi directional I/O with programmable pull-up and level change interrupt
	AN2	AN	/	A/D channel 2 input
	COUT	/	COMS	Comparator input
	T0CKI	ST	/	Timer0 clock input
	INT	ST	/	External interrupt
RA3 /MCLR /VPP	RA3	TTL	/	Change interrupt input port
	MCLR	ST	/	Master clearance
	VPP	HV	/	Programming voltage
RA4 /T1G /AN3 /OSC2	RA4	TTL	COMS	Bidirectional I/O with programmable pull-up and level change interrupt
	T1G	ST	/	Timer1 gating
	AN3	AN3	/	A/D channel 3 input

/CLKOUT	OSC2	/	XTAL	Crystal / resonator
	CLKOUT	/	COMS	FOSC/4 output
RA5 /T1CKI /OSC1 /CLKIN	RA5	TTL	COMS	Bidirectional I/O with programmable pull-up and level change interrupt
	T1CKI	ST	/	Timer1 clock
	OSC1	XTAL	/	Crystal / resonator
	CLKIN	ST	/	External clock input/RC oscillator connection terminal
RC0 /AN4	RC0	TTL	COMS	Bidirectional I/O
	AN4	AN4	/	A/D channel 4 input
RC1 /AN5	RC1	TTL	COMS	Bidirectional I/O
	AN5	AN5	/	A/D channel 5 input
RC2 /AN6	RC2	TTL	COMS	Bidirectional I/O
	AN6	AN6	/	A/D channel 6 input
RC3 /AN7	RC3	TTL	COMS	Bidirectional I/O
	AN7	AN7	/	A/D channel 7 input
RC4	RC4	TTL	COMS	Bidirectional I/O
RC5	RC5	TTL	COMS	Bidirectional I/O
VSS	VSS	Power Supply	/	Grounding reference
VDD	VDD	Power Supply	/	Positive pole of power supply

Note: Shaded part = PIC16F676 only，TTL = TTL input buffer， ST = Schmitt trigger input buffer.

The sensor uses two output pins, negative and positive. The positive and negative poles are connected to the power supply of the sensor, and the output is connected in series with the power supply line of the miner's lamp.

2.4. Selection of lithium battery

Lithium battery is a kind of chemical power supply with metal lithium or lithium-containing substances as the negative electrode. Because the standard electrode potential of lithium is very negative (relative to the standard hydrogen electrode potential is -3.05V) and the theoretical specific capacity is as high as 3.88Ah/g. Therefore, compared with conventional battery, it has the characteristics of high voltage (about 3V), high specific energy of 200-450Wh/kg, etc. The practical lithium batteries include $LiMnO_2$, $LiSOCl_2$, $LiSO_2$, $LiAg_2CrO_4$, etc. When the lithium electrode here is replaced by carbon, it becomes the latest lithium-ion battery, Table 2 shows the performance comparison between lithium battery and other batteries.

Table 2. Performance comparison between lithium battery and other batteries

Technical parameter	Nickel cadmium battery	MH-Ni battery	Lithium ion battery
Working voltage /V	1.2	1.2	3.6
Specific energy of mass /（$Wh \cdot kg^{-1}$）	50	65	90
Volume specific energy /($Wh \cdot l^{-1}$）	150	200	280
Charge and discharge life / time	500	500	1000
Working performance at -20 ℃ (100% at 25 ^{o}C)	30	25	60
Energy retention performance (% per month)	72	80	90
Charge rate C	1	1	1

2.5. Technical indicators

The technical indexes of the gas sensor are shown in Table 3.

Table 3. Technical indexes of gas sensor

Project	Technical index	Remarks
Alarm concentration	Methane≥1％	
Response time	≤20 s	
Recovery time	≤30 s	
Work environment	Temperature -15^{o}C～+50℃	Humidity≤97％RH
Static power consumption	150mW	
Alarm state power consumption		
Power supply voltage	3-5V DC	

3. The working mechanism of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics"

The initialization of single-chip microcomputer includes: stack, I/O interface, timing/counter, register and other settings. The circuit schematic diagram and circuit block diagram are shown in Fig. 3 and Fig. 4 respectively. CPU queries the status of input port (arrow points to the port of single-chip microcomputer) in the order shown in the software block diagram, detects whether the gas sensor is damaged or not, and whether it is desorbed, so as to make it work in the correct state. Accurate judgment of gas concentration exceeding the standard, real-time and accurate recognition of the number of luminescent body groups and alarm form selection. The dimming lighting is controlled by the input port (the port with the arrow facing the single chip computer). Normal operation of various light alarms (composed of square waves with different cycle and duty cycle) and desorption circuits.

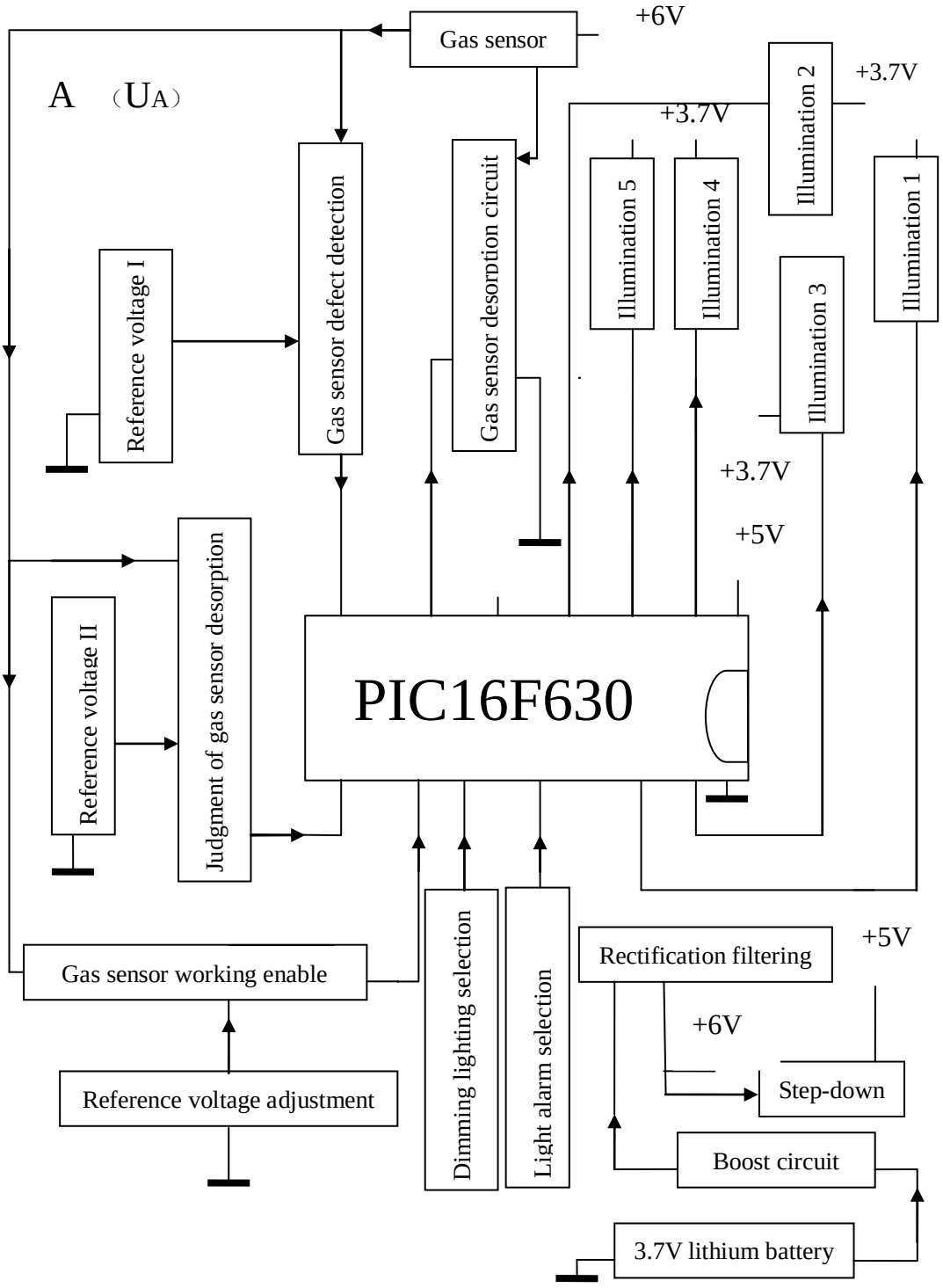

Fig.3. Circuit schematic diagram

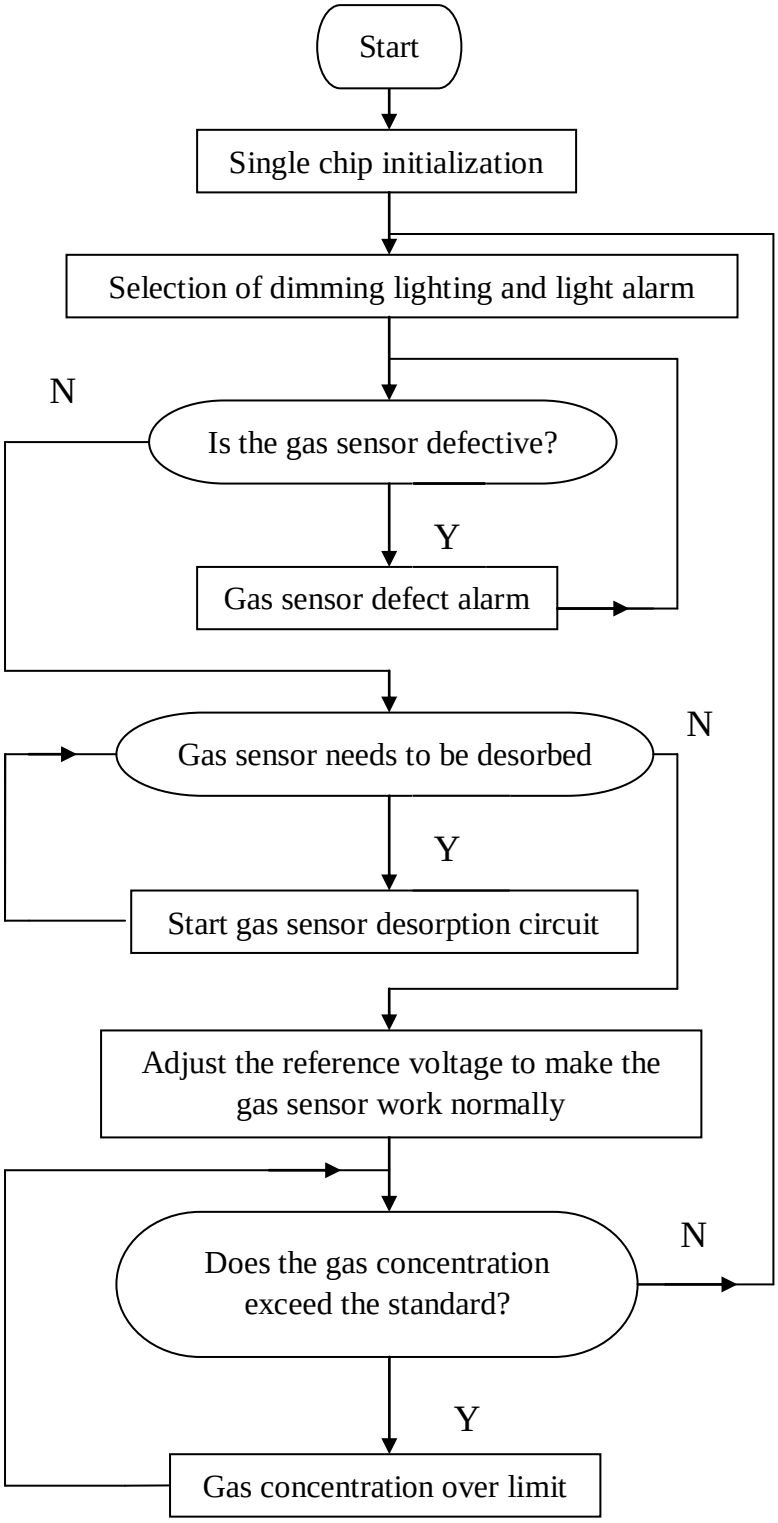

Fig.4. Circuit diagram

4. Application of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics"

4.1. Instructions for use of gas sensor

1. When the machine is started and powered on, the miner's lamp flashes twice, and each time the sensor is powered on, there is a cleaning and desorption process. The desorbing process shall be at least 35 seconds. After the desorbing, the miner's lamp flickers twice and turns into the normal working monitoring state.

2. In case of sensor failure, the miner's lamp flashes once every ten seconds.

3. When the miner's lamp detects that the methane gas reaches the alarm concentration in the air, the miner's lamp flashes once per second.

The overall design circuit diagram of the multifunctional safety helmet for coal miners of the Opto-Mechatronics is shown in Fig.5:

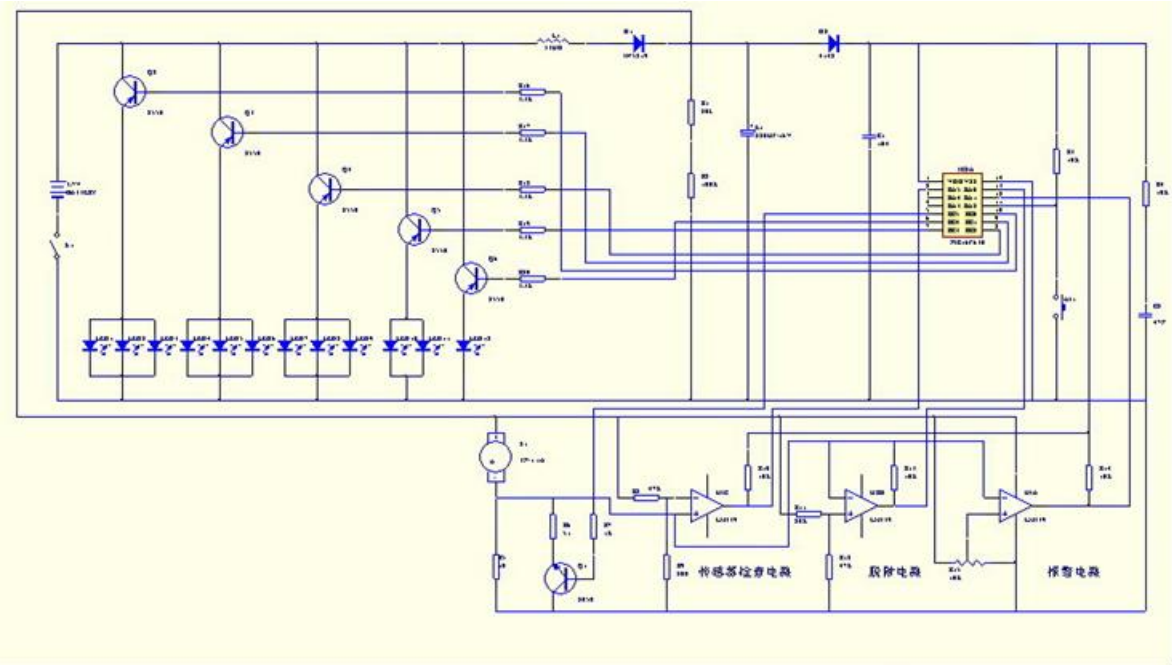

Fig.5. Overall design circuit diagram

4.2. Program and operation of PIC16F630

The procedure flow of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics" is shown in Fig.6:

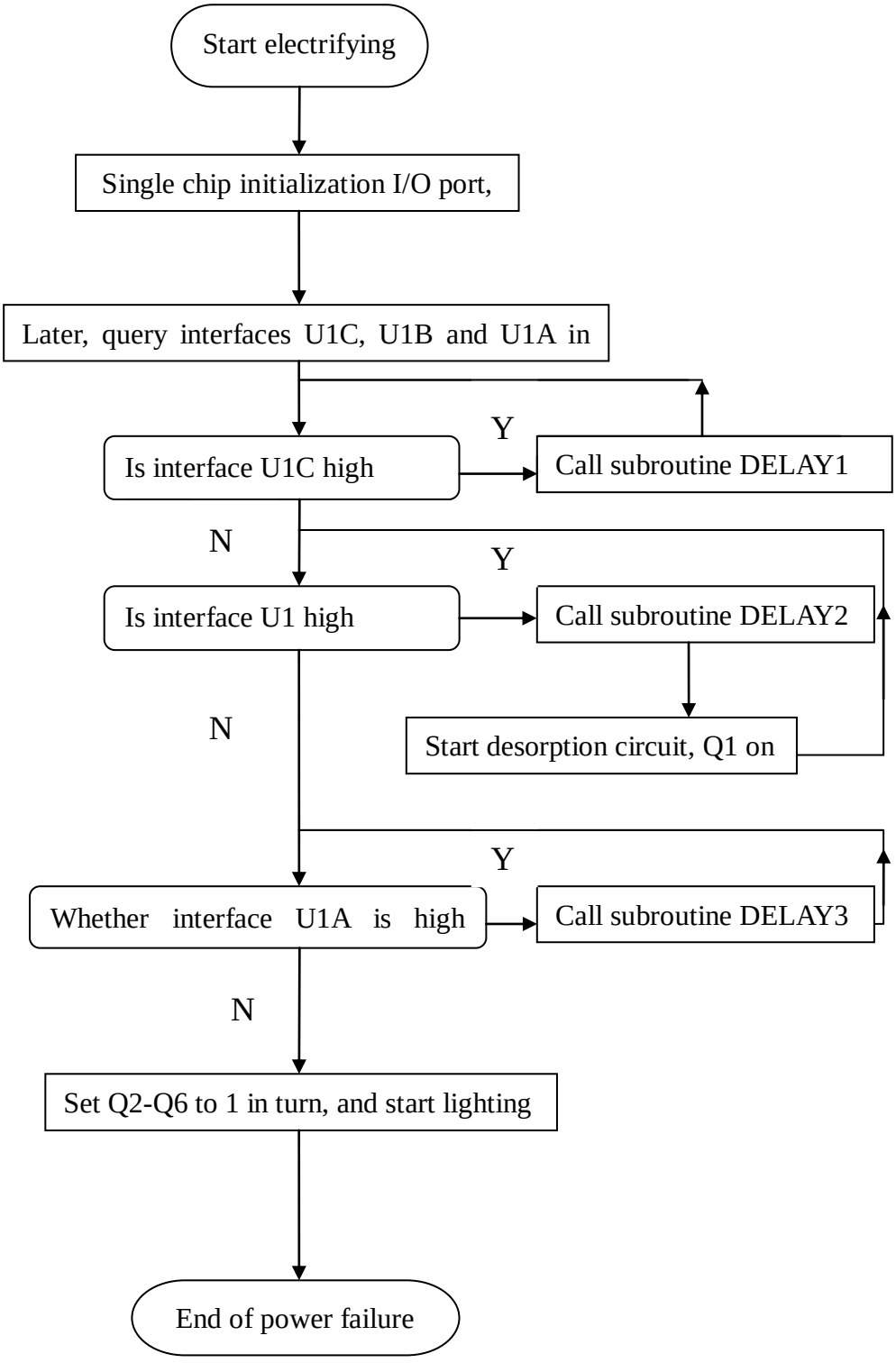

Fig.6. Procedure flow chart

We have completed the hardware and programming of lighting control circuit in this design. The result should be:

When the circuit is connected,

1. When there is no gas sensor, the LED will flash at the same time, and the flash gap is 2s;

2. When there is no desorption, the LED will flash at the same time, the flash gap is 1s, and the desorption circuit will be started at the same time;

3. When the gas exceeds the standard, the LED will flash and alarm at the same time, with a gap of 0.5s;

4. When none of the above results appear, the "multifunctional safety helmet for coal miners of the Opto-Mechatronics" is in the lighting state, and can be operated manually to make it lighting according to the required conditions.

4.3. Characteristic parameters of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics"

Table 4 shows the final characteristic parameters of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics". In the design scheme, the single-chip microcomputer is used to store the codes needed by common gas sensors in the single-chip microcomputer. The miner can choose his own remote control electrical functions by inputting codes or automatically searching, so as to achieve the general purpose.

Table 4. Final characteristic parameters of "the multifunctional safety helmet for coal miners of the Opto-Mechatronics"

Serial number	Parameter name	Value	Unit	Remarks
1	Rated voltage	3.7	V	
2	Rated capacity	7	Ah	
3	Lighting duration	≥16	h	
4	Illuminance (lighting start)	≥1800	Lx	One meter from the light
5	Illuminance (after 11 hours)	≥1300	Lx	One meter from the light
6	Light source current	≤400	mA	
7	Light source life	25000	h	
8	Illumination variable	130-1300	Lx	
9	Duration when illuminance is 601 × H	160	h	
10	Light source temperature	＜60	^{o}C	
11	Pollution situation	Nothing		
12	Liquid addition	Nothing		
13	Alarm concentration	16%+/-3%	LEL	Gas explosion value
14	Alarm response time	＜20	s	
15	Recovery time	＜30	s	

5. Conclusions

This design has greatly improved the practical efficiency of the multifunctional safety helmet for coal miners of the Opto-Mechatronics, with strong practical value, and created a precedent for the development of the multifunctional safety helmet for coal miners of the Opto-Mechatronics. Although the design is over, there are still many places to further improve. Our final goal is to break away from the teaching platform and develop and apply it to the market through software development. The following issues still need to be addressed in the future:

1. The timeliness and replacement of the "multifunctional safety helmet for coal miners of the Opto-Mechatronics".
2. Time effect of bulb life and alarm system of damage.
3. The effectiveness and real-time of the detection of the uneven gas concentration, as well as the anti-interference ability of the gas sensor to detect the interfering gas, sundries, etc.
4. Performance requirements, replacement and charging requirements for lithium battery.
5. Optimization of the mass and volume of the whole "multifunctional safety helmet for coal miners of the Opto-Mechatronics".
6. The performance comparison between "multifunctional safety helmet for coal miners of the Opto-Mechatronics" and common safety helmet is made to improve the cost performance ratio as much as possible.

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