**PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY**
e-ISSN: 2773-5303

**PEAT**

Vol. 5 No. 2 (2024) p. 742-750
https://publisher.uthm.edu.my/periodicals/index.php/peat

# Integrated Fire Safety Solution: A Microcontroller-Based Fire Alarm and Pull-Activated Fire Extinguisher System for Science Laboratory Environment

**Muhammad Ruzaini Rosman[1], Sumaiya Mashori[1]*,**

[1] *Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, 84600, Muar, Johor MALAYSIA*

*Corresponding Author: sumaiya@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2024.05.02.077

**Article Info**

Received: 02 July 2024
Accepted: 31 October 2024
Available online: 25 November 2024

**Keywords**

Integrated Fire Safety Solution,Pull-Activated System

**Abstract**

Fires in science labs endanger students, faculty, and researchers. Traditional fire alarm systems delay detection and response, increasing damage and risk. This study aims to develop an Integrated Fire Safety Solution: A Microcontroller-Based Fire Alarm and Pull-Activated Fire Extinguisher System for Science Laboratory Environment (APAFE System). The system uses an Arduino Uno Rev 3 as its brain and utilises a pull-activated mechanism on 9kg ABC powder fire extinguisher. The system was set up in a specific area measuring 62cm x 45cm x 62cm (length, width, height), assuming a standard laboratory workbench. The fire hose is positioned 10cm from the flame, and the distance between the flame sensor module and the source of fire is set at 20cm. This prototype reacts quickly to gas leaks and flames by activating a siren and warning light, while also sending a short messaging service (SMS) and a phone call to warn authority personnel (laboratory assistant) of a fire in a timely, efficient and coordinated manner to prevent it from spreading and becoming difficult to control. At the same time, the Liquid Crystal Display (LCD) will show the gas value and flame detection status. With the pull-activated mechanism, it takes 3 seconds to pull the trigger of 9kg ABC powder, which is more efficient than the existing mechanism.

## 1. Introduction

According to the Malaysian Department of Occupational Safety and Health (DOSH), the leading causes of workplace accidents are a lack of clearly defined safety guidelines for common work procedures, failure to wear Personal Protective Equipment (PPE), a lack of knowledge about Occupational Safety Health Hazards, and unsafe working conditions. It was discovered that the level of knowledge of laboratory safety practices, specifically the fire aspect, is satisfactory when compared to the aspects of chemical handling, compliance with laboratory general rules, and first aid kit use [1]. Six patients were admitted to the hospital with severe burns because of a laboratory explosion at an elementary school in Istanbul [2]. In contrast, rubbing alcohol caused a fire and minor explosion in a science lab in south-central Pennsylvania [3], and the fire spread quickly due to the presence of flammable chemicals and the age of the building [4].

Progress in Engineering Application and Technology Vol. 5 No. 2 (2024) p. 742-750

According to a Malaysian Fire and Rescue Department article published on December 15, 2014, a chemical reaction started a fire in a chemical laboratory at Sekolah Kebangsaan Dato Penggawa Barat [5]. The investigation's findings, the presence of a fire extinguisher, as shown in Figure 1, were not obtained by the relevant authorities because the fire contained chemicals that were hazardous to those attempting to extinguish it. This situation demonstrates that even having a safety system in place, no one has access to the fire extinguisher, and there is no alarm system to alert the user.

**Fig.1** The position of fire extinguisher

Therefore, the Integrated Fire Safety Solution: A Microcontroller-Based Fire Alarm and Pull-Activated Fire Extinguisher System for Science Laboratory Environment (APAFE System) is developed. This project's aims are to detect and warn authority personnel of a fire in a timely, efficient, and effective manner to prevent it from spreading and becoming difficult to control. Once the sensors detect flame radiation or gas, the warning light and alarm are activated, and the APAFE System sends an SMS and a phone call to take appropriate action. Hence, the user will respond to fire in a coordinated manner. The APAFE System prototype is intended to benefit society in terms of fire safety.

## 2. Previous Research on Microcontroller-based Fire Alarm System

Fire alarm systems are required for safety in all types of buildings, particularly science and research laboratories. Proper fire alarm system installation and equipment are critical for environmental safety. Numerous studies, including an ongoing project, have been conducted to investigate how fire alarm systems operate. Laboratories frequently contain hazardous chemicals, combustible materials, and sophisticated equipment, all of which can pose serious fire hazards. This is significant because most university lab mishaps are caused by unsafe chemical handling and equipment use [6]. Furthermore, the Universiti Malaysia Terengganu *Jawatan Kuasa Induk Keselamatan dan Kesihatan Pekerjaa*n (2020) describes accidents involving the use of chemicals and laboratory equipment involving students [7].

Most fire alarm systems include a variety of sensors, including heat, smoke, and gas detectors. When a fire is discovered, these issue fire alerts and provide information on emergency exits. However, because the fire may have already caused significant damage, such systems may not provide sufficient notice to allow for necessary action when an alert is first activated [8]. To improve laboratory fire safety, future research should assess new technology and conduct cost-benefit analyses [9]. The information provided is intended to improve the laboratory's standards and assist the staff in running the facility more efficiently [10,11].

The automatic gas detection system must sound an alarm to alert occupants, be able to automatically shut off the gas supply, and activate the designated extraction system, while fire safety must be protected by a sprinkler system, an activated fire suppression system, and a fire alarm system [12-13]. The FK-5-1-12 solution is an alternative extinguisher technology that is efficient, safer in confined spaces, and meets sustainability goals [14]. NFPA 13 is considering sprinkler system design options to reduce fire deaths and property damage, while Kodur et al. discovered a critical review of fire hazards in buildings [15-16]. Some researchers discovered an integrated fire control system using Arduino [17], an alert system using a GSM module [18], a PIC16F690 microcontroller to detect the presence of LPG gas leakage from a MQ-6 sensor [19], a GSM module that sends a Google map and URL address to the fire control office [20], and a fire extinguisher robot controlled by an ATmega microcontroller capable of entering the fire-prone areas [21].

# 3. Methodology

## 3.1 APAFE System's Prototype Construction

Figure 2 illustrates the 3D design created with Shapr3D software and the developed APAFE System prototype, with length, width, and height measurements of 97cm, 45cm, and 92cm, respectively, while Tables 1 shows the APAFE System technical specifications. The controller and electronic components for the project are mounted on top of the circuit board. On the right side, a siren and warning light were installed. The flame sensor is attached to the side of the laboratory table with 62cm x 45cm x 62cm (length, width, height), while the MQ-2 sensor is attached to the top of the laboratory table using an iron pole. This project's design is based on a laboratory table scenario, and the wooden board was chosen due to its simplicity. Aluminium sheets are placed on top of the laboratory table to serve as a base for a fire test. The free wheelers are attached to the bottom of the system, making them portable and easy to transport from one location to another.

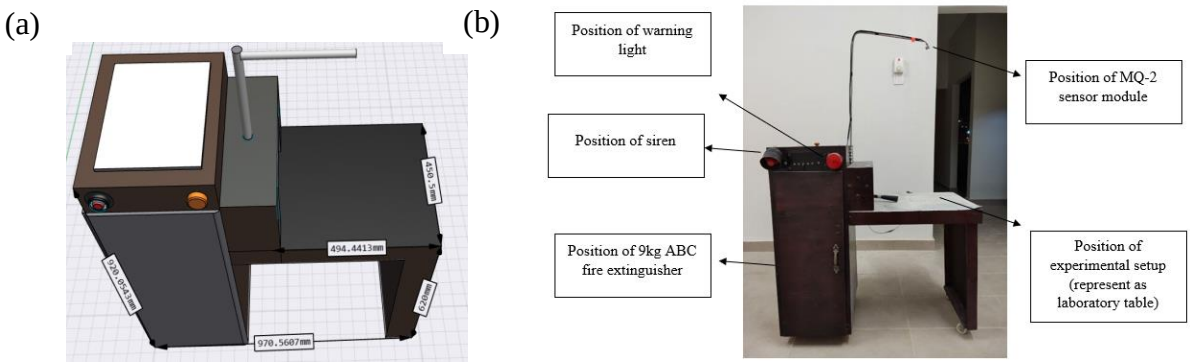


**Fig. 2** APAFE prototype (a) 3D design; (b) Developed system.

**Table 1** APAFE System prototype technical specifications

| Item | Specification |
|---|---|
| Prototype dimension | 97 cm x 45 cm x 92 cm (L x W x H) |
| Power supply | 12vdc rechargeable battery |
| Communication | GSM module |
| Payload | Max: 10kg |
| Control type | Automatic send alert to user and toggle switch to activate (Pull-Activated system) |

The system is controlled by an Arduino Uno Rev 3, as shown in Figure 3, and electronic components are integrated into APAFE prototypes in Figure 4. The system consists of two input sensors: a flame sensor that detects and responds to fires or flames, and a smoke and gas leakage detector (MQ2) that detects gases such as LPG, propane, methane, hydrogen, alcohol, smoke, and carbon monoxide. In addition, the system uses five outputs. The LCD displays the gas value and flame status, the siren and warning light activate when gas or smoke is detected, and the GSM module sends an SMS and a phone call to notify authorities of a fire.

Progress in Engineering Application and Technology Vol. 5 No. 2 (2024) p. 742-750

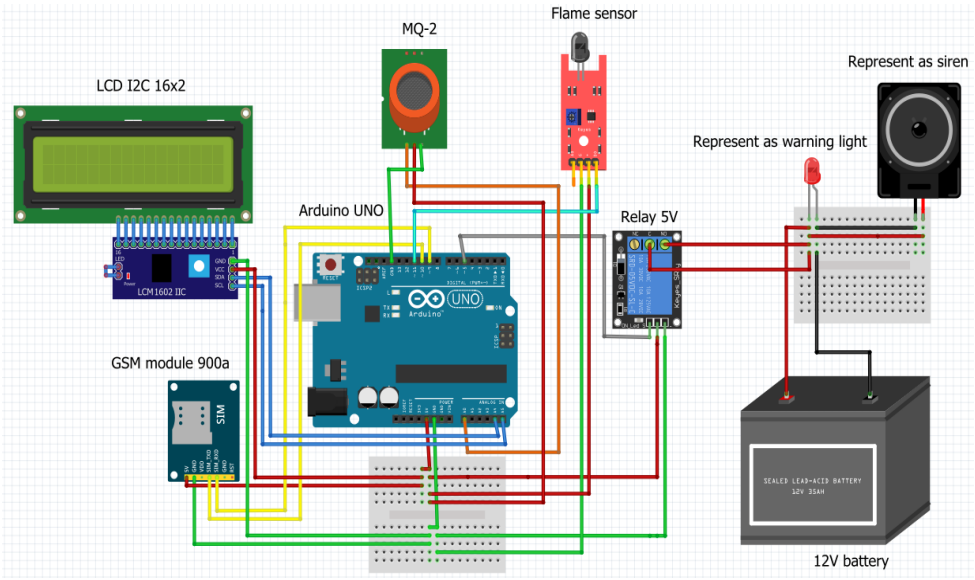


**Fig. 3** APAFE prototype circuit diagram

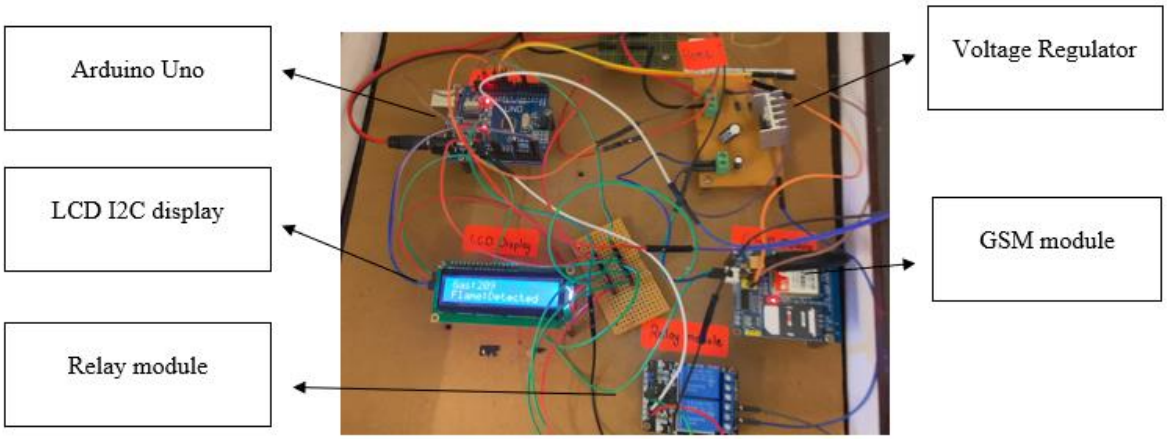


**Fig. 4** Integration of electronic components

## 3.2 Experimental Setup

Figure 5 shows some crumpled papers being burned for testing purposes, which resulted in flames near the entire setup. The fire hose is placed 10cm away from the flame, and the distance between the flame sensor module and the source of fire is set to 20cm. As soon as the sensor detects fire and smoke, the APAFE system sends a signal to the relay switch, activating the warning light and alarm, as well as sending an SMS and a phone call to notify authorities via the GSM module. A toggle switch is used to activate the power window, triggering the 9kg ABC powder fire extinguishers pull-activated mechanism. The gas value of the MQ-2 module is displayed on the LCD, and the flame detection status of the flame sensor module, as shown in Figure 6.

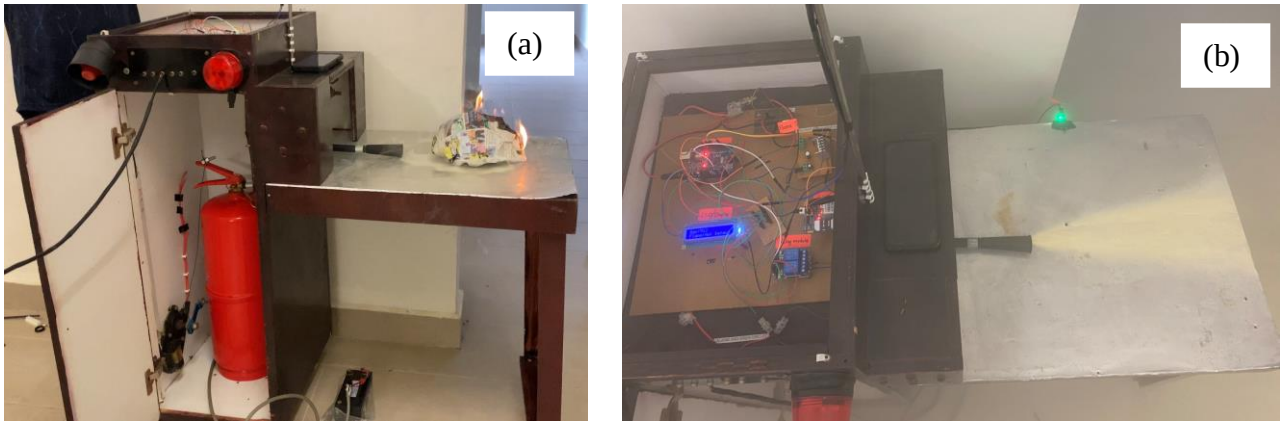


**Fig. 5** Experimental setup(a) paper to produce flame (b) position of fire hose and flame sensor module

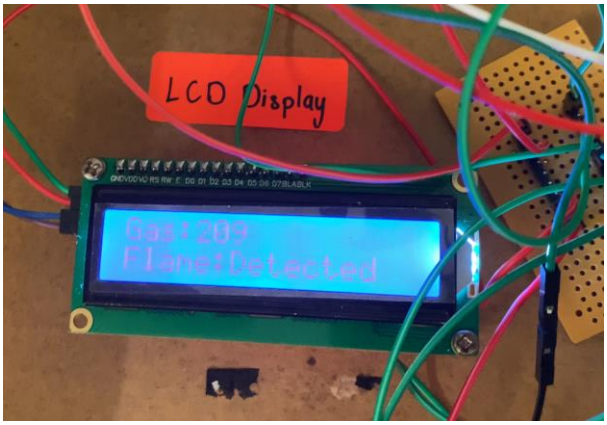


**Fig. 6** Gas value and flame status

## 4. Result and Discussion

The experiment's goal is to evaluate the safety and reliability of the developed fire solution, which includes a fire alarm and a pull-activated mechanism on a 9kg ABC powder fire extinguisher. Figure 7 shows a 12Vdc power window motor being used to pull the handle of a 9kg ABC powder fire extinguisher, triggering the pull-activated mechanism. It takes 3 seconds to pull the trigger on 9kg ABC powder.

**Fig. 7** Pull-Activated system

As shown in Figure 8, an experiment was conducted to determine whether a flame could be detected at distance of 20cm, 30cm, and 40cm from the flame sensing module. It was clearly observed that the sensor could detect the flame within a range of up to 40cm. As a result, in this study, the distance between the flame sensor module and the source of fire is set at 20cm, which is considered the most suitable distance between sensor and source of flame (at the center of the system because the width of the laboratory table is 45cm).

Progress in Engineering Application and Technology Vol. 5 No. 2 (2024) p. 742-750

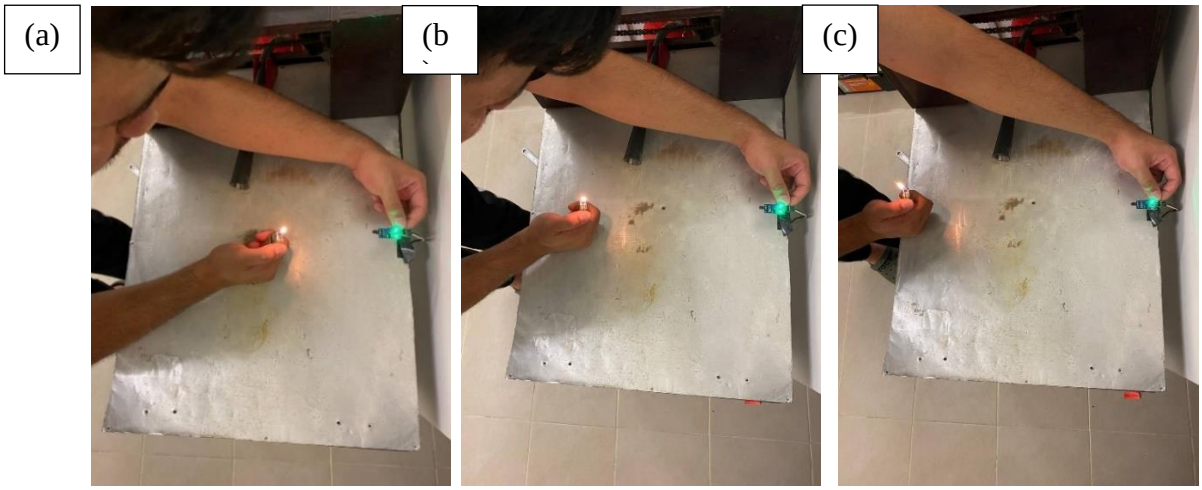


**Fig. 8** Experiment distance for fire detection. (a) 20cm (b) 30cm (c) 40cm

The MQ-2 module detects gas leaks, including LPG, butane, propane, methane, alcohol, hydrogen, and smoke. Figure 9 shows an experiment designed to detect a butane leak in a closed area. By setting the threshold limit to 450ppm, the relay module activates the warning light and siren, and LCD displays the flame detected status.

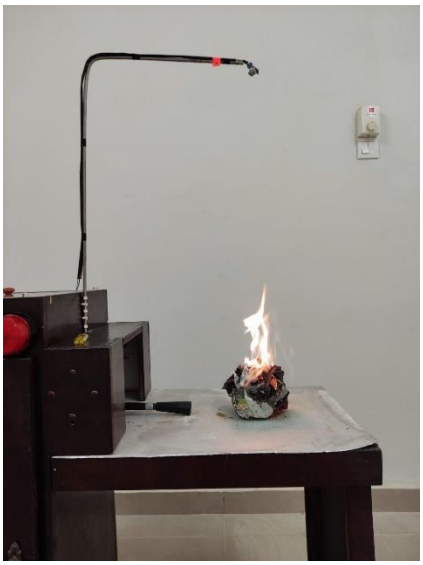

**Fig. 9** Experimental setup for MQ-2

When a fire threat is detected, the GSM module alerts the laboratory assistant, by sending the warning message, and phone call. This informs the laboratory assistant of what is happening, and he or she can act in a coordinated manner to keep it from spreading and making control difficult. Figure 10 illustrates how the experiment was set up, and Figure 11 shows the user's point of view (POV) as the GSM module sends a message or makes a call.

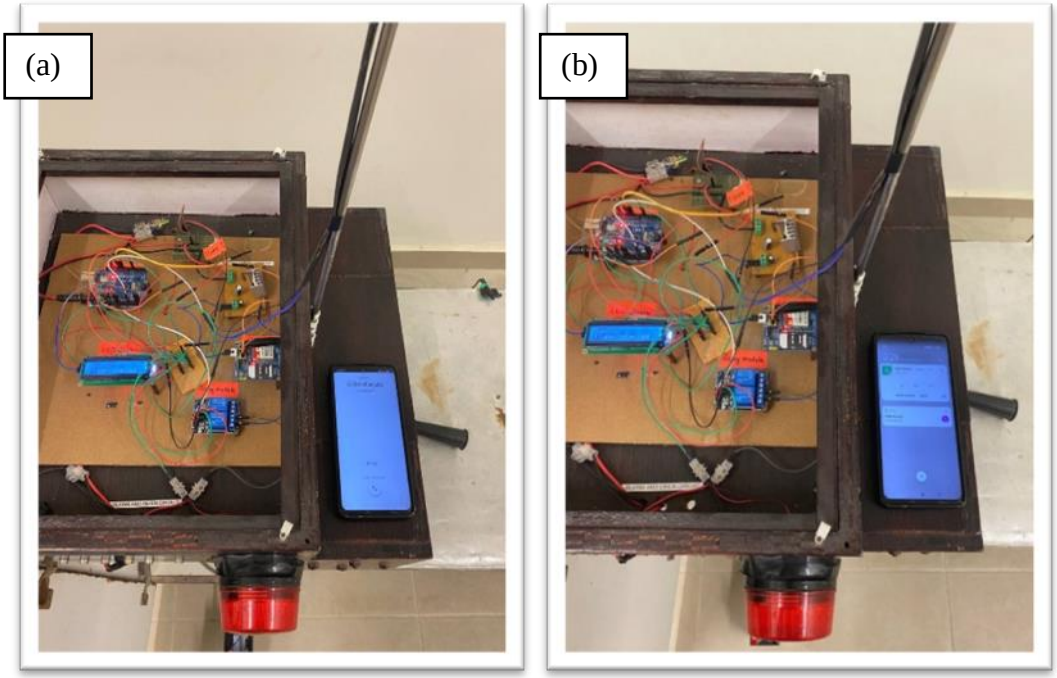


**Fig. 10** GSM module sends notification. (a) Call form (b) Message form

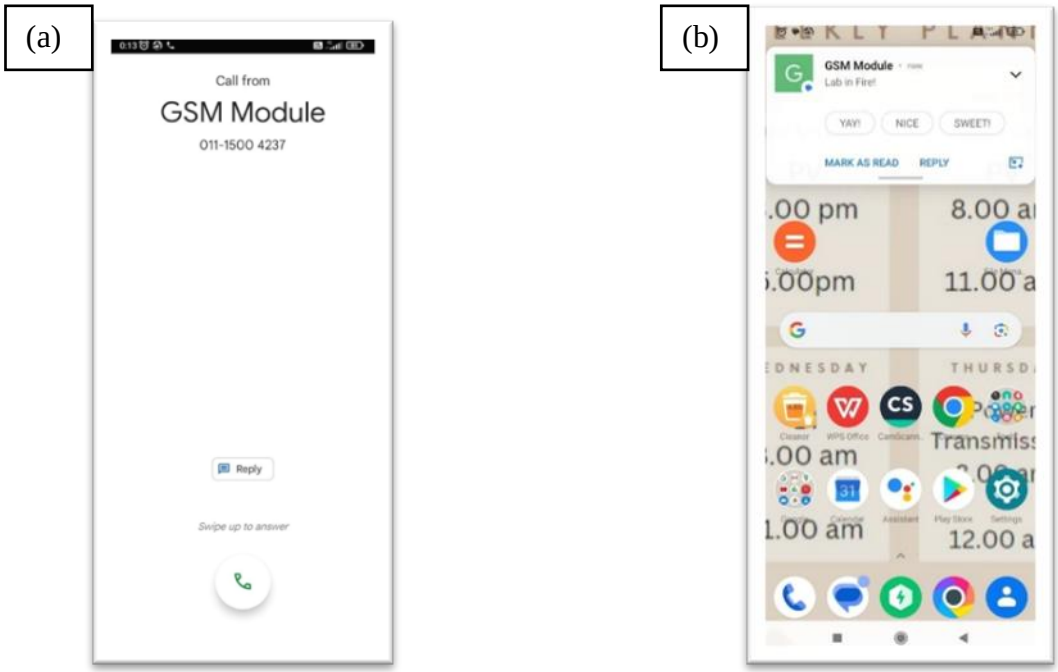


**Fig. 11** POV user when receive notification. (a) Call form (b) Message form

## 5. Conclusion

The Integrated Fire Safety Solution: A Microcontroller-Based Fire Alarm and Pull-Activated Fire Extinguisher System for Science Laboratory Environment (APAFE System) is an effective solution for early fire detection and quick action, triggering the pull-activated mechanism using 12vdc power window motor within 3 seconds of the system detecting flames and butane gas. Both the siren and the warning light have been tested to determine their effectiveness in alerting people to a fire. The use of both audible and visible signals has been shown to significantly improve evacuation and response times. The feasibility of combining a GSM module and LCD display was investigated. The display's ability to present gas measurements and flame detection in real time has been extensively investigated to improve laboratory users' situational awareness. Also highlighted are the GSM module's alerting capabilities, which include sending notifications and calling laboratory assistants.

Several suggestions can be made to improve the APAFE System's functionality and performance. First, install the LCD screen at the security station to alert the security guards or administrators, allowing them to quickly monitor and control action remotely. Second, improvements will be made, such as turning the hose clockwise to cover the entire laboratory table area and incorporating a feature that allows the Pull-Activated system to be activated using the Blynk Application.

## Acknowledgement

The authors would also like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

## References

[1] Kamaruddin M. I. and Yazit N. H (2011). *Tahap Pengetahuan Amalan Keselamatan Makmal Sains dalam Kalangan Guru Pelatih Sains*, Fakulti Pendidikan, Universiti Teknologi Malaysia. *Journal of Educational Management 4.* pp. 66-79

[2] Y. Yuce and K. H. Erkal (2017). The analysis of burns due to an explosion in a school laboratory. *Sakarya Medical Journal, 8(1)*, pp. 121-127.

[3] Michael Winter (2012). *Science lab fire burns Pa. students.* USA TODAY. Retrieved on 14 January 2023 from https://www.usatoday.com/story/news/nation/2012/11/28/students-burned-science-lab-fire-carlisle/1732629/.

[4] TheEdgeMarkets (2013). Fire destroys science lab in UiTM Shah Alam. Retrieved on 14 January 2023 from https://www.theedgemarkets.com/article/fire-destroys-science-lab-uitm-shah-alam.

[5] Fire & Rescue Department of Malaysia (2014). *Kebakaran Makmal Sekolah di Sek. Keb. Dato, Penggawa Barat, Jalan Parit Masjid Pontian, Johor.* Retrieved on 1 July 2023 from https://www.facebook.com/profile/100064601357246/search/?q=kebakaran%20makmal%20sekolah.

[6] Michelle Richards-Babb, Jennifer Bishoff, Jeffrey S. Carver, Kimberly Fisher, and Jennifer Robertson-Honecker (2010). Journal of Chemical Health & Safety 2010 17 (1), 6-14, DOI: 10.1016/j.jchas.2009.05.001

[7] *Jawatankuasa Induk Keselamatan dan Kesihatan Pekerjaan Universiti Malaysia Terengganu* (2020). *Statistik Kemalangan Melibatkan Bahan Kimia dan Peralatan Tajam*. Retrieved on 11 May 2023 from https://pppl.umt.edu.my/wp-content/uploads/sites/28/2020/05/MinitMesyuarat-JKKP-Induk-UMT-1_2020.pdf

[8] Nazir A, Mosleh H, Takruri M, Jallad A-H, Alhebsi H., "Early Fire Detection: A New Indoor Laboratory Dataset and Data Distribution Analysis. Fire," 2022, 5(1):11, DOI: 10.3390/fire501001

[9] Hauck, J., & Babrauskas, V. (2018). Cost-benefit analysis of fire sprinklers in university laboratories. Fire Safety Journal, 99, 61-67.

[10] Balafoutis, A., Koniordou, K., & Papakonstantinou, K. (2019). Evaluation of the usability of emergency exit signage in university laboratories. Safety Science, 113, 286-293.

[11] Ismail, A. R. (n.d.). *Keselamatan di Makmal: Pengurusan Dan Tanggungjawab kakitangan. Keselamatan di Makmal: Pengurusan dan Tanggungjawab Kakitangan.* https://www.researchgate.net/publication/316584360_Keselamatan_di_Makmal_Pengurusan_dan_Tanggungjawab_Kakitangan

[12] Singapore Civil Defence Force (SCDF). Technical Guidelines & Fire Safety Requirements for Laboratories Handling Chemicals. Retrieved on 27 June 2024 from https://www.scdf.gov.sg

[13] National Fire Protection Association (NFPA). (2021). NFPA 1500: Standard on Fire Department Occupational Safety, Health, and Wellness Program. NFPA.

[14] Labcompare (2024). Fire Protection for Laboratories and Facilities. Retrieved on 27 June 2024 from https://www.labcompare.com/10-Featured-Articles/610021-Fire-Protection-for-Laboratories-and-Facilities/

[15] National Fire Protection Association (NFPA). (2022). NFPA 13: Standard for the Installation of Sprinkler Systems.

[16] Kodur, V., Kumar, P. and Rafi, M.M. (2020), "Fire hazard in buildings: review, assessment and strategies for improving fire safety", PSU Research Review, Vol. 4 No. 1, pp. 1-23. https://doi.org/10.1108/PRR-12-2018-0033

[17] M. R. Habib et al., "Quick Fire Sensing Model and Extinguishing by Using an Arduino Based Fire Protection Device," 2019 5th International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 2019, pp. 435-439, DOI: 10.1109/ICAEE48663.2019.8975538

[18] Bharathkumar V., Irshad SM, Gowtham S. and R. Geethamani, "Microcontroller based digital meter with alert system using GSM," 2017 11th International Conference on Intelligent Systems and Control (ISCO), Coimbatore, India, 2017, pp. 444-448, DOI: 10.1109/ISCO.2017.7856033.

[19] S. I. Nahid et al., "Development of a Smart Automatic Gas Leakage Detector and Alarming System," 2021 IEEE 12th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2021, pp. 0789-0795, DOI: 10.1109/IEMCON53756.2021.9623207.

[20] S. Gupta, A. Mudgil, P. Bhardwaj and M. Gupta, "Design and Development of Automatic Fire Alert System," 2016 8th International Conference on Computational Intelligence and Communication Networks (CICN), Tehri, India, 2016, pp. 632-636, DOI: 10.1109/CICN.2016.130.

[21] B. S. Sampath, "Automatic Fire Extinguisher Robot," 2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Incheon, Korea, 2011, pp. 215-218, DOI: 10.1109/URAI.2011.6145964