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# Design and development of aircraft cargo fire early detection simulation system using arduino nano microcontroller

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## ABSTRACT

Fire in the aircraft cargo can cause dangerous damage to aircraft systems during flight. To prevent aircraft cargo fires, the fire early detection system must be built. In this work, we design and develop the fire early detection simulation system for aircraft cargo using Arduino nano microcontroller. The aircraft cargo is prone to fire due to the load of any type of goods such as dangerous goods, flammable stuff, or liquids, etc. This paper simulates the fire that occurs in artificial aircraft cargo and designs the detection and extinguisher prototypes using three kind sensors: flame, smoke, and temperature sensors combined with SMS gateway for user notification. We used SIM800L GSM module as communication tools to send and achieve data through short messages service (SMS) between security system and cellphones. Three sensors including flame, smoke, and temperature sensors were used as the warning indication to the hardware. When the sensors detect the fire and smoke, the red LED, buzzer, and vacuum pump will be on active mode, and SMS notification will be delivered immediately to the user's cell phone. As the fire has been extinguished by the vacuum pump, the red LED, buzzer, and vacuum pump return to standby mode and the fire warning alarm system will turn off. This research is successfully developing the fire early detection simulation systems that can be applied in real aircraft cargo.

## ABSTRAK

Kebakaran yang terjadi di dalam kargo pesawat dapat menyebabkan kerusakan serius pada sistem pesawat selama penerbangan. Dalam penelitian ini, sistem simulasi pendeteksi kebakaran dini di desain dan dikembangkan pada kargo pesawat menggunakan mikrokontroler Arduino nano. Kargo pesawat rentan terhadap kebakaran karena memuat beragam jenis barang termasuk barang berbahaya, barang mudah terbakar atau cairan, dll. Paper ini mensimulasikan kebakaran yang terjadi di dalam kargo pesawat buatan dan merancang prototipe pendeteksi dan pemadam menggunakan tiga jenis sensor: sensor api, sensor asap, dan sensor suhu yang dikombinasikan dengan SMS gateway sebagai notifikasi pengguna.Modul GSM SIM800L digunakan sebagai alat komunikasi untuk mengirim dan menerima data melalui layanan pesan singkat (SMS) antara sistem keamanan dan ponsel. Ketiga sensor termasuk sensor api, asap, dan suhu digunakan sebagai indikasi peringatan pada perangkat keras. Ketika sensor mendeteksi api dan asap, LED, buzzer, dan pompa air akan menyala, dan notifikasi SMS akan segera dikirimkan ke ponsel pengguna. Ketika api telah dipadamkan oleh pompa vakum, LED, bel dan pompa vakum kembali ke mode siaga dan sistem alarm peringatan kebakaran akan mati. Penelitian ini berhasil mengembangkan sistem simulasi pendeteksi dini kebakaran yang dapat diterapkan pada kargo pesawat yang sebenarnya.

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## 1. Introduction

Cargo compartment is an important part in cargo to protect the goods in the aircraft cargo. In March 2017, a fire was occurred at Hang Nadim International Airport, Batam, that caused by the friction of a thousand cell phone batteries that packed in the aircraft cargo [1]. Aircraft cargo fire can be caused by several factors, such as carrying hazardous goods, flammable liquids or some goods that may cause hot spots in the air. The bundle of batteries may cause a fire when the inside temperature of the cargo increases, that may form a source of heat. Sometimes, the wet load also may cause heat during a flight. In 2021, Hong Kong Airlines prohibit the Vivo mobile phone after a serious fire occurred on the pallets in the aircraft cargo (2). Therefore, it is urgently needed to build an early fire detection system, fire notification to the automatic extinguisher before a serious fire occurs.

One of the ways to build an early detection of aircraft cargo fire is to install a security system with microcontroller technology. This security system should consist of many subsystems and connected to each other; therefore, the fire detection ability can be achieved [3]. The microcontroller is usually connected to flame sensors, smoke sensors, temperature sensors and automatic fire extinguishers. Aris et al. constructed the prototype of fire detection warning system-based microcontroller for Apron Passenger Bus (APB) [4]. The Arduino microcontroller is combined with the three sensors; flame sensor, smoke sensor, and temperature sensor; that will give response to the alarm when the fire is occurred [2] designed the fire early warning system for the house fire using flame sensors, microcontroller, and SMS gateway [5]. Although the fire early warning system has recently earned much attention, only a few of research focus on the early detection system for aircraft cargo fire.

For several years, the aircraft cargo compartment for fire detection must follow the regulation by the National Transport Safety Board (NTSB) and the Federal Aviation Administration (FAA). In August 1980, the Saudi Arabian Airlines had an aircraft cargo fire that caused the death of all passengers and crew [6]. In November 1987, there was a fire in the cargo compartment of the South African airplane that caused the plane to crash into the Indian Ocean [7]. Faster fire detection is the most important indication for fire aircraft cabin, so serious airplane fire can be prevented [8].

In this paper, we proposed the design and simulation for aircraft fire early detection system-based SMS gateway. A fire detection prototype consists of THE SIM 800L module connected to the Arduino Nano. Arduino nano functions to control data that has been loaded in the program for controlling device detection systems such as controlling smoke sensors, flame sensors, and temperature sensors used in the prototype. The working principle of this fire detection system is when the sensors catch the fire and smoke, the red LED, buzzer, and water pump will be on active mode, and SMS notification will be delivered immediately to the user's cell phone. As the fire has been extinguished by the vacuum pump, the red LED, buzzer, and vacuum pump return to the normal mode and the fire warning alarm system will turn off. This proposed prototype has a great potential for the fire early detection in the aircraft cargo.

## 2. Methodology

### *2.1. The working principle*

The working principle of a fire detector and extinguisher-based SMS gateway for aircraft cargo in this paper can be described as follows:

1. After the power supply adapter is installed, the device will turn on after the power switch is activated.
2. At the first turn on, the SIM800L module will search for a signal that is marked by a blinking LED light, to turn on the tool by pressing the ON button when the SIM800L signal is normal which is marked by a flashing light. To synchronize the fire detector with the user's cell phone for receiving a SMS warning message, it is necessary to enter the user's cell phone number into the monitoring programming.
3. After the device is connected to the user's cell phone, if the monitoring program detects fire, smoke, and temperature, the device has been started yet and all of fire detector indication is OFF.
4. Monitoring mode starts by activating the start button, when the monitoring is already running, it is indicated by longer green LED flashes.
5. The reading results will be processed.
6. When there is a temperature captured by LM35 sensor, the yellow LED will light up.
7. When fire and smoke are caught by the sensor for 5 seconds, the red LED, buzzer, and water pump is automatically active, at the same time, the SMS notification will be delivered to the user's cell phone.
8. When the fire still exists for 10 seconds, the next warning SMS notification will be delivered again.
9. If the fire has been extinguished by the vacuum pump, the red LED, buzzer, and vacuum pump will non-active, and the green LED will return to standby. The warning alarm system on the hardware and software is off including the vacuum pump will be OFF after 10 seconds the fire has gone out.
10. After the vacuum pump has succeeded in extinguishing the fire, the next 10 seconds, the cooling fan will turn on as a cooler for the cargo space.
    The hardware used in this paper are SIM800L GSM/GPRS module to connect the microcontroller (Arduino Nano) to the mobile network and usually used as SMS gateway for fire detection [9]-[12], smoke sensor (MQ2), temperature sensor (LM35), buzzer, relay, and water pump. The software uses the Arduino IDE application with the C language as a program design to be inserted into the Arduino Nano.

### *2.2. Fabrication of Cargo Simulation*

The materials needed to build the cargo simulation are made of zinc material that is fire resistant enough for the fire test as shown in Figure 1(a). It must be ensured that the cargo simulation is tight without any air gaps coming in or out. In order to close the gaps between the holes, the plastic wrapping is needed for testing the vacuum pump as shown in Figure 1(b).

a b

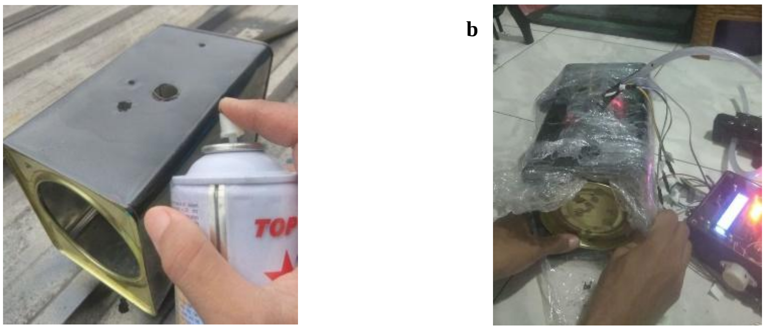

**Figure 1. a Fabrication for aircraft cargo simulation, and b using plastic wrapping for testing the vacuum pump.**

### *2.3. Block Diagram*

The design for the fire detection system in this paper is shown in Figure 2. From Figure 2, the block diagram can be explained as follows:

1. The detection block is the part of all sensors used in the device, including smoke sensor (MQ2), flame sensor and temperature sensor (LM35).
2. The Arduino Nano is the place for processing data and storing the programming from Arduino IDE to generate the desired output.
3. The information block consists of buzzer, LED, SMS notification, SIM800L module, and LCD display. This information block is the result of processing data from Arduino Nano microcontroller as detection reaction.
4. The extinguisher block consists of the relay, fan, and vacuum pump. The extinguisher block is tis an action on the response of the information block.

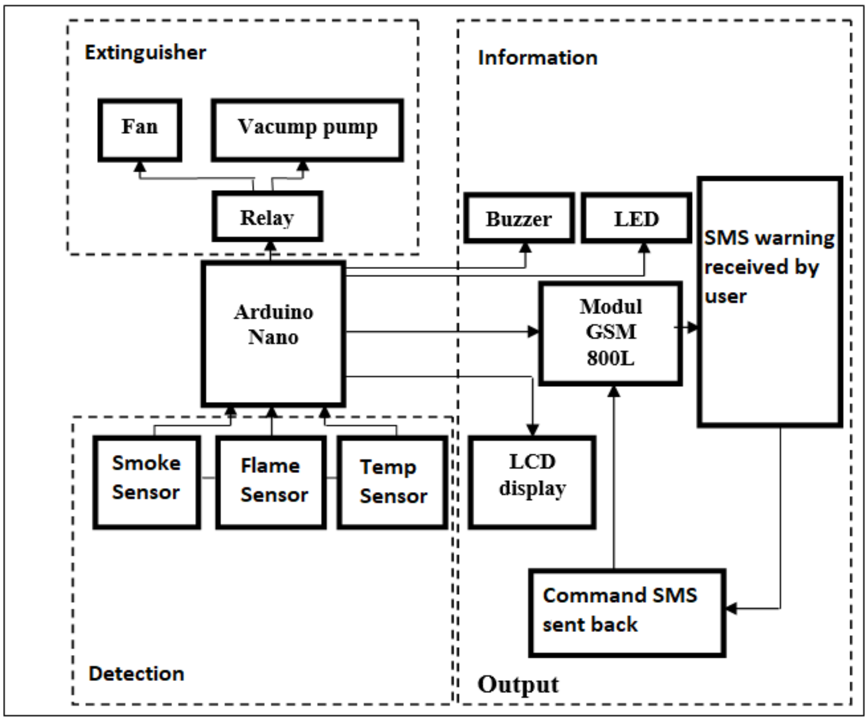


**Figure 2. Block Diagram for the fire detection system**

### *2.4. Schematics, PCB Circuit Layout and Prototype*

Figure 3 shows a schematic diagram of a fire detection and extinguisher device-based SMS gateway. The role of Arduino Nano is writing the program, compiling it into binary code and uploading it into the microcontroller memory as the SIM800L module controller that sends the SMS warning notification to the user's cell phone. Using three sensors as the detectors which are displayed on the LCD display in the form of temperature. A buzzer and LED have a role as an indicator when the sensor detects the presence of fire, and a vacuum pump as a fire extinguisher by sucking the air in the cargo simulation. Figure 4 shows the PCB track used in this work. Figure 5. shows the prototype of a fire detection and extinguisher device-based SMS gateway.

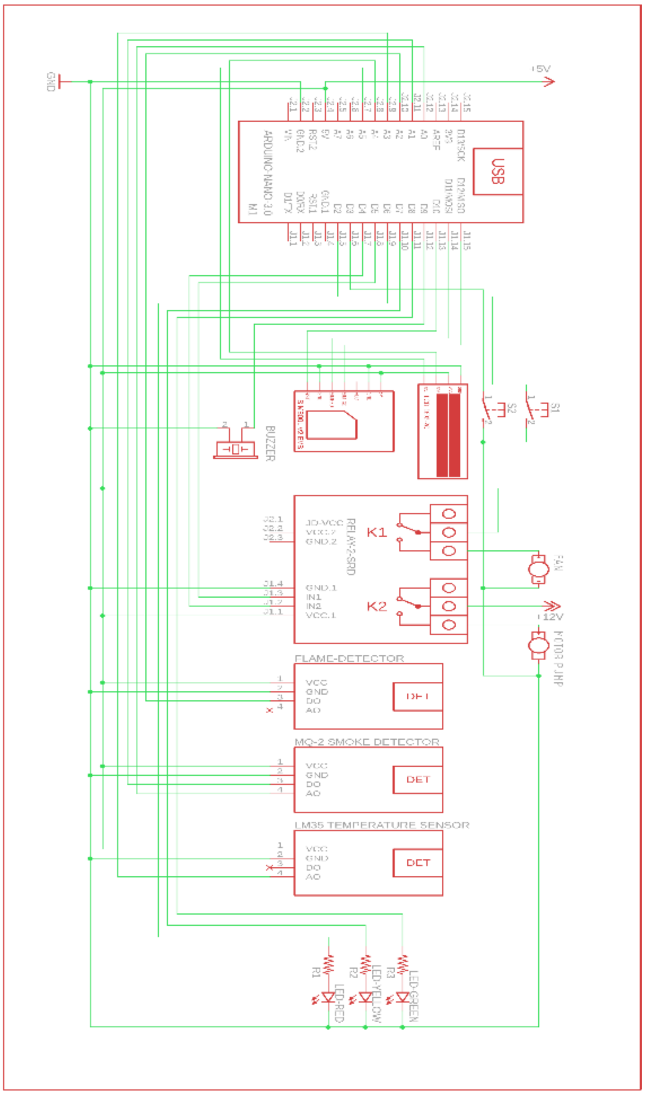

**Figure 3. A schematic diagram of a fire detection and extinguisher device-based SMS gateway.**

The numbering description of Figure 3 as follows:

1. Power adapter 5V.
2. Arduino Nano switch.
3. Arduino Nano pin.
4. SIM 800L module pin.
5. Flame detector pin.
6. Smoke detector pin.
7. Temperature detector pin.
8. 2 relay channel pins.
9. Green LEDs.
10. Yellow LED.
11. Red LEDs.
12. Buzzer.
13. LCD displays.
14. Fan.
15. Vacuum pump.

**Figure 4. The PCB trace is used in this work.**

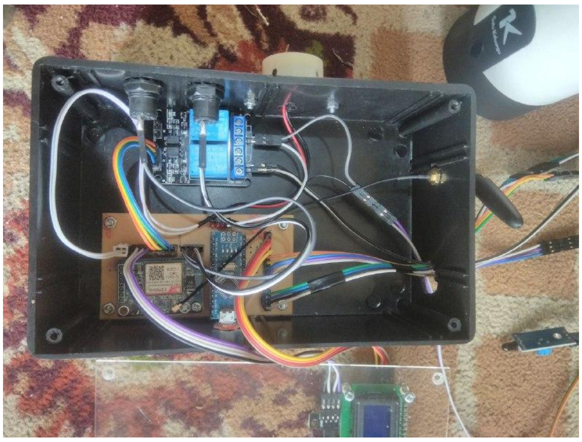

**Figure 5. The prototype of a fire detection and extinguisher device using arduino nano microcontroller**

## 3. Result and Discussions

Testing in this paper is divided into four parts, including the testing for the detection of three sensors; flame sensor, smoke sensor, temperature sensor; on the vacuum pump, and the working system of the fire extinguisher trigger. The next test is to test the working function of the prototype in sending SMS notification to the user's cell phone which is used as an alarm indicator.

### *3.1. Flame sensor testing*

Table 1 shows the results of flame sensor testing. We used candles and a match. It is shown from Table 1 that the sensor can respond to the fire when the sensor is at a higher voltage and when the fire exists.

**Table 1.** The results of flame sensors testing

| Testing | Distance (cm) | Voltage measurement (V) | Sensor response time (seconds) |
|---|---|---|---|
| Candle LIGHT | 5 | With fire:4,52 V | 10 |
| Candle LIGHT | 4 | With fire:3.98 V | Sensor can not detect fire |
| Candle OFF | 0 | No fire: 3.98 V | No sensor response |
| Match LIGHT | 4 | With fire:4,01 V | 10 |
| Match LIGHT | 3 | With fire:3.98 V | Sensor can not detect fire |
| Match OFF | 0 | No fire: 3.98 V | |

### *3.2. Smoke sensor testing*

Table 2 shows the results of smoke sensor testing. We used smoke from cigarettes and paper burns. It is shown from Table 2 that the sensor can respond to the smoke when the sensor is at the higher sensor voltage and when the smoke exists.

**Table 2.** The results of smoke sensors testing

| Testing | MQ2 sensor measurement (V) | Sensor response time (seconds) |
|---|---|---|
| Cigarette smoke | With smoke: 4.42 V | 10 s |
| NO Cigarette smoke | No smoke: 3.47 V | Sensor can not detect smoke |
| Paper burning smoke | With smoke: 4.42 V | 10 s |
| NO Paper burning smoke | No smoke: 3.47 V | Sensor can not detect smoke |

### *3.3. Temperature sensor testing*

Table 3 shows the results of temperature sensor testing. We used two heat sources; heat comes from fire and hot iron. It is shown from Table 3 that the sensor can respond when the high temperature was detected, and the yellow LED will turn on.

**Table 3.** The results of LM35 temperature sensors testing

| Testing | LM35 sensor measurement (V) | Temperature of thermometer (ºC) | LM35 Temperature (ºC) | Sensor response time (seconds) | Yellow LED |
|---|---|---|---|---|---|
| Heat from fire | With temperature: 0.01 V | 31.89 | 31 | 13 s | ON |
| Heat from hot iron | With temperature: 0.01 V | 33.97 | 35 | 12 s | ON |

### *3.4. Smoke sensor and flame sensor testing*

Table 4 shows the results of MQ2 sensor and flame sensor testing simultaneously. We used fire from candle fire and smoke from paper burning. It is shown from Table 4 that the sensor can respond to the fire when the sensor is at the distance of 5 cm and 0 cm from fire candle and smoke source, respectively. After the smoke and fire detection, buzzer, fan, and vacuum pump can work properly (all is turned ON) when the sensor detects a flame from a candle and smoke from paper burning. The vacuum pump can extinguish the fire is start when the sensors detect the fire and smoke, the red LED, buzzer, and vacuum pump will be on active mode, and SMS notification will be delivered immediately to the user's cell phone. As the fire has been extinguished by the vacuum pump, the red LED, buzzer, and vacuum pump return to standby mode and the fire warning alarm system will turn off. The vacuum pump can successfully extinguish the fire which is indicated by the vacuum pump turn off and buzzer sound. The vacuum pump turns off after 10 seconds and the fan turns on due to the heat existing in the cargo space.

**Table 4.** The results of MQ2 sensor and fire sensor testing

| Testing | Distance (cm) | MQ2 and flame sensors measurement (V) | Sensor response time (s) | Buzzer | Vacuum pump | SMS | Fan |
|---|---|---|---|---|---|---|---|
| Flame sensor testing (fire from candle) | 5 | With fire: 4.52 V | 10 | ON | ON | YES | ON |
| MQ2 sensor from paper burning | 0 | With smoke: 4.15 V | 10 | ON | ON | YES | ON |

### *3.5. Overall testing*

Table 5 shows the results of overall testing including all sensors, two kinds of extinguishers and different materials that are burned to create fire in the cargo space (paper, plastic, cloth, and Styrofoam). For the first tests, when the MQ2 sensor and flame sensor are given to different materials to be burned and accompanied by fire extinguishing uses the vacuum pump, the sensor response time at the working temperature between 29 ºC to 33 ºC is varied between 1 s to 21 s. For the second tests, When the LM35 sensor is given to different materials to be burned and accompanied by fire extinguishing uses the vacuum pump and fan simultaneously, the cargo temperature is decrease from 26.03 ºC to 29.73 ºC, and the sensor response time much faster about 1 s to 9 s to be extinguished. When the LM35 sensor is given to different materials to be burned accompanied by the fire extinguishing uses only the fan, the sensor time response to extinguish the fire needs the longer time around 7 s to 16 s. For the last test, when different materials to be burned in the closed room, it needs the longest time to extinguish the fire without turning on the fire extinguisher and the heat of cargo can reach more than 42 ºC.

**Table 5.** The results of overall testing

| Testing | Extinguisher | Material to be burned | Sensor response time (seconds) | Cargo temperature (ºC) | LM35 sensor temperature (ºC) |
|---|---|---|---|---|---|
| MQ2 & Flame | Vacuum pump | Paper | 1″ | 31.89 ºC | 31 ºC |
| | | Plastic | 21″ | 36.70 ºC | 32 ºC |
| | | Cloth | 6″ | 34.8 ºC | 33 ºC |
| | | Styrofoam | 1″ | 28.3 ºC | 29 ºC |
| LM35, MQ2, and Flame | Vacuum pump and fan | Paper | 1″ | 27.04 ºC | 27 ºC |
| | | Plastic | 9″ | 23.89 ºC | 21 ºC |
| | | Cloth | 3″ | 29.73 ºC | 29 ºC |
| | | Styrofoam | 1″ | 26.03 ºC | 25 ºC |
| LM35 | Fan | Paper | 7″ | 36.5ºC | 35 ºC |
| | | Plastic | 16 ″ | 41.8ºC | 41 ºC |
| | | Cloth | 9 ″ | 40.8ºC | 39 ºC |
| | | Styrofoam | 8 ″ | 33.3ºC | 30 ºC |
| Temperature | Closed room | Paper | 7″ | Heat≥42 ºC | 0 |
| | | Plastic | 24″ | Heat≥42 ºC | 0 |
| | | Cloth | 12″ | Heat≥42 ºC | 0 |
| | | Styrofoam | 6″ | Heat≥42 ºC | 0 |

### *3.6. SMS Gateway testing*

SMS gateway testing is set when the flame sensor and smoke (MQ-2) sensor identify fire and smoke, then the SIM800L module is controlled by Arduino Nano to send the SMS notification to the user's cell phone with a message sending delay of only 5 seconds, the SMS notification in the user's cell phone display is shown in Figure 6.

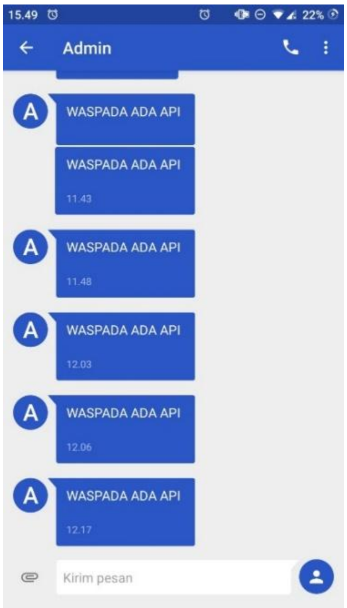


**Figure 6. The SMS notification on the user's cellphone display**

## 4. Conclusion

In this paper, the aircraft cargo fire early detection-based SMS gateway has been designed and developed. We used three sensors; flame sensor, smoke sensor, and temperature sensor; to detect the fire, smoke and increasing temperature inside the aircraft cargo simulation. The simulation, design, and testing in this paper is carried out in a way that is as similar as possible as the near-real aircraft cargo. The response of all sensors, buzzer, vacuum pump, fan, and SMS notifications in this prototype is successfully worked as expected. The improvement can be performed in this prototype by using better sensors with higher sensitivity and carried out in the larger aircraft cargo space simulation. The water extinguisher may be added in the extinguisher systems to burn out the fire at higher intensity.

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