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OPTICAL SMOKE DETECTOR

Master's thesis

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Magistritöö

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Author's declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

Optical smoke detector is a device that senses the smoke and alerts occupants. This thesis describes how to select the optimal components and implement multi-wavelength and multi-angle photodiode-based smoke detector using an MSP432P401R microcontroller with an extra operational amplifier. The thesis also includes interfacing temperature sensor with the microcontroller. The proposed solution could substantially reduce the smoke detection time and minimize the number of false alarms. This work mainly focuses on development of software and hardware for the smart multi-channel optimal smoke detector, as well as conducting tests. Some ideas to improve the performance of the optical smoke detector are also proposed in this project as a future work.

The Texas Instruments MSP432 platform is taken in the focus of this project. It has a large space for data and code. Another important advantage is that this platform can operate in low-power mode. Embedded peripherals do not increase power consumption significantly.

Keywords: Optical smoke detector, Multi-wavelength, Multi-angle, False alarms, Microcontroller, Temperature sensor

This thesis is written in English and is 64 pages long, including 4 chapters, 45 figures and 5 tables.

Annotatsioon

Optiline Suitsuandur

Optiline suitsuandur on seade, mis tajub suitsu ning hoiatab inimesi tulekahju eest. Suitsuanduri eesmärk on anda tulekahju korral hoiatus, mis laseb inimestel varakult alustada tule kustutamist või evakueeruda. Sel põhjusel on suitsuandur oluline turvalisuse jaoks. Tuli tekitab suitsu kõrval ka kuumust, leeki ning gaase. Kodumajapidamised kasutavad enamasti optilist suitsuandurit, mis on odav ning lihtne. Selle puuduseks on aga kõrge valehäirete arv, sest optiline suitsuandur võib reageerida ka veeaurule, mis tekkib näiteks toidu valmistamisel.

Antud lõputöö kirjeldab sobivate komponentide valimist ning mitme lainepikkusega ja mitme kiirega fotoanduritel põhineva suitsuanduri teostust, kasutades MSP432P401R mikrokontrollerit koos täiendava operatsiooni võimendiga. Töö sisaldab ka temperatuurianduri liidestamist kontrolleriga. Teostatav suitsuandur võib oluliselt lühendada suitsu avastamise aega ning vähendada valehäirete arvu. See töö keskendub peamiselt tarkvara ning riistvara arendamisele aruka mitme kanaliga optilise suitsuanduri jaoks ning selle anduri katsetamisele. Mõned mõtted, kuidas täiustada optilise suitsuanduri toimimist, on välja pakutud tulevase tööna

Selle projekti põhiosaks on võetud MSP432 platvorm. Sellel platvormil on suur mälumaht nii koodi kui andmete jaoks. Veelgi tähtsam on see et antud platvorm töötab väikese võimsusega režiimis. Sisseehitatud seadmed ei suurenda oluliselt energiatarvet.

Märksõnad: optiline suitsuandur, mitme lainepikkusega, mitme kiirega, valehäired, mikrokontroller, temperatuuriandur

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 64 leheküljel, 4 peatükki, 45 joonist, 5 tabelit.

List of abbreviations and terms

ADC	Analog-to-Digital Converter
ARM	Advanced RISC Machine
CAM	Computer-Aided Manufacturing
CAN	Controller Area Network
CCS	Code Computer Studio
CLSC	Complex Instruction Set Computing
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DC	Direct Current
DMA	Direct Memory Access
DSP	Digital Signal Processor
EEPROM	Electrically Erasable Programmable Read-Only Memory
GPIO	General-Purpose Input/Output
GSM	Global System for Mobile Communication
I/O	Input/Output
I^2C	Inter-Integrated Circuit
I^2S	Inter-Integrated sound
ICs	Integrated Circuits
IDE	Integrated Development Environment
IR	Infrared
IrDA	Infrared Data Association
ISA	Industry Standard Architecture
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LiDAR	Light Detection and Ranging
LIN	Local interconnect Network
MCU	Microcontroller
MPU	Microprocessor
NTC	Negative Temperature Coefficient
OpAmp	Operational Amplifier
PCB	Printed Circuit Board
PD	Photodiode
PIC	Peripheral Interface Controller

PWM	Pulse Width Modulation
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
ROM	Read-Only Memory
RTC	Real-Time Clock
SAI	Serial Audio Interface
SAR	Successive Approximation Register
SDRAM	Synchronous Dynamic Random-Access Memory
SMS	Short Message Service
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TI	Texas Instrument
ToF	Time-of-Flight
TX/RX	Transmitter/Receiver
UART	Universal Asynchronous Receiver-Transmitter
USART	Universal Synchronous/Asynchronous Receiver-Transmitter
USB	Universal Serial Bus
WDT	Watchdog Time
WSN	Wireless Sensor Network

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1 Introduction

Fire is a major threat to properties and lives [1]. Since the first invention of smoke detector, the continuous research and study have been carried out to enhance the capability and reliability of smoke detector and reduce the nuisance sources disturbances [2]. There are two kinds of smoke detectors, photoelectric and ionization smoke detector, which are both used to detect fire [3]. When coming to fire progressing, there are three phases. The first stage is to generate gases and smoke is generated in the second phase followed by the last step which is fire progression appearing with flame [4]. Compared with ionization detectors, photoelectric smoke detectors can respond faster to fire in its smouldering stage, which means an earlier alert is provided. However, ionization smoke detectors response faster in the final phase (flaming stage) and are weaker in high air-flow environments [5]. According to the characteristics of both smoke detectors, optical smoke detectors are more reliable and widely used in residential, office or industrial plant [6].

1.1 Motivation

The benefits of smoke detector system, such as smoke detection for commercial, industrial and residential buildings, are remarkable. Fire can be easier stopped, if it could be sensed earlier. Hence occupants can get more time to escape from the premises. On the other hand, detecting low levels of smoke is vital for preventing the smoke from reaching the visible stage.

Detectors sensitivity and accuracy are developed with the advances achieved in smart sensor systems technology.

There are various products available and affordable in the market. However, we are facing a huge challenge in smoke detector – false fire alarm. According to one study in European countries in March 2014, researchers collected data from Sweden, England, Germany, Switzerland and Denmark. In general, ~5% real alarms and ~95% false alarms were observed in the data collected from most countries except Switzerland with a substantial lower false alarm rate of ~85% [7]. In England, toasters are very common and generate a lot of false activations [7]. Usually, the smoke detectors are directly connected with the fire station. Once the alarm is triggered, for instance by cooking that produces fumes, or human malicious activity, fire trucks will without additional confirmation be dispatched from a fire station, which is a waste of money and distraction of the fire brigades from their duties. Because of false alarms, some people just remove the batteries of smoke detectors which is a very dangerous behaviour.

Due to the fact that consumers are more educated and market awareness is increasing, products designers have to continually improve new technology and add new features for smoke detectors that can fulfil customer's needs and detect fire fast with fewer false alarms. On the other hand, the marketing is quite competitive, the initial smoke detector is outdated.

"Smoke alarms are compulsory in all new construction, and a law passed in May 2016 required all rental properties to be fitted with smoke alarms. Alarms must have a battery life at least 8 years or be hard-wired [8]."

The research of smoke detector has been implemented to avoid the false alarms by improving the ability of detectors and reduce the reaction time to the fire source. In other words, it is going to reduce the sensitivity to nuisance sources and response time to fire sources [2].

1.2 Objectives

This work aims to test the following goals using MSP432 microcontroller device:

- Build a prototype for optical sensor system using multiple IR LEDs and multiple photodiodes
- Add extra sensors to MCU additional interfaces, such as resistive sensor for temperature detection and capacitive sensor for humidity detection
- Test the commercial optical smoke alarm and prototype performance

There are many issues to be solved to achieve these goals. First, power consumption must be calculated accurately, since it has to support so many sensor systems. Second, specifications of components should be chosen very carefully. Moreover, the complex algorithm is supposed to be considered.

1.3 State-of-art

1.3.1 A smoke detector with MSP430F2012

According to previous development, an ultra-low-power photo-diode-bases smoke detector was implemented with MSP430F2012 and additional operational amplifier [9]. Within a chamber, there are an infrared LED and one IR receiver (photodiode) are used to detect the presence of smoke. The IR diode is pulsed periodically, and the IR receiver signal is examined to determine if smoke is present in the chamber. An operational Amplifier used to magnify the IR receiver current as a trans-impedance amplifier, so it can be sampled by the ADC in the MCU [9]. Between sampling periods, the operational amplifier and IR circuity are shut down, and the MCU is in a standby mode, consuming less than 1-uA. As can be seen in figure 1 [10], usually the light beam passed straight. While the path of light is interrupted by the smoke, according to the principle of light scattering, the smoke will scatter fraction of light into the photodiode, the smoke detector will be activated [11].

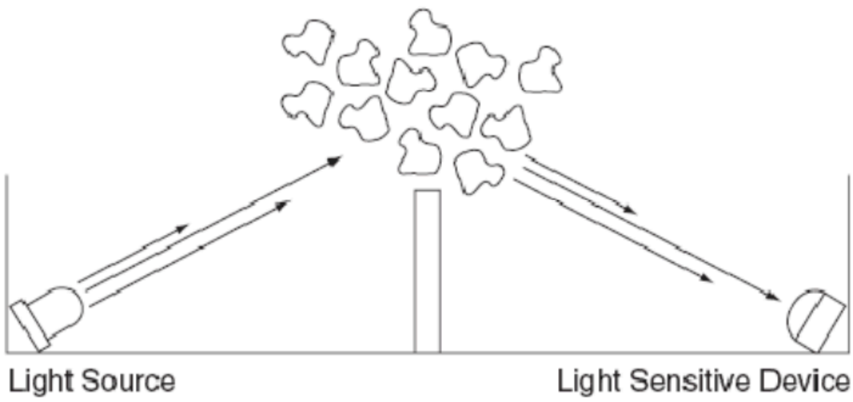


Figure 1. Light scattering detector with smoke.

In order to minimize false alarms, the smoke must be detected three times before triggering the alarm. The Timer-A clock divider is set to be divided by 4 after the first smoke detection. Therefore, there are 4-second interval between the next sampling and first smoke detection. If the second time also detect the smoke, the clock divider Timer-A is set to be divided by 1. Just give one second between the third sampling and the second detection of smoke. If the smoke is observed at the third time, the smoke alarm will be triggered. As can be seen from figure 2 [9], this application is using operational amplifier TLV2780 powered by MSP430 pin 1.5. Therefore, it can reduce the power consumption and miniature the dimension [9].

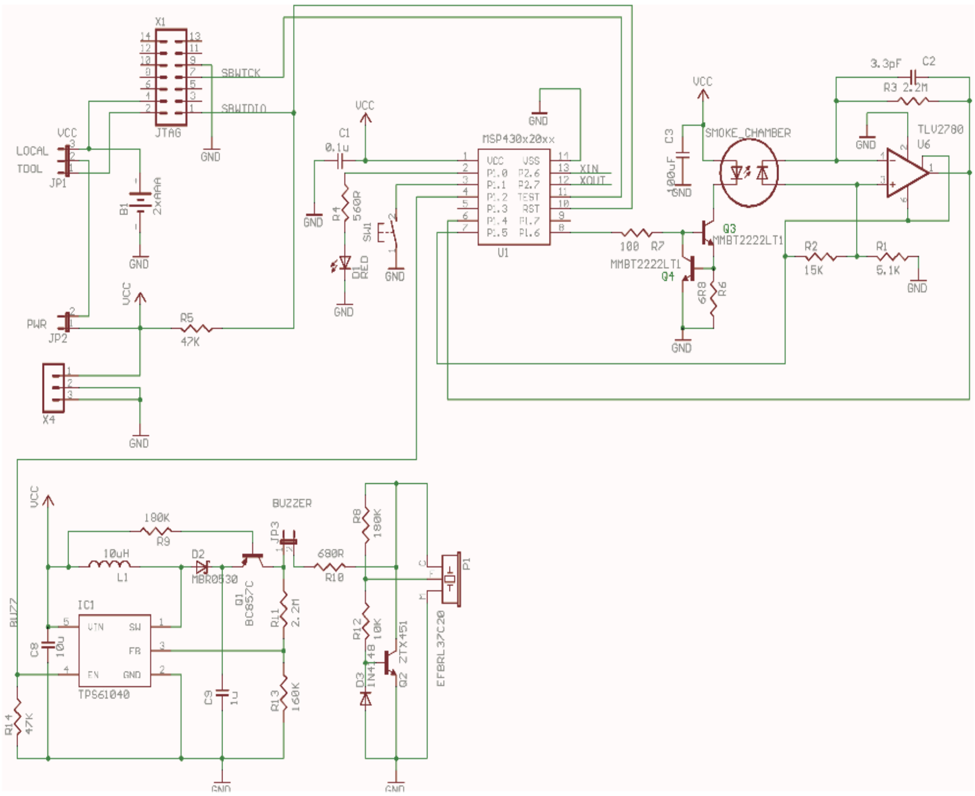


Figure 2. Schematic of smoke detector.

1.3.2 Samsung S3F8S29 smoke detector

In this design, Samsung microcontroller S3F8S29 is used which has 24 pins, 272 bytes and 8-K bytes. In addition, it has 12-bit resolution ADC with 13 channels, a 16-bit timer, two channel 8-bit/12-bit/14-bit PWM and an 8-bit timer. According to these special characteristics of S3F8S29, it becomes proper for smoke detector application. In order to measure the smoke detector signal, 12-bit resolution ADC is used. For low power consumption, the current consumption is less than 150uA with 455 ceramic OSC. For this system, the operating temperature is -10℃ to +50℃, the operating voltage is 24V DC [10].

An infrared LED and an infrared receiver are used to detect smoke within a chamber. By ADC, the analogue signal is converted to digital signal (figure 3 [10]).

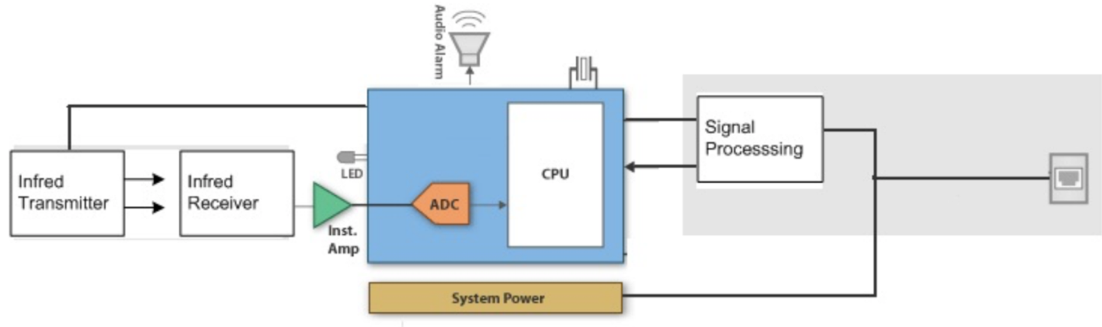


Figure 3. Smoke detector system block diagram.

As show in figure 4 [10], the system sensor 2-wire bus is used and the bus 24 v is utilised to generate 3.3V for the MCU and 10V for the smoke detector.

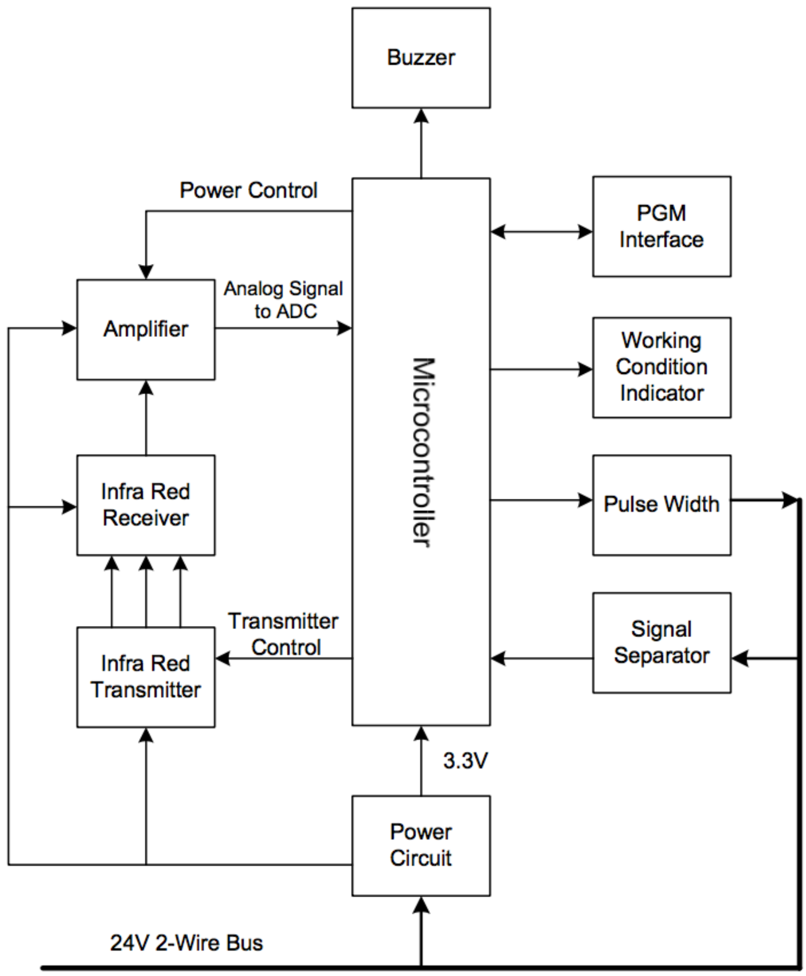


Figure 4. Hardware block diagram.

1.3.3 Patents

With involving various creative methods and tools, there are so many patents published every year. For instance, some remarkable examples can be found:

- US 8085157 B2, this invention belongs to optical smoke detector which using a light sensor and a multi-frequency light source to achieve multiple angle, multiple wavelength scattering. The invention's main advantages are low consumption, fairly broad applicability and cost-effective [12].

- US 8587442B2, smoke alarm with temporal evaluation of backscatter signal, test method for the functional ability of smoke detector. This technology doesn't use chamber for scattering light. Indeed, it includes a base element with a flat mounting surface which has a light emitter attached. This light emitter is keeping illuminating light. In addition, there is a light receiver is placed next to the light emitter, as show in figure 5 [13].

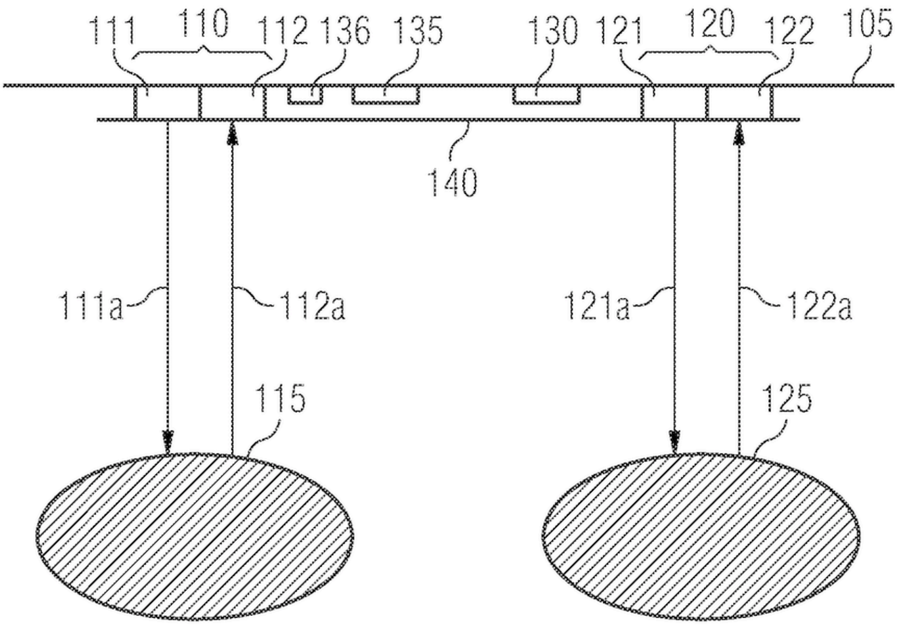


Figure 5. The backscattering smoke alarm.

1.4 Improvements

1.4.1 Higher sensitivity and quicker response

For traditional smoke detectors, they use one IR LED and one photodiode. Therefore, scattering zone is limited, reaction time is relatively long, and sensitivity is also low. Early detection of fire is very important because it can give the occupants more time to evacuate from the building and in many cases the fire can be stopped before it gets out of control, minimizing the damage to property and risk of casualties. For this project, at least three pairs of IR LEDs and photodiodes will be used. This way the scattering zone would be significantly increased. As a result, the sensitivity of the smoke detector will be higher. The reaction time will be shorter.

1.4.2 Minimize false alarms

Traditional smoke detectors cause a large number of false alarms. False alarms can be triggered by cooking fumes, water vapour (for instance, while taking a shower or boiling water), dust build-up, aerosol sprays and a number of other factors. False alarms reduce awareness of the occupants, increasing a number of casualties in case of a real fire. In case of automatic notification systems, they cause higher workload on fire services, wasting resources, and can cause property damage in case of automatic fire extinguishing systems.

False alarms occur because optical smoke detectors react on any factors that scatter light, such as water vapour and fumes that are not an indication of an actual fire.

One of the purposes of this project is to create a smoke detector which is less likely to cause false alarms. It achieves that by taking into account such factors as humidity and temperature.

1.4.3 Detection of smokeless fires

In certain cases, fire does not produce enough smoke to trigger the alarm. But the temperature will be increased. The smoke detector that is in scope of this project should be capable of detecting smokeless fires by taking into account not just smoke, but also temperature. It will be implemented by adding a temperature sensor, as well as larger scattering area for higher smoke sensitivity.

1.5 Challenges

With those significant improvements, there are still some challenges that should be taken into account.

1.5.1 Increase power consumption

Compared to traditional smoke detector, in this project, the number of components is higher. Hence, the power consumption is substantially increased. Most of smoke detectors are powered by disposable batteries. Such smoke detectors can last for several years before a battery has to be replaced. At this rate, battery replacement does not consume a lot of time or money, and the environmental impact is insignificant. With increased power consumption, battery has to be replaced more often, increasing running costs and damage to the environment.

In order to overcome this problem, two strategies can be applied. One of them is to control the power consumption flow. There are serval ways to implement it. Microcontroller can be used in low-power-mode. In addition, sensors (temperature and humidity) can be used with certain intervals. This way, power can be saved, but the reaction time will increase.

The second strategy is to provide more efficient power source. It can be resolved by using rechargeable batteries. This way running costs and environmental impact can be reduced. However, user will have to charge batteries by themselves. Another possible solution is to have a fixed power line. The problems of battery replacement are negated, and since the power is uninterrupted, human factor will be decreased. The disadvantage of this method is that installation becomes more difficult, and a more complex power converter is required. Additionally, in case of power outages a sensor will not be functioning. Having a low capacity battery will negate this problem, but will increase product cost and design complexity.

1.5.2 Product price

Due to increased number of components, the cost of product would be increased as well. As a result, this product will be less competitive on the market.

In order to solve this issue, components with lower price can be used. Another approach is to optimize the design so that less components would be used whenever possible.

1.5.3 More complex algorithm

Since more components are used in this project, a higher attention should be paid on the algorithms. Programmer must take into account not just individual measurements, but also their combinations and decide which set of parameters should define an alarm. The code should be sufficiently complex to allow for simultaneous usage of multiple channels in real time, but at the same time sufficiently compact to run on a microcontroller, and reliable enough to work in any circumstances without errors.

The reliability is critical for the smoke detector since a bug may cause it to become inoperable, but with few indication to notify the user that there is a malfunction. This way the smoke detector can fail to report an alarm in time, causing damage or even fatalities due to fire not detected early enough.

2 Research and Development

This chapter is dedicated to collecting scientific data and designing hardware and software to implement optical smoke detector. There is some research needed to be done before the work can be started.

2.1 Principle of operation

Designing smoke detector requires knowing the principle of aerosol detection and being able to distinguish smoke from non-fire aerosols.

2.1.1 Optical smoke detection

Optical smoke detectors are based on the principle of light scattering or principle of light of obscuration to provide early smoke warning efficiently [14]. Due to its sensitivity and simplicity, light scattering principle is spread used in optical smoke detection. An optical smoke detector has a chamber, which can minimize the unwanted light [15]. Within a chamber, there are one Infrared LED and one photodiode (an IR sensor which consist of a pair of an IR LED and a photodiode) [16]. The photodiode is positioned outside of the light cone of LED. Therefore, when there is no smoke, the photodiode cannot receive any light (figure 6 [17]).

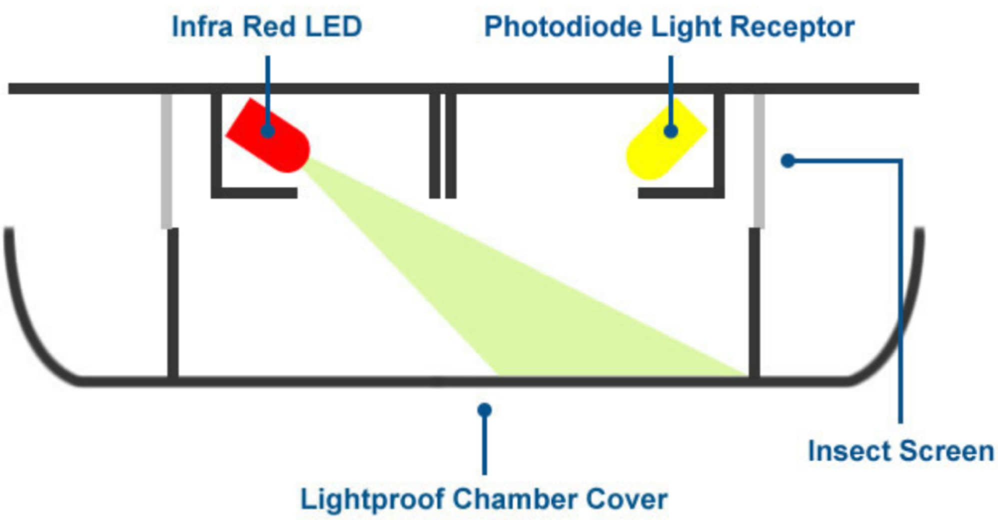


Figure 6. Smoke detector chamber without smoke.

As can be seen in figure 7 [17], when a fire generates smoke, the smoke enters the chamber, smoke particles will scatter the light beam in different directions. Some light reaches the photodiode, the photodiode will convert the light into electrical current. Once the current has passed the pre-set threshold, which would indicate significant amount of smoke in the chamber, the alarm is activated and sounded.

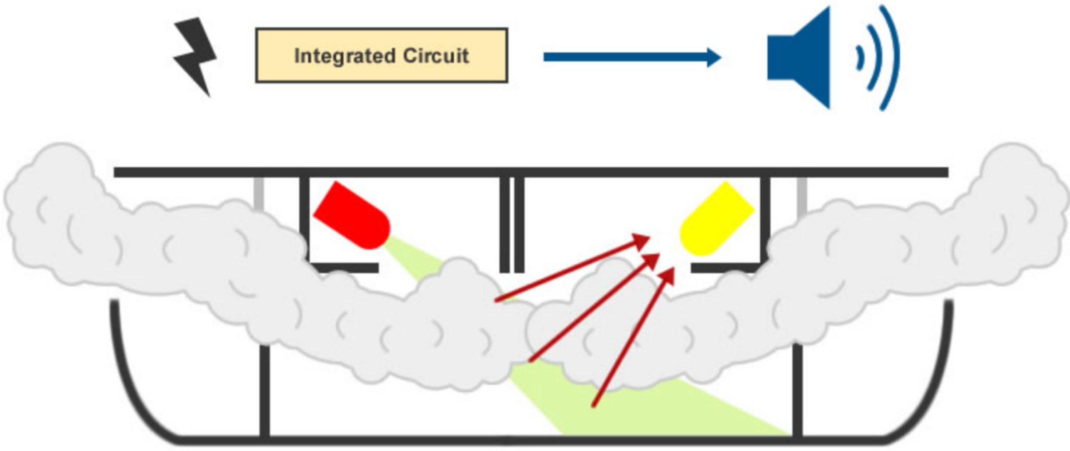


Figure 7. Smoke detector chamber with smoke.

2.1.2 Wavelengths and angles

Light scattering does not always reliably indicate the smoke. Non-fire aerosols can also scatter the light beam, which can reach the photodiode, cause false alarms. In order to reduce false alarms to nuisance resources, some methods should be designed to distinguish smoke from non-fire aerosols.

Nowadays, there are so many low cost optoelectronic components available. Especially for the infrared wavelength (800nm-900nm) components, they have very great performance. This wavelength is significantly applied in light scattering smoke detectors [18].

Multi-wavelength and multi-angle can be implemented in this system. According to the Mie theory, the light scattering is influenced by particle size distribution and wavelength. By correlating the light intensity at different angles and wavelengths, aerosol can be distinguished [19]. Moreover, using multi-photodiode and multi-LED simultaneously can reduce the reaction time and improve sensitivity. Figure 8 [19] illuminates the scattering angle and scattering zone within one pair of LED and photodiode. Therefore, once more than one pair of LED and photodiode are applied, the scattering zone will be increased.

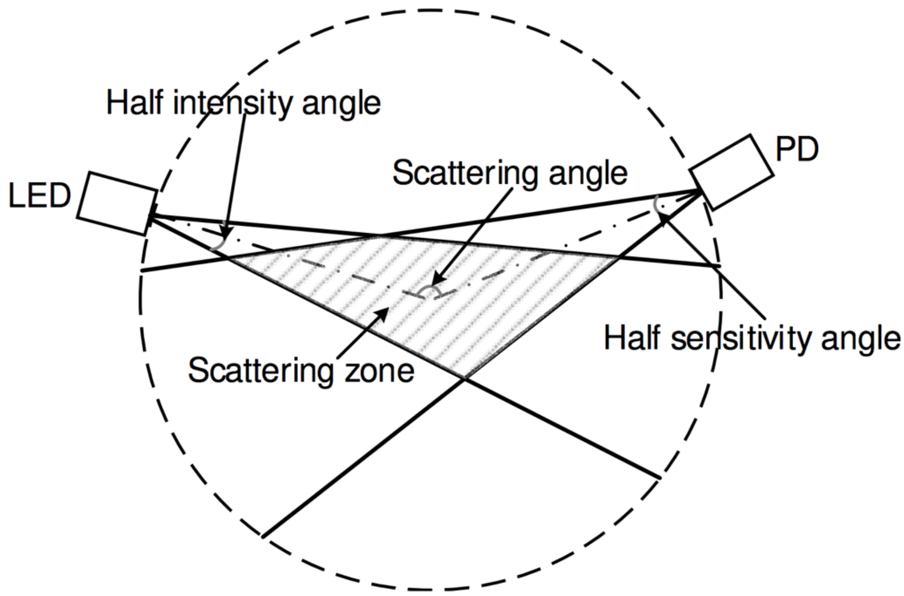


Figure 8. The scattering angle of optical smoke detector.

2.1.3 Multi-criteria smoke detection

There are so many false alarm sources, such as dust, steam, fume, theatrical smoke etcetera. In order to improve the performance of smoke detector and nuisance immunity, multi-criteria detector can be applied. Multi-criteria detector consists of multiple sensors which separated react physical stimulus such as fire gases, smoke or heat. On the other hand, it can also implement more than one sensor to detect the same stimulus [20].

Therefore, additional sensors can be used, such as humidity sensor, temperature sensor and gas sensor etcetera. For the case of a smokeless fire, the room temperature will be measured to decide whether the alarm should be activated. Before implementing the system, the threshold can be predefined. Once the temperature is above the value, the alarm will be triggered. For humidity sensor, it can minimize the false alarms which are caused by vapours which are generated by taking showers or boiling water. The output signal of sensors is mathematically evaluated to determine the alarm.

2.2 Selections of key components

2.2.1 Comparison of different Microcontrollers

Microcontroller, is a small computer on an integrated circuit, which consist of one or more CPUs along with memory and programmable inputs/outputs peripherals, interface with additional firmware devices and implement a series of pre-programmed tasks [21].

In the market, there are so many types of microcontrollers which be selected, such as ARM, AVR, 8051, and PIC MCUs etcetera.

As can be seen in table 1 [21], compared with other three MCUs, An ARM is available at 32-bit and even 64-bit RISC multi-core processors. It can be used in vast applications with high speed operation. Most importantly, the power consumption is very low. For optical smoke detector, one significant factor is the battery life. Hence, one optical smoke detector can last several years with ARM MCU. A study illustrates most smoke detectors last 8 to 10 years, which is quite cost effective.

Table 1. Main difference between AVR, ARM, 8051 and PIC microcontrollers.

	8051	PIC	AVR	ARM
Bus width	8-bit for standard core	8/16/32-bit	8/32-bit	32-bit mostly also available in 64-bit
Communication Protocols	UART, USART,SPI,I2C	PIC, UART, USART, LIN, CAN, Ethernet, SPI, I2S	UART, USART, SPI, I2C, (special purpose AVR support CAN, USB, Ethernet)	UART, USART, LIN, I2C, SPI, CAN, USB, Ethernet, I2S, DSP, SAI (serial audio interface), IrDA
Speed	12 Clock/instruction cycle	4 Clock/instruction cycle	1 clock/ instruction cycle	1 clock/ instruction cycle
Memory	ROM, SRAM, FLASH	SRAM, FLASH	Flash, SRAM, EEPROM	Flash, SDRAM, EEPROM
ISA	CLSC	Some feature of RISC	RISC	RISC
Memory Architecture	Von Neumann architecture	Harvard architecture	Modified	Modified Harvard architecture
Power Consumption	Average	Low	Low	Low
Families	8051 variants	PIC16,PIC17, PIC18, PIC24, PIC32	Tiny, Atmega, Xmega, special purpose AVR	ARMv4,5,6,7 and series
Community	Vast	Very Good	Very Good	Vast
Manufacturer	NXP, Atmel, Silicon Labs, Dallas, Cyprus, Infineon, etc.	Microchip Average	Atmel	Apple, Nvidia, Qualcomm, Samsung Electronics, and TI etc.
Cost (as compared to features provide)	Very Low	Average	Average	Low
Other Feature	Known for its Standard	Cheap	Cheap, effective	High speed operation Vast
Popular Microcontrollers	AT89C51, P89v51, etc.	PIC18fXX8, PIC16f88X, PIC32MXX	Atmega8, 16, 32, Arduino Community	LPC2148, ARM Cortex-M0 to ARM Cortex-M7, etc.

With the development of ICs, microcontroller becomes smaller and smaller, at the same time, it is more sophisticated, low-cost with lower power consumption and user-friendly. Therefore, microcontrollers are widely used in many applications, especially in automatically controlled devices and products, such as robots, remote control, automatic building, mobiles phones, security alarms and smart industry and other embedded systems. In the contemporary world, the development of industry and robotics cannot be executed without microcontroller.

In this project, MSP432P401R is used, which has ARM 32-bit Cortex-X4F CPU Floating-point Unit and memory protection unit. It has advanced low-power analog features and ultra-low-power operating modes. The power consumption is 80 uA/MHz in active mode and 660 nA in standby mode [22]. MSP432P401R functional block diagram (figure 9 [22]) demonstrates different functions which MCU can provide.

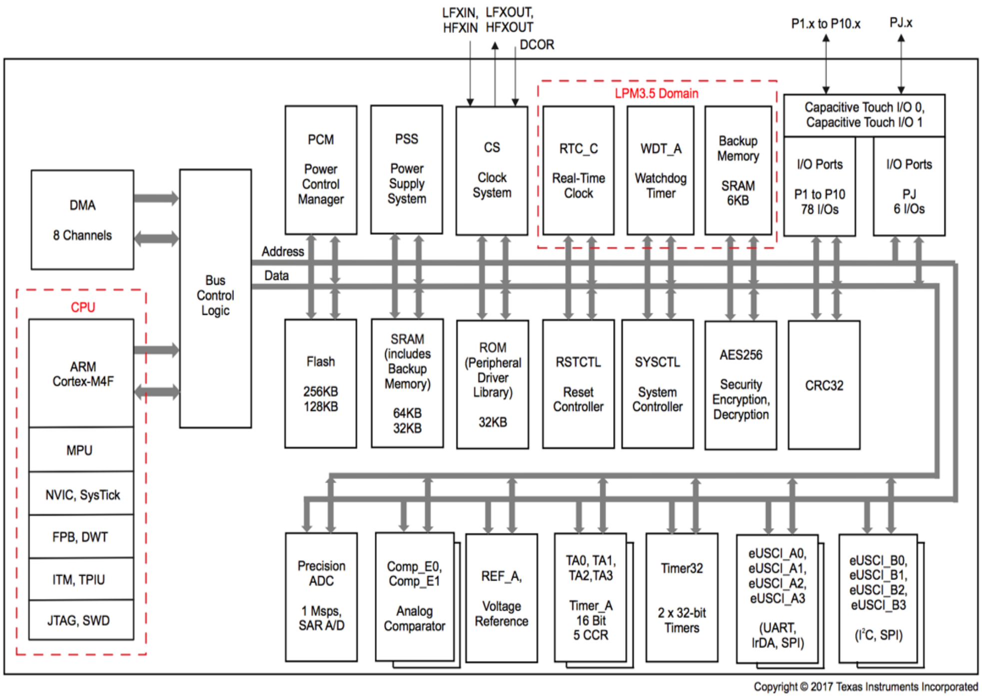


Figure 9. MSP432P401R functional block diagram.

2.2.2 Infrared LED

In this project, green and Infrared LEDs are deployed. Photodiode of SFH 203P is used in this experiment. Its relative spectral sensitivity wavelength can detect from 400-1100nm. Therefore, it is more convenient and practical to employ visible LEDs and Infrared LEDs. Both of them can be connected with MCU in parallel. As can be seen in figure 10 [23] and 11 [24], 568nm and 940nm are the optimal wavelength for green LED and Infrared LED.

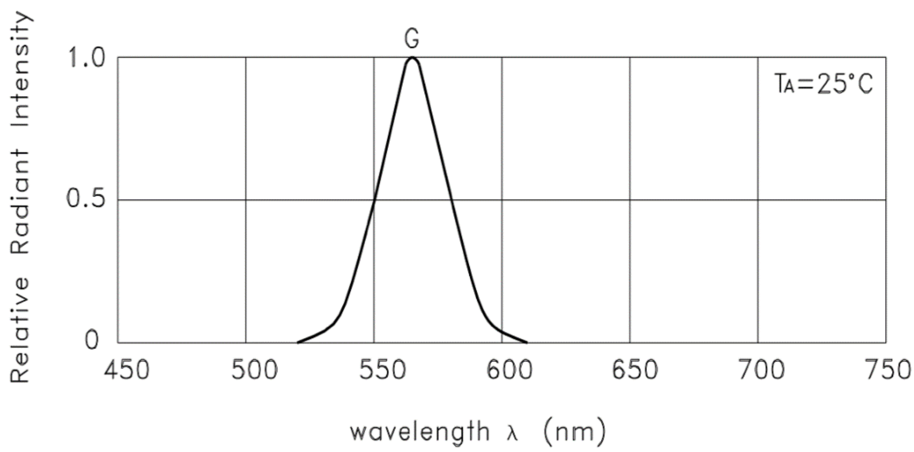


Figure 10. Relative intensity vs. wavelength of green LED.

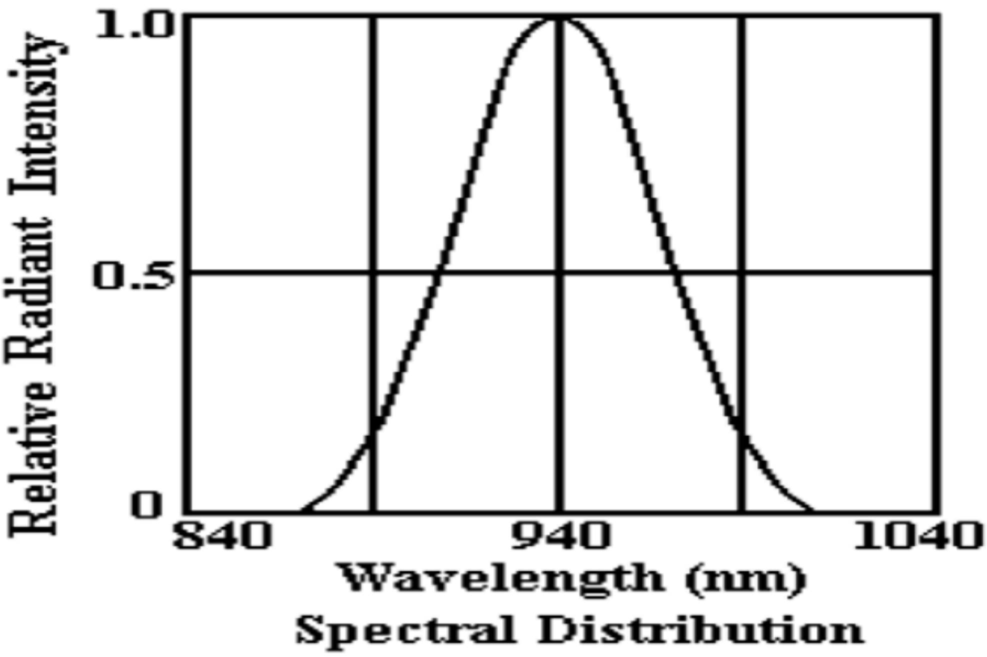


Figure 11. Relative intensity vs. wavelength of Infrared LED.

2.2.3 Photodiode

A photodiode which can convert light signals into electrical current is a semiconductor device. Photodiode which include active p-n junction aborts photos to generate current. This p-n junction is working in reverse bias which can be seen in figure 12 [25]. The photodiode voltage/current characteristics is same as a diode, with the addition a current which is generated by photon [26].

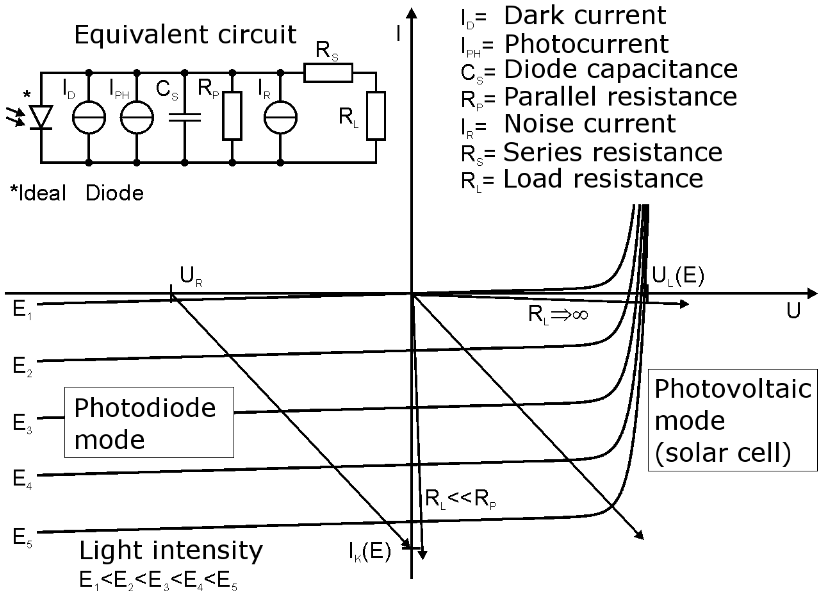


Figure 12. I-V characteristic of a photodiode.

More than one photodiode has been used in this project, such as BPV10NF silicon PIN photodiode and BPW83 silicon PIN photodiode. Different photodiodes have different relative spectral sensitivity. In order to implement multi-wavelength, wide bandwidth is better for experiments.

Compare figure 13 [27] and figure 14 [28], SFH 203P photodiode can detect wide wavelength spectrum and very small amount of light. Hence, it is suitable for multi-wavelength project. In order to implement infrared LED and Green LED at the same time, SFH 203P can fulfil this requirement.

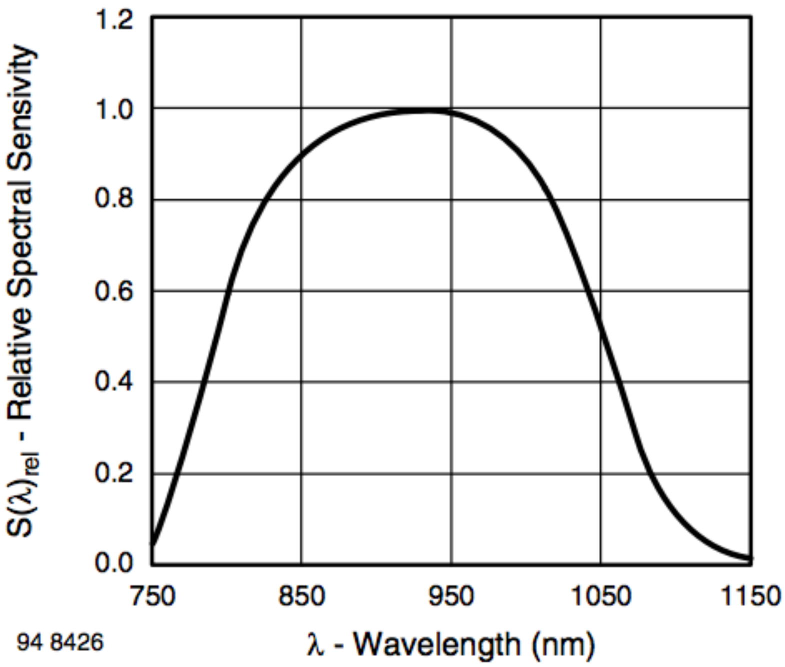


Figure 13. Relative spectral sensitivity vs. Wavelength of BPV10NF.

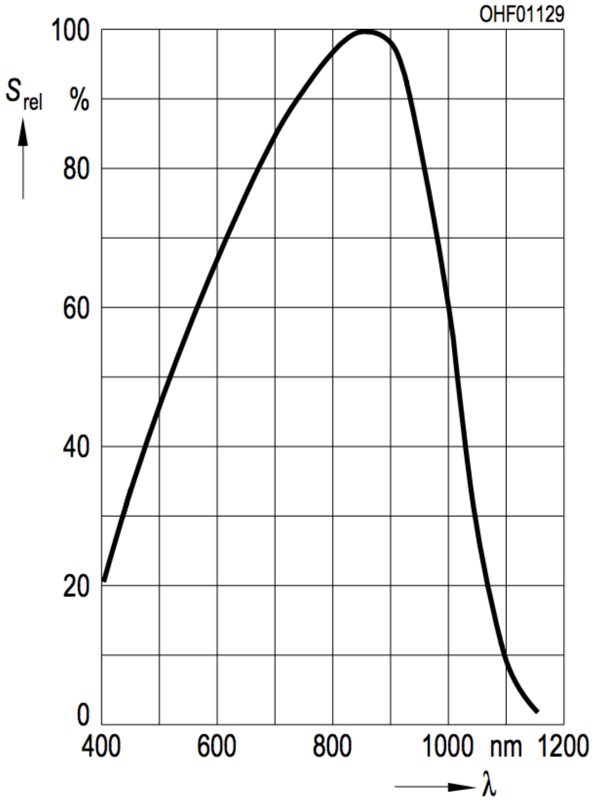


Figure 14. Relative spectral sensitivity vs. Wavelength of SFH 203P.

Figure 15 shows the connection between relative radiant sensitivity and angular displacement of BPV10NF [27].

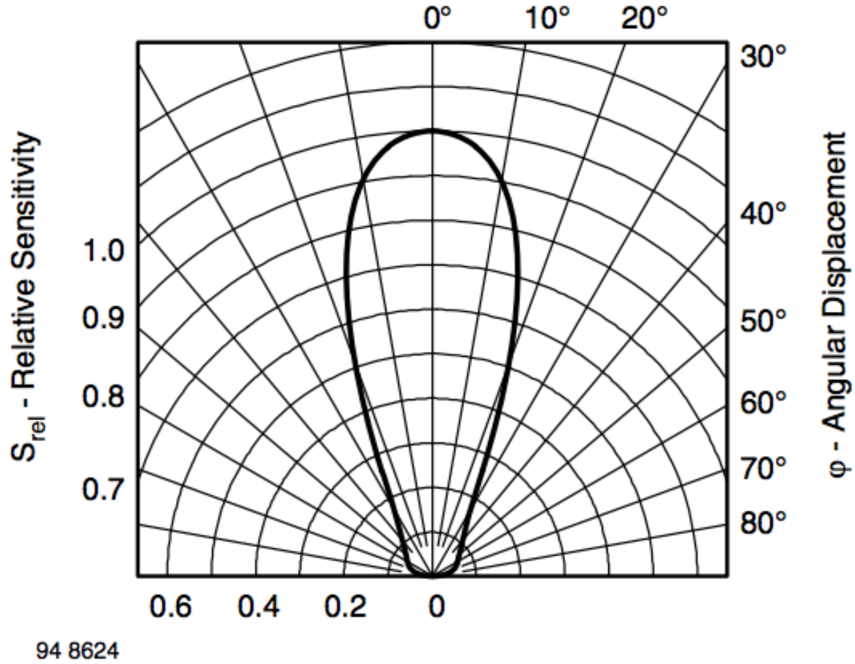


Figure 15. Relative radiant sensitivity vs. Angular Displacement of BPV10NF.

2.2.4 Temperature sensor

A thermistor is a kind of resistor that its resistance will be changed relying on the change of ambient temperature. Typically, NTC (negative temperature coefficient) is utilised in industrial area. With NTC thermistor, the resistance will be decreased as temperature rises [29]. As can be seen in figure 16 [29], the relationship between the resistance and temperature is not linear. The temperature can be easily measured within NTC-resistor. Therefore, in case smokeless fire, the smoke detector still can be triggered.

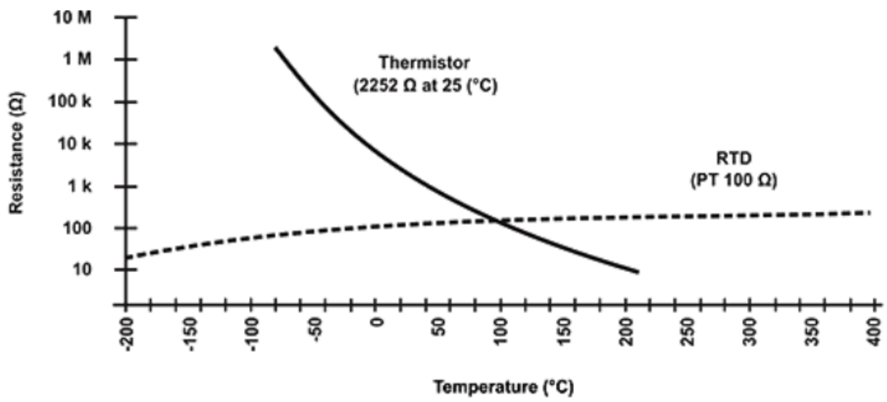


Figure 16. Characteristic NTC curve.

2.2.5 Operational Amplifier

LMx58-N low power dual-operational amplifier is used in this experiment. The large DC voltage gain is 100 dB. The bandwidth is 1MHz. The LMx58 series contains two independent, internally frequency, and high gain operational amplifiers. Those two OpAmps are designed to work from a single power supply over a large range of voltages [30]. It has 8 pins which can be indicated in figure 17 [30].

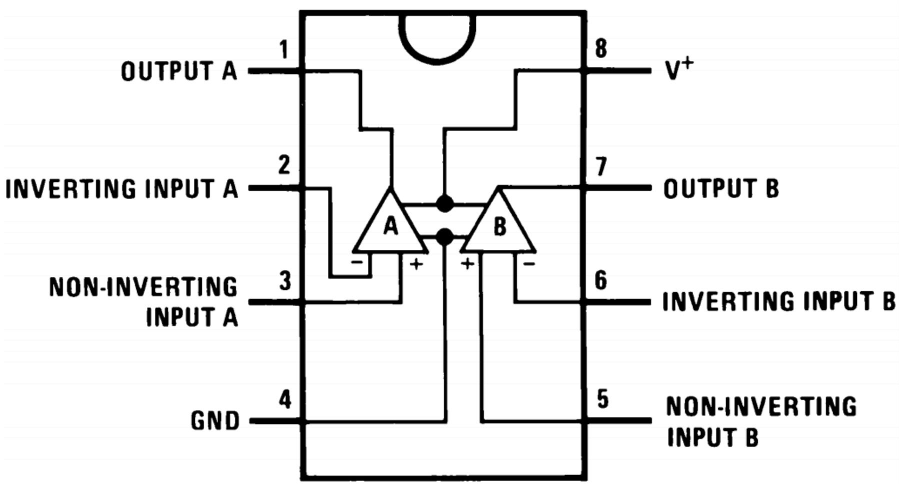


Figure 17. pin configuration.

From table 2, pin function of LMx58-N is shown [30].

Table 2. Pin function.

PIN			TYPE	DESCRIPTION
D/P/LMC NO.	DSBGA NO.	NAME		
1	A1	OUTA	O	Output , Channel A
2	B1	-INA	I	Inverting Input, Channel A
3	C1	+INA	I	Non-Inverting Input, Channel A
4	C2	GND / V-	P	Ground for Single supply configurations. negative supply for dual supply configurations
5	C3	+INB	I	Output, Channel B
6	B3	-INB	I	Inverting Input, Channel B
7	A3	OUTB	O	Non-Inverting Input, Channel B
8	A2	V+	P	Positive Supply

2.2.6 Buzzer

Buzzer is employed in this project as well. Instead of just using LED to indicate the fire alert, buzzer is also added into the circuit. Apparently, buzzer can provide loud sound and inform occupants danger.

2.3 Software tools

2.3.1 Code composer studio 7.2.0

Texas Instrument code composer studio 7.2.0 (ccsv7) is used for programming in the experiment (figure 18). Code composer studio is an integrated development environment (IDE) that supports TI's Microcontroller and embedded portfolio.

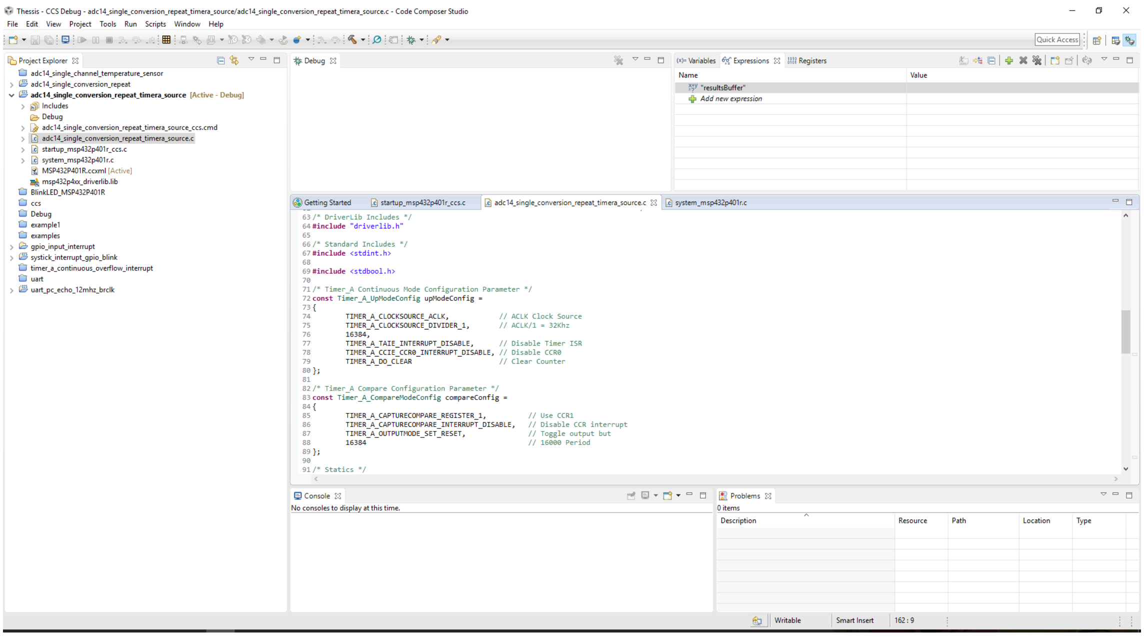


Figure 18. Code composer studio.

2.3.2 EAGLE

EAGLE is a software for PCB (printed circuit board) layout, schematic capture, auto-router and computer-aided manufacturing (CAM) feature. Due to the various component sources, it is easy to implement circuit designs. There are two editors for EAGLE: the schematic editor and the layout editor. The schematic editor helps users create a symbolic easy-to-read representation of circuit design. The layout editor changes the circuit to physical design. Figure 19 and 20 show the schematic editor and layout editor respectively.

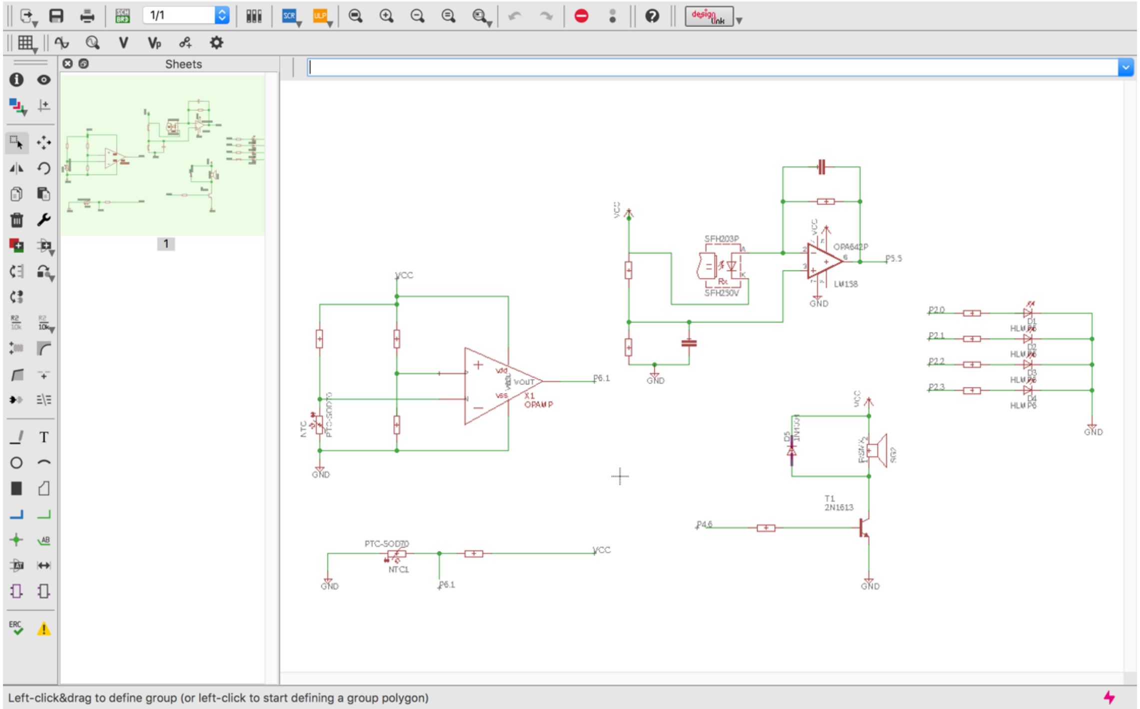


Figure 19. The schematic editor of EAGLE 8.6.3.

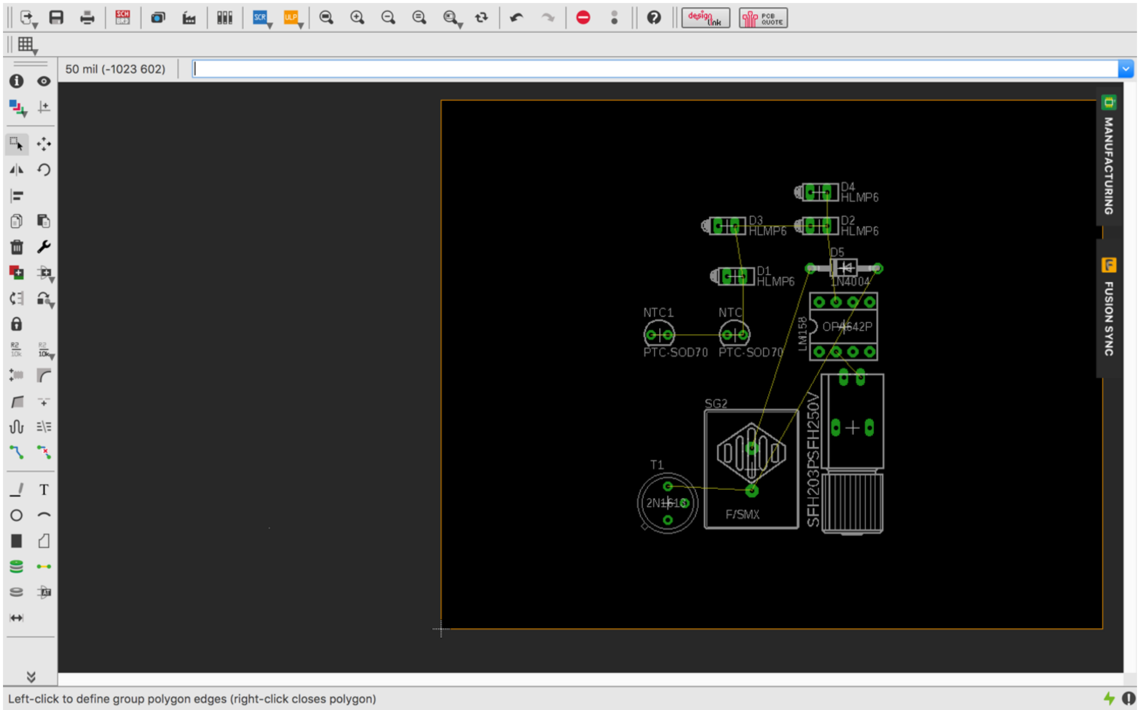


Figure 20. The layout editor of EAGLE 8.6.3.

2.3.3 LTspice

LTspice is a software simulator from Linear Technology. Figure 21 is the integrated circuit of photodiode which is made by LTspice.

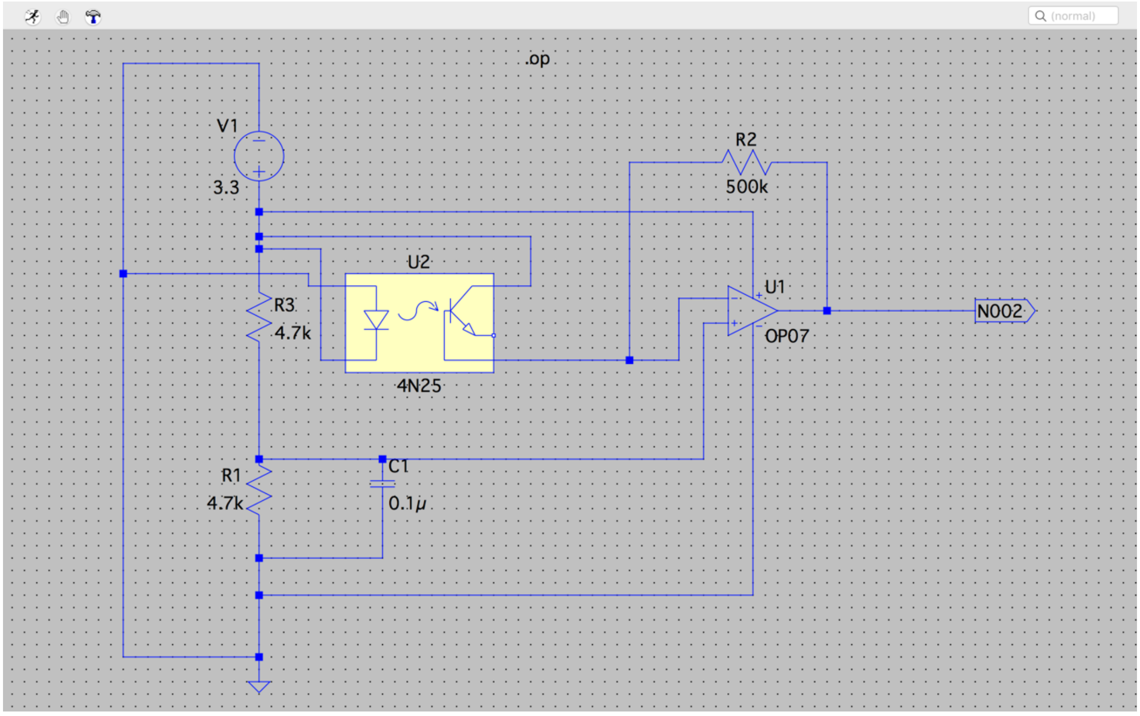


Figure 21. Integrated circuit of photodiode.

2.4 Experiments

Microcontroller is the essence of the system, which can read the data from the inputs (monitors or sensors), process and write data to the outputs (controls). It is a small computer on an integrated circuit. In this project, it can receive all the inputs from different sensors (receivers), such as optical sensor, Time-of-Flight sensor and temperature sensor.

2.4.1 Schematic

Photodiode, which is made of semiconductor and consists of p-n junction, is designed to function in reverse bias. Therefore, the anode of photodiode should be connected with the inverting input of operational amplifier, shown in figure 22.

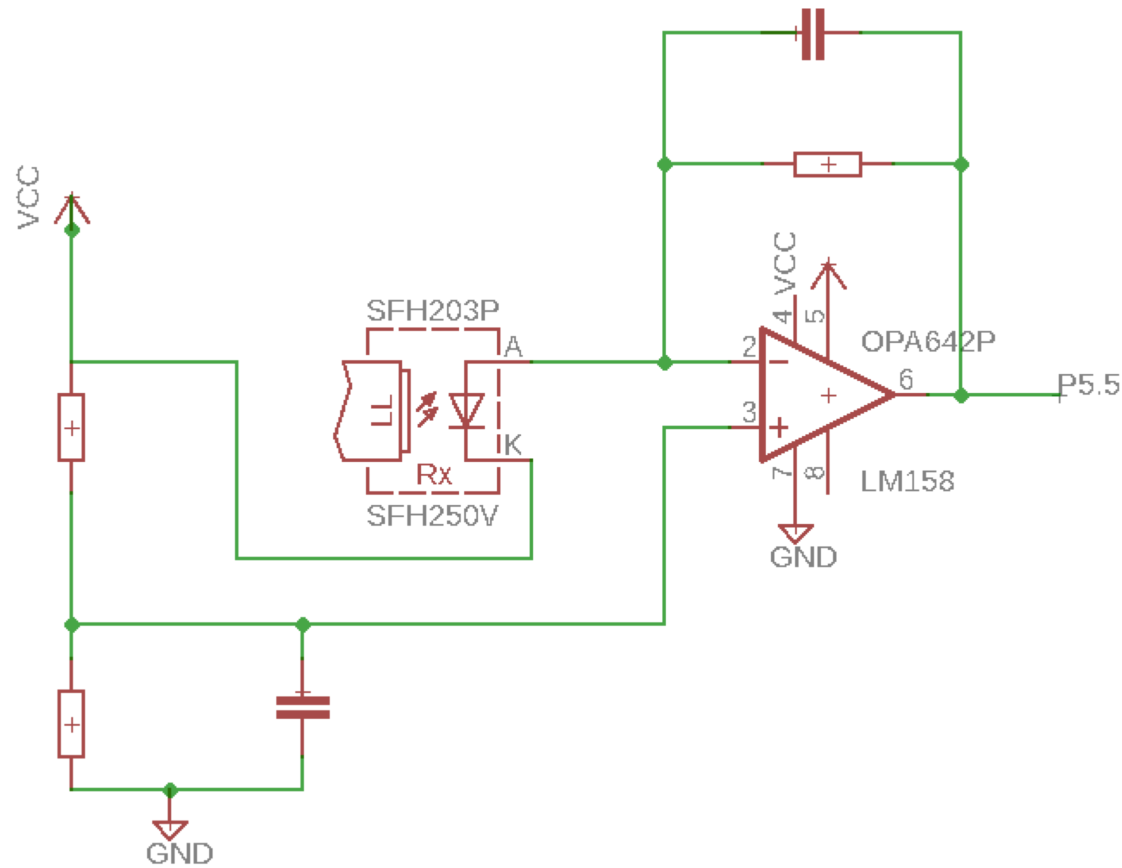


Figure 22. Schematic of Photodiode.

The light emitting element (LEDs) utilizes resistors to limit the current that flow through the LEDs (figure 23). According to the requirements of the optical smoke detector, the LEDs are always on and keeping sending beams into the chamber. Therefore, LEDs can be directly powered by the MCUs [31]. The forward currents of Infrared LEDs (LIR053) and green LEDs (L-1503GD) are 20 mA. In order to guarantee maximum brightness of LEDs, P2.0, P2.1, P2.2 and P2.3 can be used to power 4 LEDs (can be seen in table 2) [32].

Table 3. Digital interfacing (currents) of MSP432.

Family	Example	I_{OH}	I_{OL}	I_{IH}	I_{IL}
Standard TTL	7404	0.4 mA	16 mA	40 μA	1.6 mA
Schottky TTL	74S04	1 mA	20 mA	50 μA	2 mA
Low Power Schottky	74LS04	0.4 mA	4 mA	20 μA	0.4 mA
High Speed CMOS	74HC04	4 mA	4 mA	1 μA	1 μA
Adv High Speed CMOS	74AHC04	4 mA	4 mA	1 μA	1 μA
MSP432 regular drive	MSP432	6 mA	6 mA	20 nA	20 nA
MSP432 high drive	MSP432	20 mA	20 mA	20 nA	20 nA
TM4C 8mA-drive	TM4C123	8 mA	8 mA	2 μA	2 μA
TM4C 12mA-drive	TM4C1294	12 mA	12 mA	2 μA	2 μA

Increased drive strength on P2.0, P2.1, P2.2, and P2.3

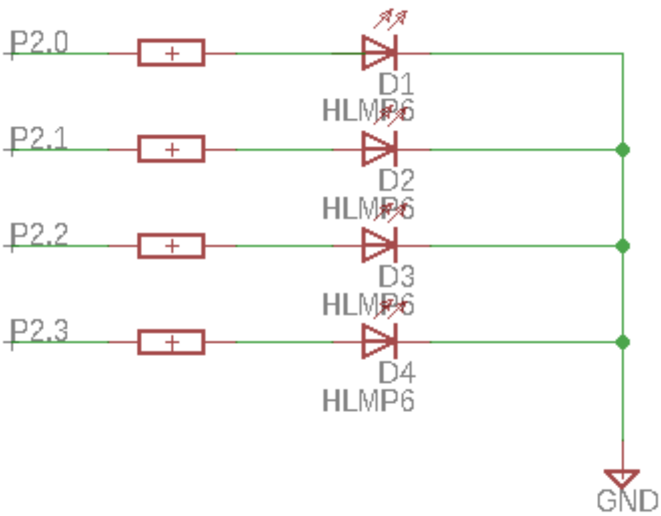


Figure 23. Schematic of Infrared LED & Green LED.

Temperature is an analogue signal. In microcontroller digital systems, digital signal is required. Therefore, an analogue-to-digital converter is needed. There are so many ways to fulfil this requirement. Using an MCU to read the temperature is quite easy. Instead of using an ADC. A voltage comparator that generate 1-bit output can be applied. As can be seen in figure 24, this 1-bit can drive a single MCU's I/O [33].

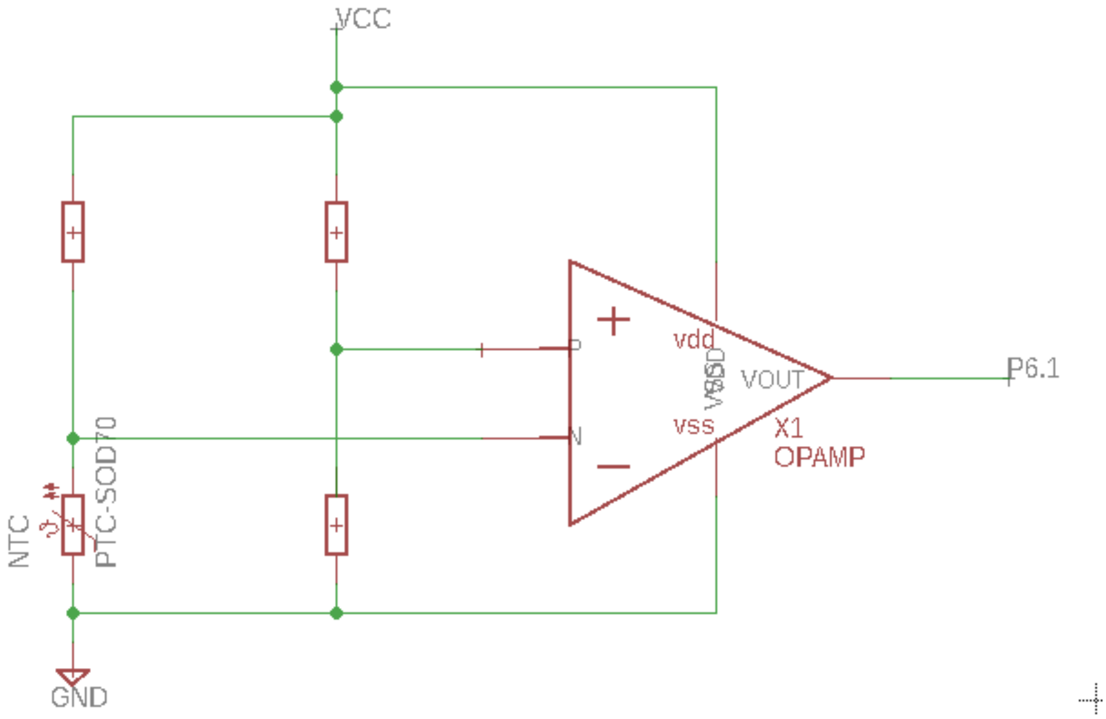


Figure 24. Schematic of temperature sensor.

There is an internal ADC14 inside MSP432P401R. The power supply 3.3V can be directly connected with one end of the resistor, the other end of resistor connects to one pin of the thermistor and other pin of thermistor to ground. The analogue pin of microcontroller is connected to the 'centre' of the resistor and thermistor, as can be seen in figure 25 [34].

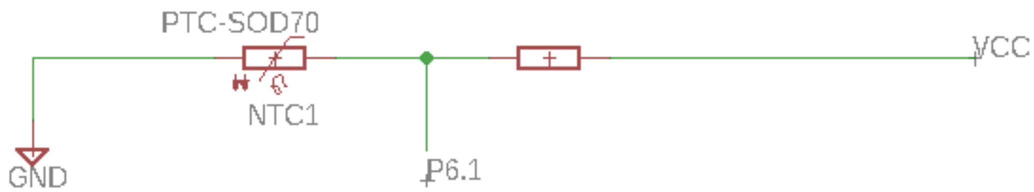


Figure 25. Schematic of NTC.

According to the voltage divider, the resistance of thermistor can be calculated,

$$Vntc = \frac{Rntc}{R+Rntc} * VCC \tag{1}$$

$$\frac{VCC}{Vntc} = 1 + \frac{R}{Rntc} \tag{2}$$

$$\frac{16384}{Ncode} = \frac{VCC}{Vntc} \tag{3}$$

Where VCC is 3.3V (the power supply from microcontroller).

Once the value of Rntc is calculated, compared with table 4 [35], the temperature can easily get.

Table 4. Resistance value vs. Temperature.

RESISTANCE VALUES AT INTERMEDIATE TEMPERATURES WITH R_{25} AT (2.2, 2.7, 3.3, 4.7, 5.0, 6.8, 10) kΩ									
T_{OPER} (°C)	PART NUMBER NTCLE100E3222*** R_T (Ω)	PART NUMBER NTCLE100E3272*** R_T (Ω)	PART NUMBER NTCLE100E3332*** R_T (Ω)	PART NUMBER NTCLE100E3472*** R_T (Ω)	PART NUMBER NTCLE100E3502*** R_T (Ω)	PART NUMBER NTCLE100E3682*** R_T (Ω)	PART NUMBER NTCLE100E3103*** R_T (Ω)	TCR (%/K)	$\Delta R/R$ DUE TO $B_{tol.}$ (%)
- 40	73 061	89 665	109 591	156 084	166 047	225 824	332 094	- 6.62	2.79
- 35	52 778	64 773	79 167	112 753	119 950	163 132	239 900	- 6.39	2.52
- 30	38 544	47 304	57 816	82 344	87 600	119 136	175 200	- 6.18	2.26
- 25	28 443	34 907	42 665	60 765	64 643	87 915	129 287	- 5.98	2.02
- 20	21 199	26 017	31 798	45 288	48 179	65 524	96 358	- 5.78	1.78
- 15	15 950	19 575	23 925	34 075	36 250	49 300	72 500	- 5.60	1.55
- 10	12 110	14 862	18 165	25 872	27 523	37 431	55 046	- 5.42	1.33
- 5	9275	11 382	13 912	19 814	21 078	28 667	42 157	- 5.25	1.12
0	7162	8790	10 743	15 300	16 277	22 137	32 554	- 5.09	0.92
5	5574	6841	8362	11 909	12 669	17 230	25 339	- 4.93	0.72
10	4372	5365	6558	9340	9936	13 513	19 872	- 4.79	0.53
15	3454	4239	5180	7378	7849	10 675	15 698	- 4.64	0.35
20	2747	3372	4121	5869	6244	8492	12 488	- 4.51	0.17
25	2200	2700	3300	4700	5000	6800	10 000	- 4.38	0.00
30	1773	2176	2659	3788	4030	5480	8059	- 4.25	0.17
35	1438	1764	2156	3071	3267	4444	6535	- 4.13	0.32
40	1173	1439	1759	2505	2665	3624	5330	- 4.02	0.48
45	961.8	1180	1443	2055	2186	2973	4372	- 3.91	0.63
50	793.2	973.4	1190	1694	1803	2452	3605	- 3.80	0.77
55	657.5	806.9	986.3	1405	1494	2032	2989	- 3.70	0.91
60	547.8	672.3	821.7	1170	1245	1693	2490	- 3.60	1.05
65	458.6	562.8	687.9	979.7	1042	1417	2084	- 3.51	1.18
70	385.7	473.3	578.5	823.9	876.5	1192	1753	- 3.42	1.31
75	325.8	399.8	488.7	696.0	740.5	1007	1481	- 3.33	1.44
80	276.4	339.2	414.6	590.5	628.2	854.3	1256	- 3.25	1.56
85	235.5	289.0	353.2	503.0	535.2	727.8	1070	- 3.17	1.68
90	201.4	247.2	302.1	430.2	457.7	622.5	915.4	- 3.09	1.79
95	172.9	212.2	259.4	369.4	393.0	534.5	786.0	- 3.01	1.90
100	149.0	182.9	223.5	318.3	338.6	460.6	677.3	- 2.94	2.01
105	128.9	158.2	193.3	275.3	292.9	398.3	585.7	- 2.87	2.12
110	111.8	137.2	167.7	238.9	254.2	345.7	508.3	- 2.80	2.22
115	97.37	119.5	146.1	208.0	221.3	301.0	442.6	- 2.74	2.32
120	85.05	104.4	127.6	181.7	193.3	262.9	386.6	- 2.67	2.42
125	74.52	91.46	111.8	159.2	169.4	230.3	338.7	- 2.61	2.51
130	65.49	80.38	98.24	139.9	148.8	202.4	297.7	- 2.55	2.61
135	57.72	70.84	86.59	123.3	131.2	178.4	262.4	- 2.50	2.70
140	51.02	62.62	76.53	109.0	116.0	157.7	231.9	- 2.44	2.78
145	45.22	55.49	67.83	96.60	102.8	139.8	205.5	- 2.39	2.87
150	40.18	49.31	60.27	85.84	91.32	124.2	182.6	- 2.34	2.96

Figure 26 shows the schematic of buzzer.

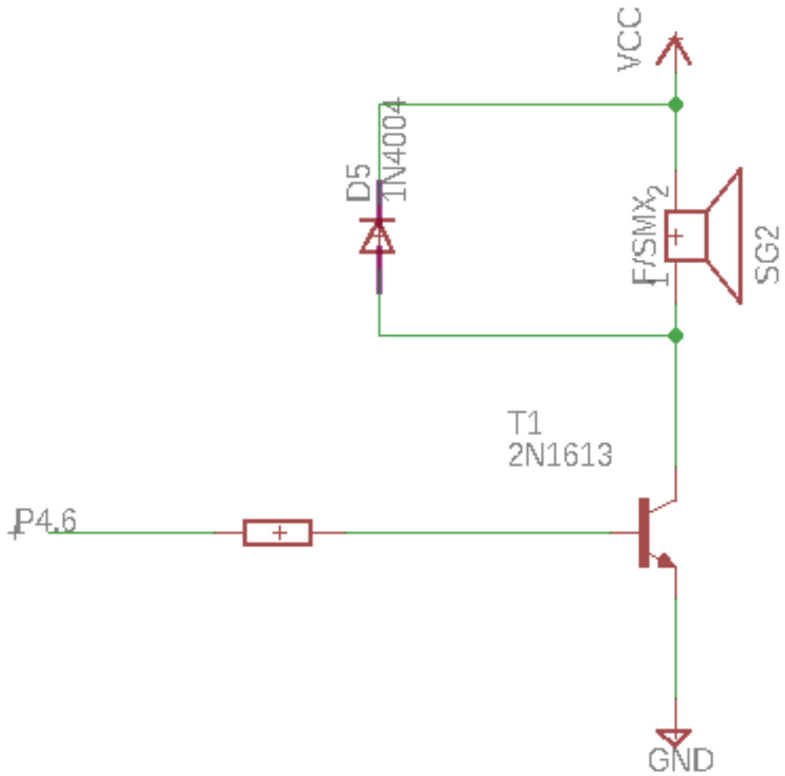


Figure 26. Schematic of buzzer.

2.5 Prototype

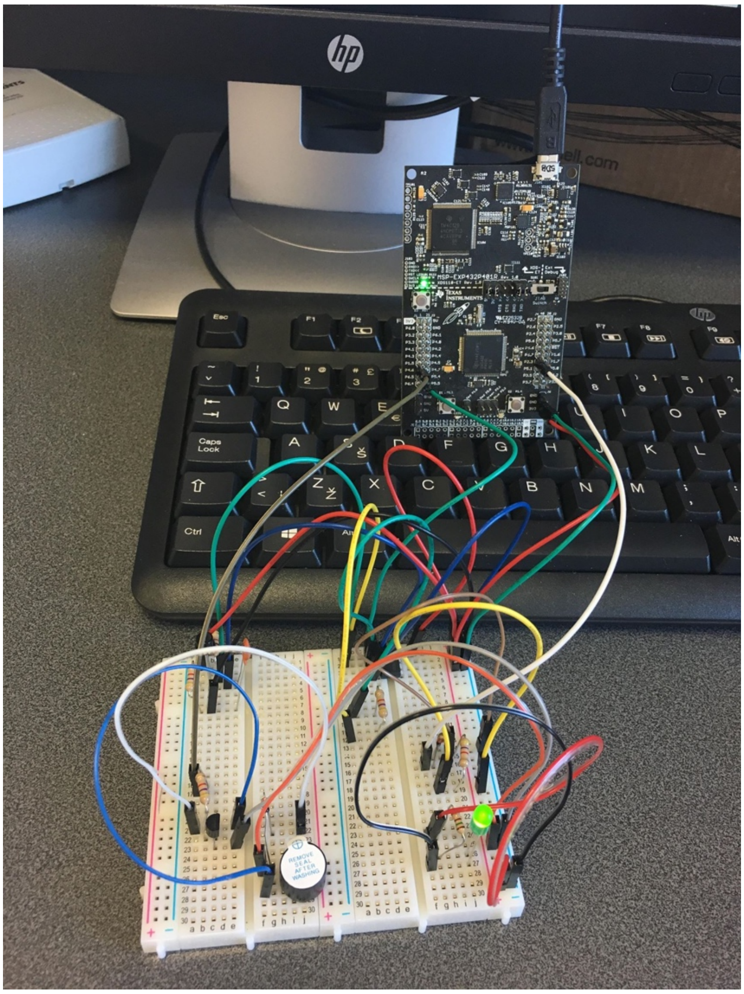


Figure 27. Prototype of Optical smoke detector

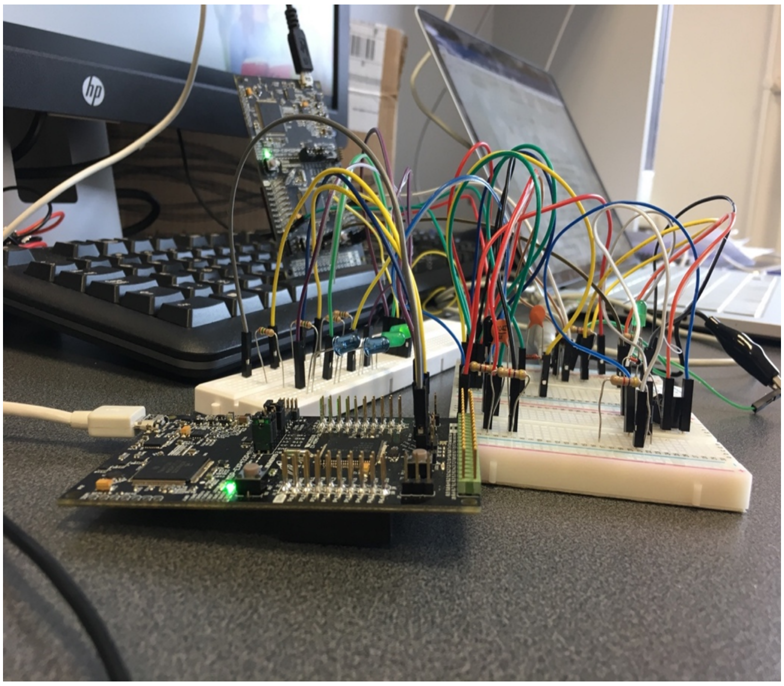


Figure 28. The prototype of optical smoke detector with 4 LEDS in parallel

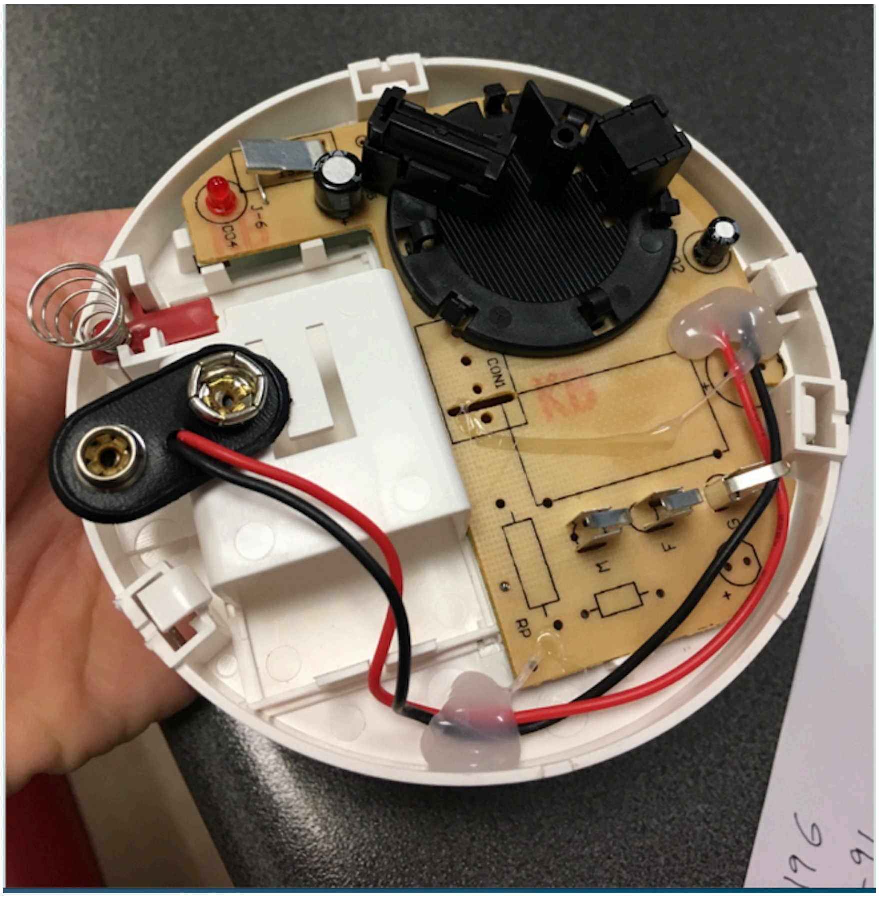


Figure 29. The real inner structure of commercial optical smoke detector

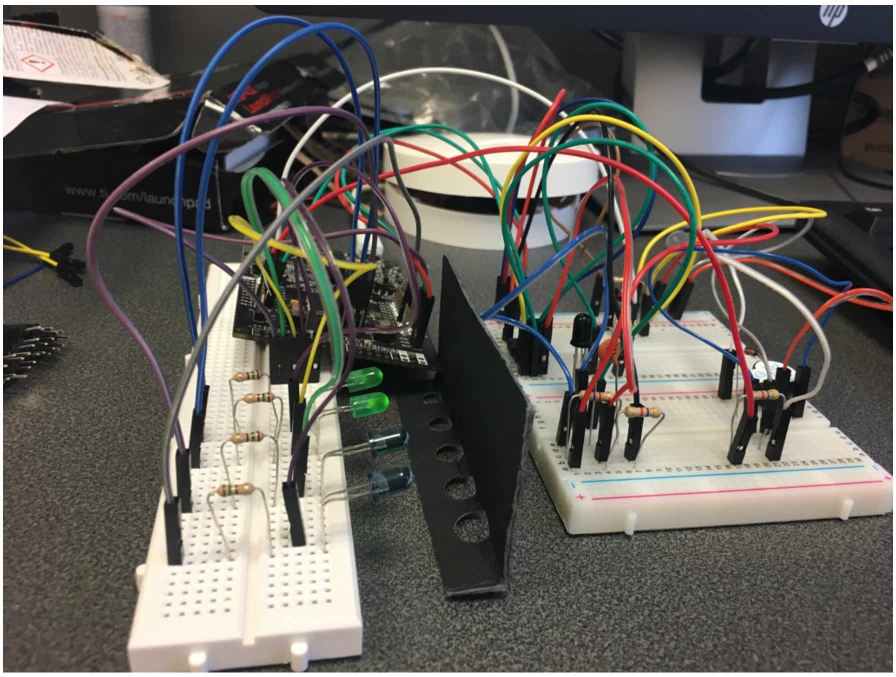


Figure 30. Block the LEDs and photodiode

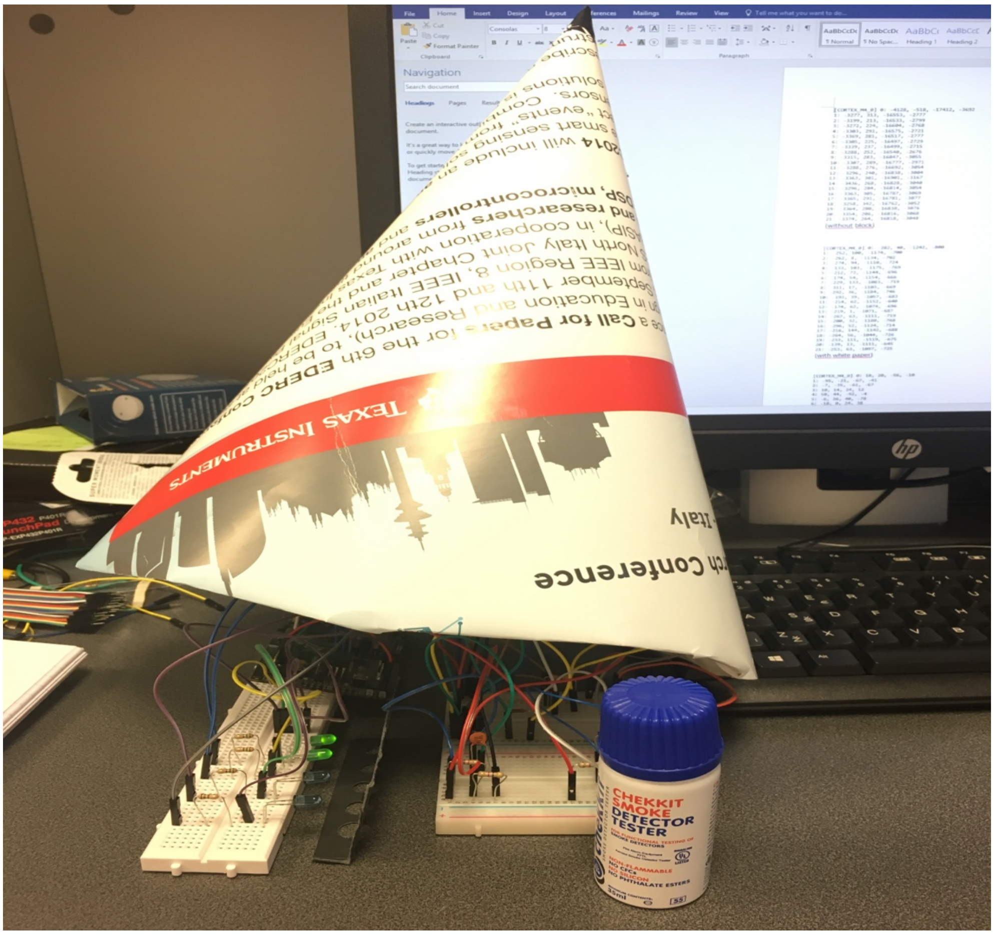


Figure 31. Test the performance with cover

Test the performance of photodiode circuit, it should be implemented within a chamber. Therefore, after using the aerosol smoke detector tester, the current can be generated by the photodiode according to the scattering of light.

3 Results and Evaluation

With the help of LTspice, the output can be simulated (the simulation of output voltage of photodiode can be seen in figure 32). By measuring the voltage drop (1.641V) with multimeter between photodiode SFH 203P, the operational amplifier output can be calculated.

$$V_- = VCC - Vpd = 3.3\text{V} - 1.641\text{V} = 1.659\text{V} \quad (4)$$

$$V_+ = \frac{R}{R+R} * VCC = 0.5 * 3.3V = 1.65V \quad (5)$$

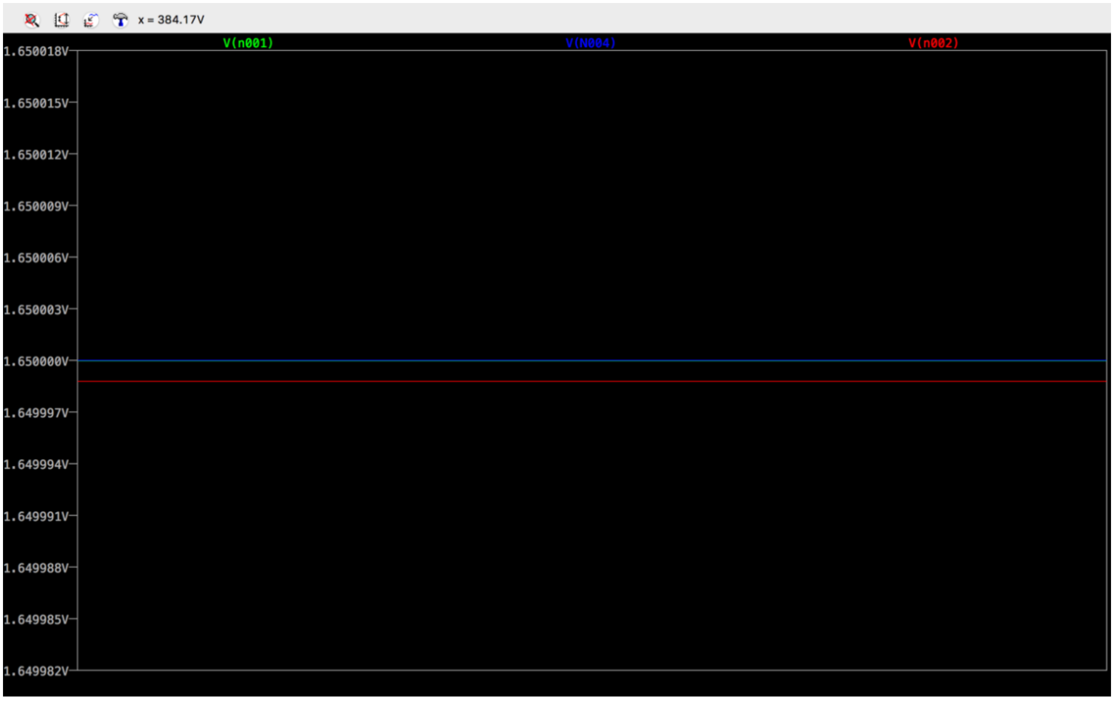
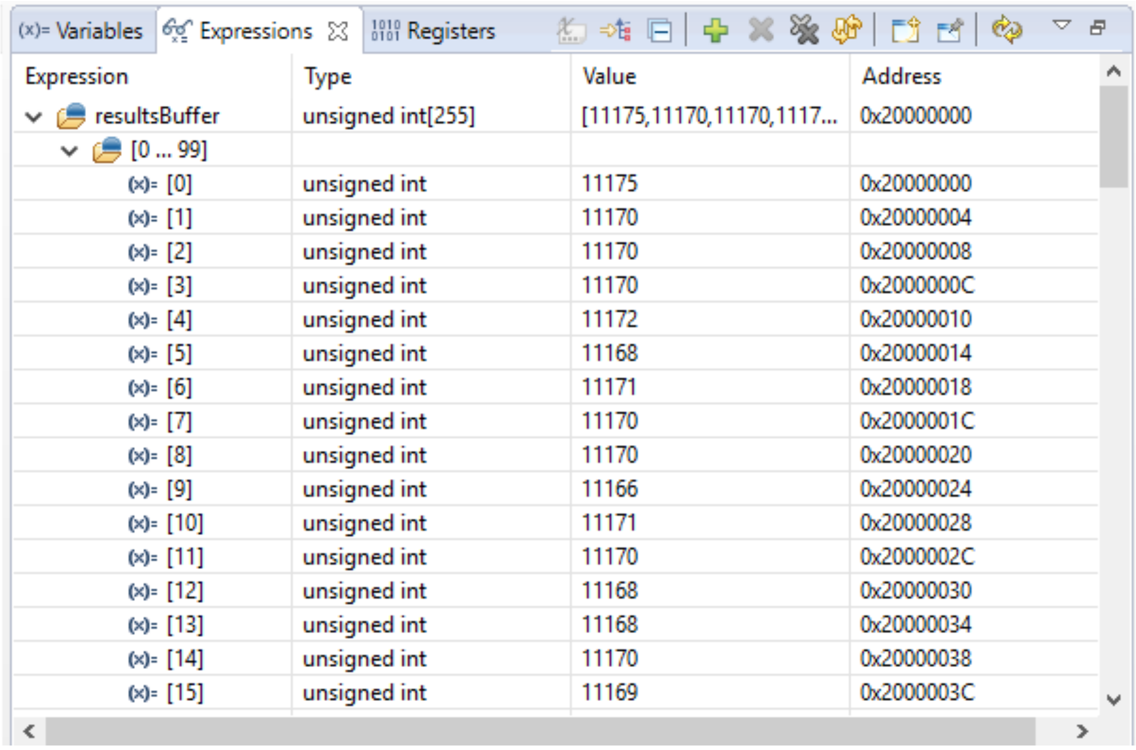


Figure 32. The simulation of output voltage of photodiode

Under the oscilloscope measurement, the output of photodiode circuit is changing all the time. Since 4 LEDs are blinking with the control of software, the voltage of operational amplifier is fluctuated, as can be seen in figure 33.

Figure 33. The output voltage of Photodiode circuit

From figure 34, the output of thermistor can be calculated by the results Buffer.



(x)= Variables | Expressions | Registers

Expression	Type	Value	Address
resultsBuffer	unsigned int[255]	[11175,11170,11170,1117...	0x20000000
[0 ... 99]			
[0]	unsigned int	11175	0x20000000
[1]	unsigned int	11170	0x20000004
[2]	unsigned int	11170	0x20000008
[3]	unsigned int	11170	0x2000000C
[4]	unsigned int	11172	0x20000010
[5]	unsigned int	11168	0x20000014
[6]	unsigned int	11171	0x20000018
[7]	unsigned int	11170	0x2000001C
[8]	unsigned int	11170	0x20000020
[9]	unsigned int	11166	0x20000024
[10]	unsigned int	11171	0x20000028
[11]	unsigned int	11170	0x2000002C
[12]	unsigned int	11168	0x20000030
[13]	unsigned int	11168	0x20000034
[14]	unsigned int	11170	0x20000038
[15]	unsigned int	11169	0x2000003C

Figure 34. The code size of Thermistor

From figure 35, the waveforms of LEDs can be modified to change the output of photodiode. Figure 36 and 37 illuminate the different outcomes.

```
/*statics*/
#define ADCBUFFSIZE 48// 12
#define _4x1 1,1,1,1
#define _4x0 -1,-1,-1,-1

short led1wave[ADCBUFFSIZE]={_4x1,_4x0,_4x1,_4x0,  _4x1,_4x0,_4x1,_4x0,  _4x1,_4x0,_4x1,_4x0};
short led2wave[ADCBUFFSIZE]={_4x1,_4x0,_4x0,_4x1,  _4x1,_4x0,_4x0,_4x1,  _4x1,_4x0,_4x0,_4x1};
short led3wave[ADCBUFFSIZE]={_4x1,_4x1,_4x1,_4x0,  _4x0,_4x0,_4x1,_4x1,  _4x1,_4x0,_4x0,_4x0};
short led4wave[ADCBUFFSIZE]={_4x1,_4x1,_4x1,_4x1,  _4x1,_4x1,_4x0,_4x0,  _4x0,_4x0,_4x0,_4x0};


static volatile uint_fast16_t resultsBuffer[ADCBUFFSIZE];
static volatile uint8_t resPos=0;

long rec=0;
void ADC14_IRQHandler(void)
{
    uint64_t status;

    status = MAP_ADC14_getEnabledInterruptStatus();
    MAP_ADC14_clearInterruptFlag(status);

    if(led1wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2, GPIO_PIN0);
    else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN0);

    if(led2wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2, GPIO_PIN1);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN1);

    if(led3wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2, GPIO_PIN2);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN2);

    if(led4wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2, GPIO_PIN3);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN3);

    if (status & ADC_INT0)
    {
        resultsBuffer[resPos++] = MAP_ADC14_getResult(ADC_MEM0);
        if(resPos>=ADCBUFFSIZE)
        {
  short k1;
  int sum1=0;
  int sum2=0;
  int sum3=0;
  int sum4=0;
      for (k1=0; k1<  ADCBUFFSIZE ; k1++)
      {
      sum1+=   resultsBuffer[k1]* led1wave[k1];
      sum2+=   resultsBuffer[k1]* led2wave[k1];
      sum3+=   resultsBuffer[k1]* led3wave[k1];
      sum4+=   resultsBuffer[k1]* led4wave[k1];
      }
            resPos=0;
            //process the buffer!
 printf ("%d: %d, %d, %d, %d\n", rec++, sum1, sum2,sum3,sum4);

        }
    }

}
```

Figure 35. Code of LEDs

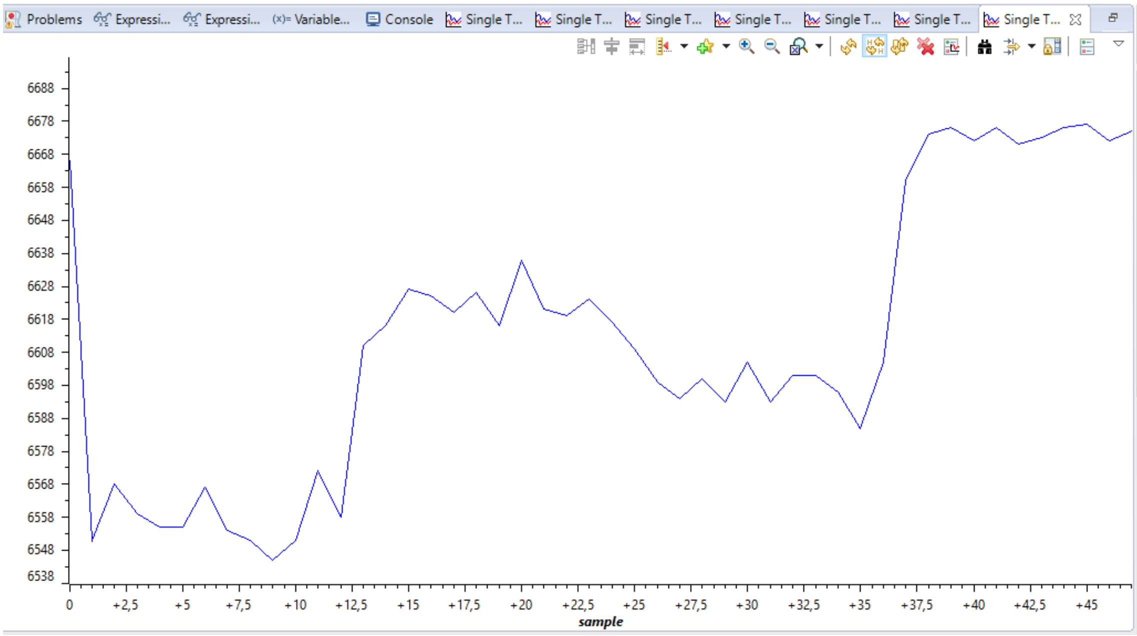


Figure 36. The output of photodiode

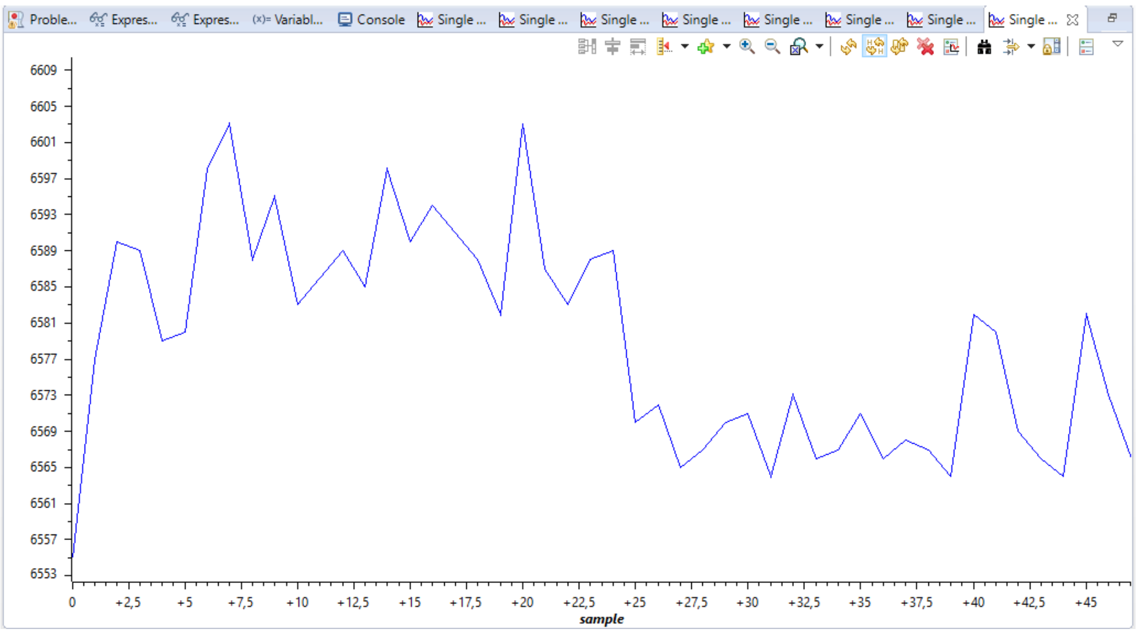


Figure 37. The output of photodiode after changing the state of LEDS

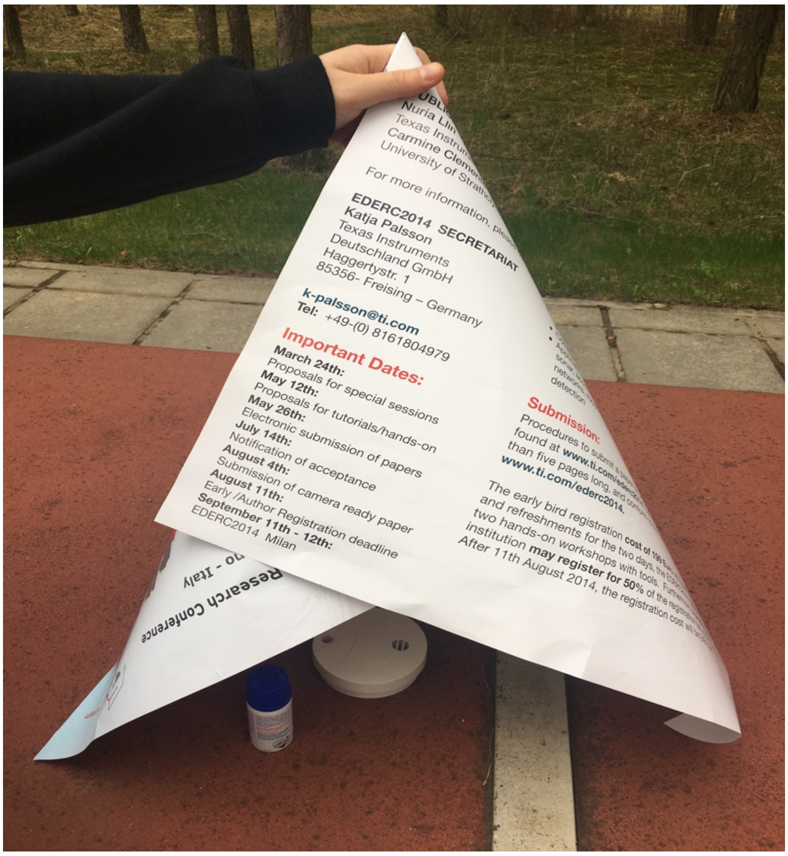


Figure 38. Test the performance of commercial optical smoke alarm SD218

In order to further examine the performance and principle of optical smoke alarm, the author bought a commercial smoke alarm SD218 and tested it outside with aerosol smoke detector and cigarette smoke. The response time to aerosol and cigarette smoke is 11 and 15 seconds relatively (the distance between the smoke source and smoke alarm is 30 centimetres).

Under different circumstances, the results are various.

- Without blocking 4 LEDS and photodiode

From those data (figure 39), which indicate the correlation results of sums, the working situation of photodiode can be detector. Due to LED3 and 4 are infrared LLEDs, the results LED3 and LED4 are larger than LED1 LED2.

```
[CORTEX_M4_0] 0: 55, -1645, -17637, 17637
1: 34, -1528, -17630, 17630
2: -101, -1693, -17711, 17711
3: -70, -1538, -17660, 17660
4: 11, -1573, -17713, 17713
5: 33, -1551, -17733, 17733
6: 78, -1572, -17664, 17664
7: 53, -1599, -17637, 17637
8: -56, -1658, -17668, 17668
9: 32, -1626, -17754, 17754
10: 46, -1608, -17710, 17710
11: -4, -1542, -17672, 17672
12: 96, -1606, -17762, 17762
13: -95, -1645, -17749, 17749
14: 74, -1578, -17620, 17620
15: -33, -1649, -17791, 17791
16: -84, -1560, -17698, 17698
17: 29, -1625, -17695, 17695
18: -4, -1578, -17776, 17776
19: -142, -1638, -17600, 17600
20: 8, -1436, -17690, 17690
```

Figure 39. The outputs of photodiode without blocking.

- Using black paper block LEDs and photodiode

```
[CORTEX_M4_0] 0: 10, 20, -56, -10
1: -95, -21, -67, -41
2: -7, -35, -61, -67
3: 10, 14, 24, 12
4: 50, 44, -42, -4
5: -6, 26, 40, -78
6: -18, 0, 24, 38
7: -61, -1, 41, -75
8: 18, 56, 6, -56
9: -46, 46, 38, -16
10: -47, 57, -5, -27
11: 18, -32, -8, 26
12: 7, 27, -79, -27
13: -4, 78, -32, 16
14: -29, -15, 45, 13
15: 40, -10, 4, -16
16: -47, -27, -39, -47
17: 2, -50, -34, 28
18: -4, 32, 6, 96
19: -7, -11, -3, -33
20: 81, 9, -5, 19
21: -32, 16, -8, 24
```

Figure 40. The outputs of photodiode with blocking.

From figure 41, after number 24, the value of sums is substantially increased within the aerosol smoke detector tester. The response time is around 10 seconds.

```
[CORTEX_M4_0] 0: -204, 72, -830, -928
1: -196, 88, -824, -872
2: -129, 113, -771, -747
3: -52, 114, -758, -780
4: -166, 82, -754, -770
5: -119, -17, -763, -747
6: -64, 4, -574, -722
7: -37, -7, -621, -649
8: -130, 110, -726, -712
9: -87, 123, -669, -863
10: -126, 124, -754, -824
11: -144, 176, -758, -716
12: -141, 163, -725, -829
13: -177, 21, -671, -821
14: -133, 31, -727, -803
15: -80, 56, -760, -824
16: -144, 74, -618, -868
17: -152, 16, -748, -918
18: -15, 91, -701, -849
19: -126, 106, -716, -854
20: -144, 64, -770, -924
21: -174, 144, -740, -862
22: -117, 47, -729, -981
23: -164, 102, -668, -924
24: -175, 119, -741, -1007
25: -235, 123, -947, -1429
26: -118, 178, -894, -1384
27: -189, 81, -955, -1463
28: -200, 102, -874, -1434
29: -187, 93, -907, -1343
30: -133, 161, -905, -1387
31: -181, 123, -853, -1317
32: -237, 105, -901, -1337
33: -189, 147, -843, -1407
34: -181, 163, -859, -1359
35: -142, 150, -902, -1376
36: -242, 120, -934, -1388
37: -241, 161, -999, -1389
38: -159, 101, -887, -1359
39: -193, 179, -843, -1377
40: -104, 156, -896, -1386
41: -189, 133, -923, -1375
42: -139, 93, -909, -1417
43: -182, 18, -890, -1364
```

Figure 41. The outputs of photodiode with the aerosol smoke detector tester.

In order to make sure 4 LEDs beams affect photodiode individually, the selection of waveforms is essential. After calculating the cross-correlation of 4 LEDs waveforms, all of them are 0. It means there is no cross-talking between them.

	1	2	3	4	5	6	7	8	9	10	11	12
LED1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
LED2	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1
LED3	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1
LED4	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1

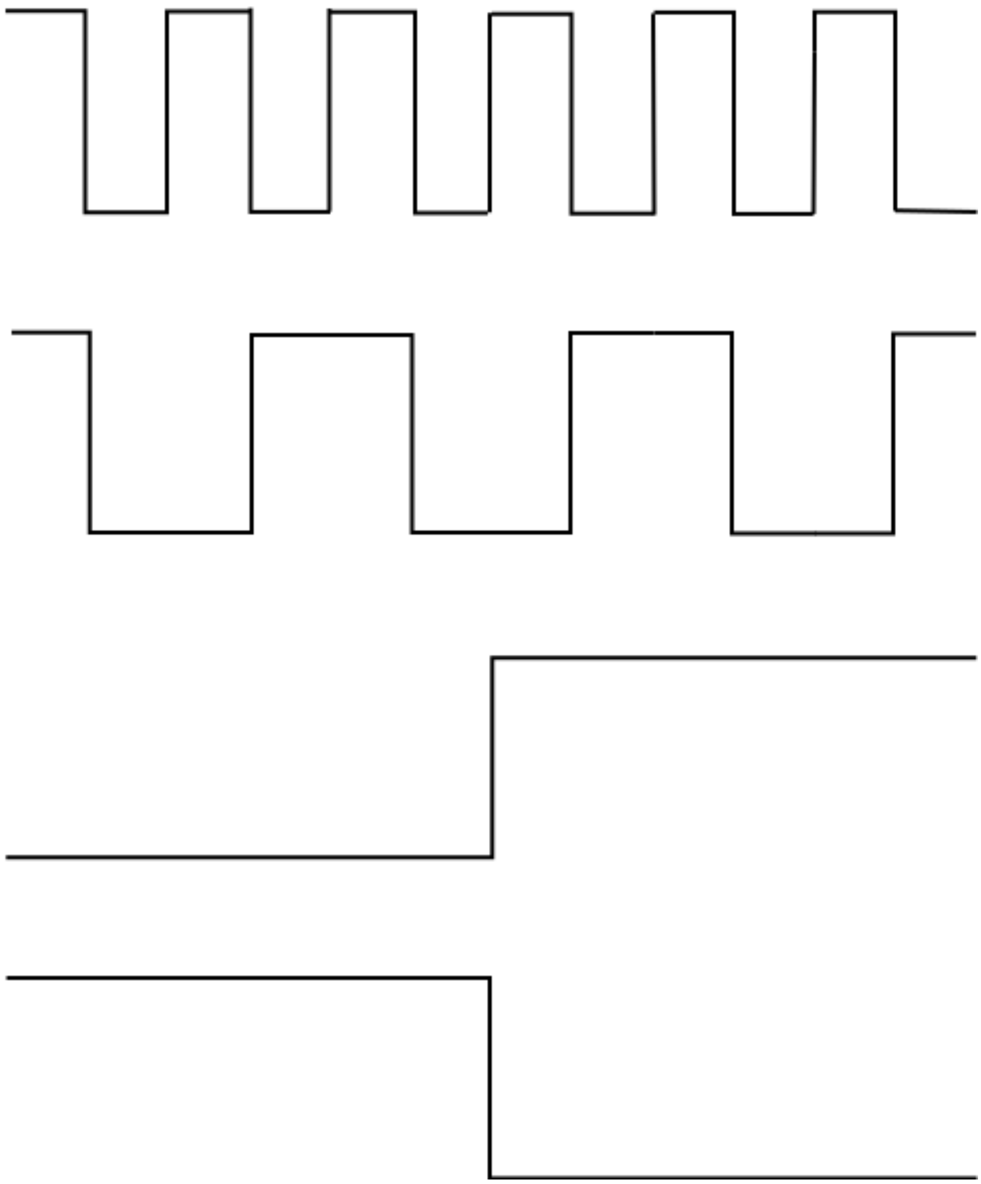


Figure 42. Waveforms of 4 LEDs.

Cross-correlation calculation:

$$Y_{1,2} = \frac{1}{12} * \sum_{k=0}^{12} X_{1,k} * X_{2,k} = 0$$

$$Y_{1,3} = \frac{1}{12} * \sum_{k=0}^{12} X_{1,k} * X_{3,k} = 0$$

$$Y_{1,4} = \frac{1}{12} * \sum_{k=0}^{12} X_{1,k} * X_{4,k} = 0$$

$$Y_{2,3} = \frac{1}{12} * \sum_{k=0}^{12} X_{2,k} * X_{3,k} = 0$$

$$Y_{2,4} = \frac{1}{12} * \sum_{k=0}^{12} X_{2,k} * X_{4,k} = 0$$

$$Y_{3,4} = \frac{1}{12} * \sum_{k=0}^{12} X_{3,k} * X_{4,k} = 0$$

4 Conclusions and Future work

Optical smoke detector based on principle of light scattering. MSP432P401R, high-sensitivity photodiode, and other components make significant differences in this project.

Author of this work drew a conclusion where it is essential to understand the characteristics of photodiode which is the essence component for the prototype. With different software tools, the design part could be done easily. In order to optimize the performance of optical smoke detector, the author suggest that some future work still can be enhanced and make the product more sophisticated.

4.1 Interface a Liquid Crystal Display (LCD)

For this prototype, in the future, it could be added a LCD. Hence, from the LCD, the temperature, humidity and smoke concentration will be illuminated on the screen.

4.2 Use time-of-flight sensor to detect smoke without chamber

4.2.1 Time-of-Flight distance measurement system

Time-of-Flight system can measure the time of the light travel. According to the known velocity of light, the distance between the light source and object can be easily calculated. As can be seen in figure 42 [36], a modulated signal is emitted by a transmitter, when it reached the target, the target reflects a portion of signal back to the receiver. There is a special processor which correlates the transmitted signal and the received signal measuring the flight time [36].

Due to the principle of this technology, it is named light detection and ranging (LiDAR). LED or laser transmitters are employed in this technology, it is working at light speed (about 300000 km/s in air).

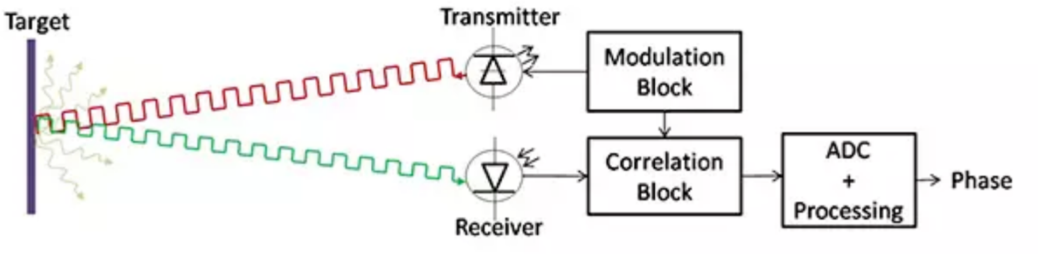


Figure 43. The principle of ToF.

Because of ToF's employment, there is no need for chamber or labyrinth. Hence, the ToF sensor can be placed with the photodetector in parallel on the ceiling.

4.2.2 Time-of-Flight sensor

LiDAR systems need to execute functions reliably and quickly. Therefore, the Time-of-Flight sensor has to provide fast and accurate ranging measurement. The VL6180X is the latest electronic product based on ST's patented Flight Sense technology. The VL6180X can precisely measure the time of the light travels from the nearest object to the sensor. The technical specifications of ToF sensor can be found in table 5 [37].In this project, the distance between the sensor and the smoke can be easily calculated by the light travel time from the sensor to smoke. It can provide more information of fire situation. An I2C is used for result reading and host control. Two programmable GPIO pins are employed for measurement ready and threshold interrupts [37].

Table 5. Technical specifications of ToF sensor.

Feature	Detail
Package	Optical LGA12
Size	4.8 x 2.8 x 1.0 mm
Ranging	0 to 100 mm(1)
Ambient light sensor	< 1 Lux up to 100 kLux(2) 16-bit output(3) 8 manual gain settings
Operating voltage: • Functional range • Optimum range(4)	 2.6 to 3.0 V 2.7 to 2.9 V
Operating temperature: • Functional range • Optimum range(4)	 -20 to 70°C -10 to 60°C
Typical power consumption	Hardware standby (GPIO0 = 0): < 1 μA(5) Software standby: < 1 μA(5.) ALS: 300 μA Ranging: 1.7 mA (typical average)(6)
IR emitter	850 nm
I^2C	400 kHz serial bus Address: 0x29 (7-bit)

4.3 Automated optical smoke detector based on SMS

With the advent of digital technology, it is possible to connect smartphone will the smoke detector via GSM network (figure 44) [38]. Therefore, when people are outside of the premises, the smoke detector systems can send a short message and alert the fire to achieve remote detection. In order to achieve this aim, the wireless communication network needs to be established, which is a wireless local area network to link two or more electronics devices without wires [39]. There are several methods that can be implemented: GSM network, wireless sensor network, wireless networks (RF TX/RX pair) and Ethernet etc. Among all of these means, GSM network is the most feasible and cost-effective way to build the smart systems [11].

GSM stands for Global System for Mobile Communication. It was developed in 1970. Aftermath, it was implemented mobile communication in an open and digital cellular technology for transmitting mobile audio and data services operates in different frequency bands, such as 900MHz, 1800MHz and 1900MHz [38].

Figure 44. GSM Modem.

With the improvements of fire detectors, it is not just focus on smoke detection. Other than smoke sensor, temperature sensor, gas sensor and humidity sensor are employed in the fire-alarm system. Moreover, all the sensor units can be connected via common data line to the MCU. Meanwhile, a GSM kit is needed to send alert information to the users. It is based on network module and able to running in standard GSM bands. When it comes to GSM, there are so many factors considered. In order to achieve this goal, image processing, wireless sensor networks, Ethernet and various digital communication technologies can be implemented in the remote alarm system [11]. Real-time surveillance, automatic alarm and monitoring can be provided via WSNs. Compared with traditional wired networking technique, WSNs consists of massive wireless networks with low-cost sensors. Those sensors can collect and distribute all the useful data for automated fire alarm system [1]. Figure 45 illustrates the flow code of the automated optical smoke based on SMS [11].

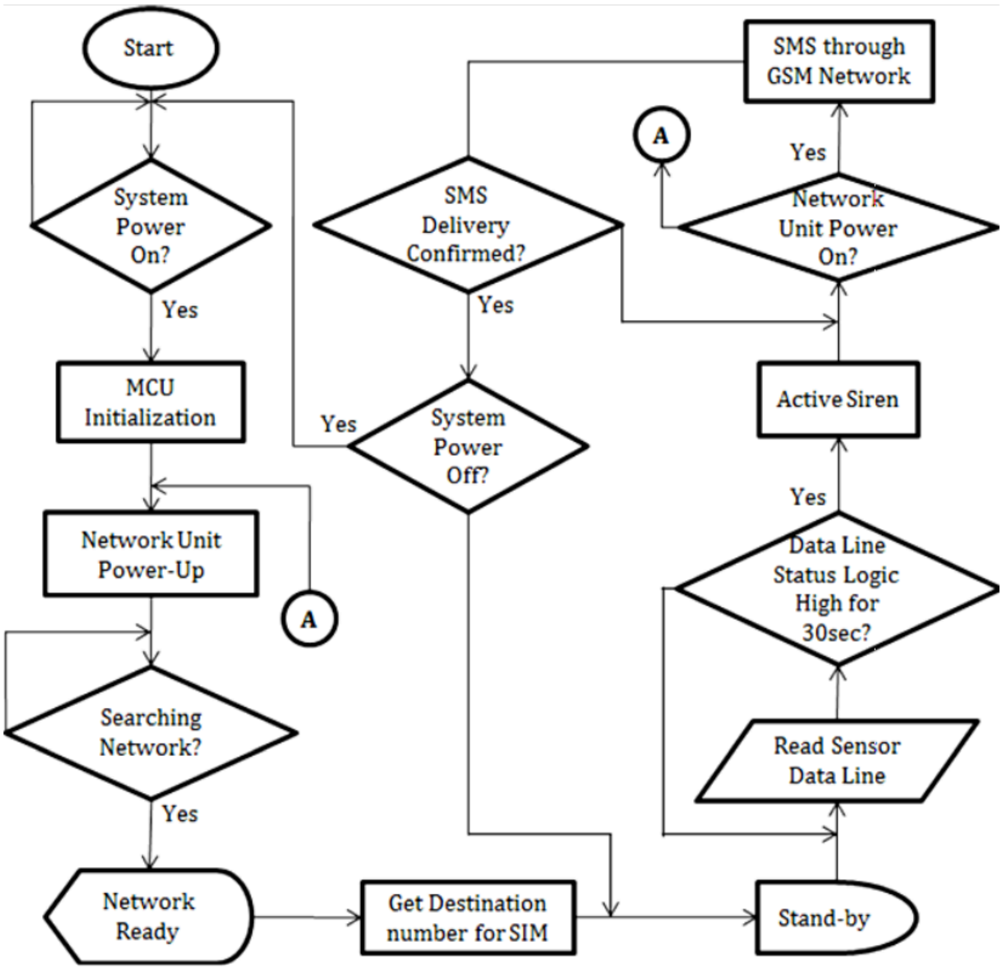


Figure 45. Flow code of the system program.

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Appendix 1 – Code

```
/* DriverLib Includes */
#include "driverlib.h"

/* Standard Includes */
#include <stdint.h>

#include <stdbool.h>

#define XPERIOD 400// 4000 //16384

/* Timer_A Continuous Mode Configuration Parameter */
const Timer_A_UpModeConfig upModeConfig =
{
        TIMER_A_CLOCKSOURCE_ACLK,            // ACLK Clock Source
        TIMER_A_CLOCKSOURCE_DIVIDER_1,       // ACLK/1 = 32Khz
        XPERIOD,//16384,
        TIMER_A_TAIE_INTERRUPT_DISABLE,      // Disable Timer ISR
        TIMER_A_CCIE_CCR0_INTERRUPT_DISABLE, // Disable CCR0
        TIMER_A_DO_CLEAR                     // Clear Counter
};

/* Timer_A Compare Configuration Parameter */
const Timer_A_CompareModeConfig compareConfig =
{
        TIMER_A_CAPTURECOMPARE_REGISTER_1,          // Use CCR1
        TIMER_A_CAPTURECOMPARE_INTERRUPT_DISABLE,   // Disable CCR
interrupt
        TIMER_A_OUTPUTMODE_SET_RESET,               // Toggle output
but
        XPERIOD //16384                                       // 16000
Period
};


int main(void)


{
    /* Halting WDT  */
    MAP_WDT_A_holdTimer();
```

```
    MAP_Interrupt_enableSleepOnIsrExit();
    //resPos = 0;



    /* Setting up clocks
     * MCLK = MCLK = 3MHz
     * ACLK = REFO = 32Khz */
    MAP_CS_initClockSignal(CS_ACLK, CS_REFOCLK_SELECT,
CS_CLOCK_DIVIDER_1);

    /* Initializing ADC (MCLK/1/1) */
    MAP_ADC14_enableModule();
    MAP_ADC14_initModule(ADC_CLOCKSOURCE_MCLK, ADC_PREDIVIDER_1,
ADC_DIVIDER_1,
            0);

    /* Configuring GPIOs (5.5 A0) */
    MAP_GPIO_setAsPeripheralModuleFunctionInputPin(GPIO_PORT_P5,
GPIO_PIN5,
    GPIO_TERTIARY_MODULE_FUNCTION);

    /* Configuring ADC Memory */
    MAP_ADC14_configureSingleSampleMode(ADC_MEM0, true);
    MAP_ADC14_configureConversionMemory(ADC_MEM0,
ADC_VREFPOS_AVCC_VREFNEG_VSS,
    ADC_INPUT_A0, false);

    /* Configuring Timer_A in continuous mode and sourced from ACLK */
    MAP_Timer_A_configureUpMode(TIMER_A0_BASE, &upModeConfig);

    /* Configuring Timer_A0 in CCR1 to trigger at 16000 (0.5s) */
    MAP_Timer_A_initCompare(TIMER_A0_BASE, &compareConfig);

    /* Configuring the sample trigger to be sourced from Timer_A0  and
setting it
     * to automatic iteration after it is triggered*/
    MAP_ADC14_setSampleHoldTrigger(ADC_TRIGGER_SOURCE1, false);

    /* Enabling the interrupt when a conversion on channel 1 is
complete and
     * enabling conversions */
    MAP_ADC14_enableInterrupt(ADC_INT0);
    MAP_ADC14_enableConversion();

    /* Enabling Interrupts */
    MAP_Interrupt_enableInterrupt(INT_ADC14);
```

```
    MAP_Interrupt_enableMaster();

    /* Starting the Timer */
    MAP_Timer_A_startCounter(TIMER_A0_BASE, TIMER_A_UP_MODE);

    /* Configuring GPIO as an output */
              MAP_GPIO_setAsOutputPin(GPIO_PORT_P2, GPIO_PIN0);
              MAP_GPIO_setAsOutputPin(GPIO_PORT_P2, GPIO_PIN1);
              MAP_GPIO_setAsOutputPin(GPIO_PORT_P2, GPIO_PIN2);
              MAP_GPIO_setAsOutputPin(GPIO_PORT_P2, GPIO_PIN3);

    /* Going to sleep */
    while (1)
    {
        MAP_PCM_gotoLPM0();
    }
}
* ADC_MEM0 */

/*statics*/
#define ADCBUFFSIZE 48// 12
#define _4x1 1,1,1,1
#define _4x0 -1,-1,-1,-1

short led1wave[ADCBUFFSIZE]={_4x1,_4x0,_4x1,_4x0,
_4x1,_4x0,_4x1,_4x0,  _4x1,_4x0,_4x1,_4x0};
short led2wave[ADCBUFFSIZE]={_4x1,_4x0,_4x0,_4x1,
_4x1,_4x0,_4x0,_4x1,  _4x1,_4x0,_4x0,_4x1};
short led3wave[ADCBUFFSIZE]={_4x0,_4x0,_4x0,_4x0,
_4x0,_4x0,_4x1,_4x1,  _4x1,_4x1,_4x1,_4x1};
short led4wave[ADCBUFFSIZE]={_4x1,_4x1,_4x1,_4x1,
_4x1,_4x1,_4x0,_4x0,  _4x0,_4x0,_4x0,_4x0};

/*char led1wave[ADCBUFFSIZE]={1,1,1,1,0,0,0,0,1,1,1,1};
char led2wave[ADCBUFFSIZE]={1,1,1,1,-1,-1,-1,-1,1,1,1,1};
char led3wave[ADCBUFFSIZE]={1,0,1,0,1,0,1,0,1,0,1,0};
char led4wave[ADCBUFFSIZE]={0,1,0,1,0,1,0,1,0,1,0,1};*/

static volatile uint_fast16_t resultsBuffer[ADCBUFFSIZE];
static volatile uint8_t resPos=0;

long rec=0;
void ADC14_IRQHandler(void)
{
    uint64_t status;
    status = MAP_ADC14_getEnabledInterruptStatus();
    MAP_ADC14_clearInterruptFlag(status);
```

```
      /* MAP_GPIO_toggleOutputOnPin(GPIO_PORT_P2, GPIO_PIN0);
       MAP_GPIO_toggleOutputOnPin(GPIO_PORT_P2, GPIO_PIN1);
       MAP_GPIO_toggleOutputOnPin(GPIO_PORT_P2, GPIO_PIN2);
       MAP_GPIO_toggleOutputOnPin(GPIO_PORT_P2, GPIO_PIN3);*/

    if(led1wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2,
GPIO_PIN0);
    else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN0);

    if(led2wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2,
GPIO_PIN1);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN1);

    if(led3wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2,
GPIO_PIN2);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN2);

    if(led4wave[resPos]>0)MAP_GPIO_setOutputHighOnPin(GPIO_PORT_P2,
GPIO_PIN3);
        else MAP_GPIO_setOutputLowOnPin(GPIO_PORT_P2, GPIO_PIN3);

    if (status & ADC_INT0)
    {
        resultsBuffer[resPos++] = MAP_ADC14_getResult(ADC_MEM0);
        if(resPos>=ADCBUFFSIZE)
        {
  short k1;
  int sum1=0;
  int sum2=0;
  int sum3=0;
  int sum4=0;
      for (k1=0; k1<  ADCBUFFSIZE ; k1++)
      {
      sum1+=   resultsBuffer[k1]* led1wave[k1];
      sum2+=   resultsBuffer[k1]* led2wave[k1];
      sum3+=   resultsBuffer[k1]* led3wave[k1];
      sum4+=   resultsBuffer[k1]* led4wave[k1];
      }
            resPos=0;
            //process the buffer!
 printf ("%d: %d, %d, %d, %d\n", rec++, sum1, sum2,sum3,sum4);

        }
    }

}
```