An IoT-based Fire Safety Management System for Educational Buildings: A Case Study

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***Abstract*—Safety is a serious concern that should be addressed carefully in different locations including homes, workplaces and educational buildings. The risk of fire is the most significant threat in many educational facilities such as schools, universities, offices, etc. The main goal of this work is developing an effective system that allows early managing of fires to avoid material and human losses. With the advent of the Internet of Things (IoT), the implementation of such system became possible. A low-cost system incorporating IoT sensors is constructed in this study to collect data (heat, the number of people at the fire scene, ...) in real time. The system provides a control panel that displays readings from all sensors on a single web page. When the collected values exceed a particular threshold, the system sends a message to the building keeper's phone, allowing him to notify the authorities or dispatch firemen in real time. One of the system's most important characteristics is that it keeps track of how many people are at the fire scene, simplifying the evacuation process and allowing civil defense authorities to efficiently manage resources. The system has been successfully tested in a variety of circumstances in an educational building (Al-Faisaliah female campus, University of Jeddah, Saudi Arabia).**

Keywords*—*Safety; fire; Internet of Things (IoT); sensors; cloud based platform; ThingSpeak

I. Introduction

Safety is defined as the condition of being protected from or unlikely to cause danger, risk, or injury. People are continuously exposed to dangers in their homes, workplace or roads. Occupants of Educational buildings such as students, educators and administrative staff have different awareness levels regarding safety practices and beliefs. Since educational buildings are continuously occupied, safety issues should be addressed properly and procedures used to reduce risks have to be implemented prior to unexpected accidents. The main objective of the present paper is to develop and implement a complete management system for monitoring safety. This can improve the safe conditions in educational buildings especially in Al-Faisaliah female campus, University of Jeddah, Saudi Arabia. To achieve the research objectives, a procedure including several steps will be implemented. The first step is dedicated to the study of safety requirements in educational buildings issued in official documents provided by civil defense authorities [1]. In the second step, to assess the commitment and awareness of the users of Al-Faisaliah Campus with health and safety conditions, an online survey was chosen to collect data because it can reach a large number of individuals and has a minimal risk of data inaccuracies.

Results of the survey conducted have shown that the safety culture inside Al-Faisaliah Campus is very poor. The results showed also that fire is the most dangerous threat that can occur. The official records have verified that fact. According to Saudi Civil Defense statistics [1], for the year 1440-1441 H, the number of firefighting operations was more than 42,000, equivalent to 119 firefighting operations per day. More than 14,000 were fires in the workplace, at a rate of 35.41%. The region of Mecca occupied the first place in the number of operations. Human losses are about 2000 cases, between 149 deaths and 1,809 injuries, and financial losses are more than 49 million Saudi Riyals (1 USD = 3.76 SAR).

The previous statistics have clearly indicated a rise in the daily rate of fires in workplaces such as schools and offices. The average rate of this kind of fires reached 42 fires per day. There are a multitude of causes for fires. According to the statistics, thermal demand was one of the most common causes of fires, with a percentage of 37.71%, equivalent to 45 fires per day. Next, 22.0% of the electricity is tampered with an average of 27 fires per day. Finally, the third cause of fire is the flaming heat source. From statistics above, the conclusion is that fires are big threats that may cause disasters in the studied educational building. In order to contribute to limit dangers, smart solutions relying on new technologies such as Internet of Things (IoT) should be developed and deployed. The proposed safety management system may help first educational building occupants in reacting immediately once a threat is initiated and second may assist civil defense authorities during their interventions. In addition, the safety department of the University should take benefit from the proposed system to remotely control the safety situation inside the campus.

Through using IoT technology, a complete low-cost smart solution that enables the management and monitoring of fire in real time was suggested. The building's status was remotely monitored via a friendly dashboard. This dashboard displays the data issued from sensors in one Web page. A message delivered to the building keeper's mobile phone is activated if a collected parameter exceeds its threshold. So that he can call the police or firefighters to arrive right away. A huge benefit of the system is its ability to count the number of individuals involved at the fire scene. This will ease the evacuation efforts.

The remaining of this paper is organized as follows. First, many studies related to safety issues including advantages and disadvantages of each approach will be summarized. Second, the proposed safety management system as well as its components and its operation will be detailed. finally, conclusions, recommendations and future work will be drawn.

II. Literature Review

A. Safety

This short literature review tries to cover the main aspects of safety that will be addressed in this study. Fire is considered as the most significant risk that has to be assessed regularly. In [2], qualitative approaches have been presented. The purpose was to identify and eliminate fire hazards. The study established that hotel utilities are of high risk. 76 items related to safety in hotels have been proposed and classified into seven main classes. The proposed methodical approach can be used by fire safety inspectors. Several tools including short oral survey, semi-structured interviews with subcontractors, etc. have been used to assess safety culture among investors working in the household construction sector in Australia [3]. Thus, a method of source causes analysis was employed to categorize the safety culture of subcontractors into seven different areas, including the building site, work procedures, equipment and materials. Recommendations drawn at the end of the study are built around free training of the subcontractors. The Cypriot manufacturing sector safety practices have been studied in [4] using a nation-wide survey in Nicosia. The opinion of managers regarding fire occurrence has been demonstrated to be influenced by several factors such as the no-smoking rule, the presence of fire alarms, and the practice of allowing employees to sleep on the job. Although the safety situation is generally good, there is still potential for enhancement, according to the study's findings. Since electricity is classified as a silent killer, identifying safety beliefs among Australian electrical workers has been addressed in [5]. The planned behavior concept has been used as a theoretical framework. Focus groups and interviews with 46 certified electrical professionals were analyzed according to advantages, disadvantages, referents, barriers and facilitators affecting respectively the safety beliefs and culture. In Saudi Arabia, few works have addressed the problem of safety. In reference [6], Saudi Arabia's safety regulations for worksites have been assessed by surveying the work being done on several projects. Protection assessment scores have been found to be typically superior across all categories for the large projects; whereas low assessment ratings, particularly in firefighting, healthcare, and comfort, were typical for small projects. Protection measures in residential building assessment procedures have been implemented . A field assessment study about fire awareness measures has been conducted in [7] through a survey in residential buildings. The obtained results showed that the safety awareness on fire is poor. Based on the observations, a number of strategies including effective codes and official requirements, designs taking into account safety and educational programs have been proposed as recommendation to improve safety awareness culture. In the same direction, the study in [8] has focused on the methods adopted by Saudi Arabia firms to solve safety issues when creating residential structures. The research concluded that safety design must be undertaken by qualified architects and engineers. Through a representative company survey conducted in Germany [9], workplace risk assessments have been studied. The frequency of patterns influencing OHS measures has been evaluated in N=6500 companies. The study suggested that more effort is to be deployed by the authorities to improve the safety practices and beliefs. In [10], it has been evaluated how the Hail region of Saudi Arabia views and employs electrical safety. Hail region level of electric safety awareness has been found to be 0.76 out of 4. This low score reflects a bad culture of electrical safety. Numerous suggestions covering numerous relevant parties have been put forth. From the above literature review about safety, it can be remarked that fire is the main concern since it may cause irreversible dangers that can affect human lives and properties in addition to its high impact on economy and social life [11]. For this reason, the study main focus will be fire safety management based on IoT technology.

B. Internet of Things (IoT)

The term "Internet of Things" (IoT) refers to a network of physical objects which are equipped with sensors, programs, as well as other tools that allow them to communicate with other objects and systems over the Internet. IoT is essential for raising living standards. Indeed, it is able to human well-being and the quality of life enhancement [12]. Fire is among the common problems that may be managed/solved by using solutions around IoT technology. In order to prevent the loss of priceless lives and critical infrastructure in the case of a fire, it is imperative to establish an early, and precise fire detection system. Integrating contemporary technology, such as IoT, advanced analytics, and WSN, can result in accurate fire detection systems for real-time monitoring and crisis management [13].

The abundance of sensors, which are small devices with environmental sensing capabilities, is what gives IoT its greatest strength. Technologies for detecting fire can be divided into those that detect temperature, gases, and flames. Early-fire detection is the main function of fire sensing devices. A good fire system imposes that sensors must Identify a fire issue in its early stages. Heat sensors function properly. But, they are not fast. Make them moving can increase their speed. Smoke detectors have a poor accuracy rate. They can perform better if a visual sensor system is added. Due to the irreversible nature, fragility, and poor selectivity of gas sensors, their usage is extremely restricted in buildings.

Currently, the emphasis is on employing robots to fight fire in critical cases. This procedure is always performed from the outside of the burning place. But robots are heavier due to sensor systems and fire suppression equipment mounted on them. This fact creates a difficulty with balance and high-speed movement for internal fire detection. Hence, more study is required to develop improved sensing systems [14].

C. Related Work

An review of various relevant Internet - of - things intelligent fire detection and management works is provided in this section. Reference [15] utilized numerous sensors to gather real-time readings. When an emergency arises, sensor data are examined to start a sprinkler system. This has an important issue which is the non-prevention of fire occurrence. The authors in [16] used a Raspberry Pi to create a fully coded fire warning framework. Whenever a fire is discovered, a tailored app sends out an alert along with a URL to a website that contains pictures captured by embedded cameras. A Convolutional Neural Network approach for identifying fire in real pictures was introduced in [17]. Results were superior than those suggested in the literature. The authors proposed a future improvement that would use videos rather than photos. The authors in [18] proposed a system that uses multiple sensors to collect readings. An artificial intelligence -based algorithm analyzes and processes the gathered data. In the event of fires, airflow and a water spray are then activated. This has a significant flaw since it can only function properly in enclosed spaces. The development of a smart ventilation and lighting solution that could recognize people and control lights was the subject of reference [19]. Additionally, heat and gases could be remotely measured and gathered. The fact that this equipment was only used in one chamber is among the drawbacks. More improvements and research may be required before it can be used on a wide basis. The Ubidots platform was utilized by the authors of [20] to create an improved forest fire monitoring system. A buzzer sounds to notify users whenever sensor readings cross a predetermined limit. One problem with the suggested solution is that sensors placed outside are inaccurate since weather conditions can alter them. Authors created a smart home inspection for fire prevention in [21] that incorporated a multitude of sensors in each connected home area. To quickly alert the user of a fire incident, they used the Global System for Mobile Communications (GSM). Experiment is performed using a Fire Dynamic Simulator. One problem with the suggested solution is how to effectively handle the enormous volume of data that has been gathered. Some of the proposed systems above include technical flaws, such as needless complexity and exorbitant costs. Therefore, this research suggests an intelligent system that provides real-time data collection and monitoring and alerting for the building occupants and any concerned authorities.

In order to make the system innovative and better than the previously developed systems, a comparative study based on several criteria has been conducted (Table I). The main criteria considered in this study are the types of:

- sensors
- the environment
- alarms
- dashboard
- new features
- processing (ML/IP/FL: ML for machine learning. IP for image processing. And IF for fuzzy logic)

Based on the previous comparison (Table I), the following conclusions can be noted:

TABLE I. COMPARISON BETWEEN THE PROPOSED SYSTEM AND SIMILAR ONES

Criteria / Reference	[15]	[16]	[17]	[18]	[19]	[20]	[21]	The proposed system
Temperature	√	×	×	√	√	√	√	√
Smoke	√	×	×	√	√	×	√	√
Flame	×	√	×	√	√	×	√	×
Gas	√	×	×	√	√	×	√	×
PIR	×	×	×	×	×	√	×	√
Camera	×	√	√	×	×	×	×	×
Cloud dash-board	√	×	×	×	×	√	×	√
Indoor	√	√	√	√	√	×	×	√
ML/IP/FL	×	√	√	√	×	×	√	×
Counting People	×	×	×	×	×	×	×	√
alert	×	√	×	√	√	√	√	√

- Many of the systems above have technical limitations (unnecessary complexity).
- The largest error is trusting a single type of fire sensor. Doing so will lead to more false alerts.
- It is insufficient to just use an audible alarm to notify stakeholders. It may be necessary to warn the building guard via message whenever a fire arises in particular circumstances, such as when he is outdoors.
- Sending a message is not enough in case of emergencies. A dashboard is required to the surveillance of the building.
- Firefighters frequently don't know how many people are in the burning building. This makes the evacuation process exceedingly challenging. By keeping track of this number, fireman's work will be easily achieved and their resources will be used more effectively.

In this prototype, a multitude of sensors were used. This can ensure precise fire detection. Additionally, a buzzer and LED were employed to create an audible and a visual alarms in case of emergency. Then, two Passive Infrared (PIR) sensors for counting people entering and exiting were deployed. Finally, a dashboard that enables the surveillance of the building was implemented. When an emergency arises, a message will be automatically delivered to the building guard.

III. DESIGN AND DEVELOPMENT

A. Study Area

The study area chosen for assessing performances of this low-cost fire monitoring station is Al-Faisaliah Campus (Female branch of the University of Jeddah: Fig. 1). More precisely, the experiments are conducted in Building 11 (see

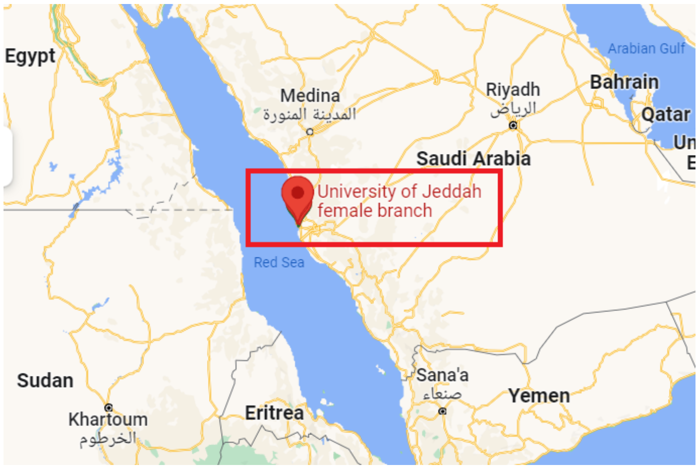

Fig. 1. Al-Faisaliah Campus (Female Branch of the University of Jeddah).

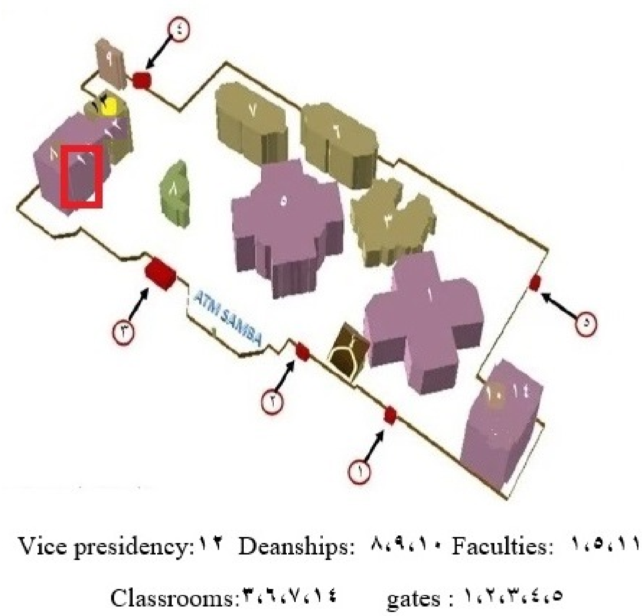

Fig. 2. The Monitored Area (Building 11: in Red Square).

Fig. 2). For the development of this smart fire monitoring system, the work was divided into the following stages:

B. Functional and Non-Functional Requirements

The functional requirements specify what the proposed solution must perform during its operation. On the other hand, non-functional requirements are those characteristics of the device that can be observed throughout its execution. The following are the specified requirements:

1) Functional Requirements: The stakeholders are the building guard and the administrator.

- the building guard can view:
  1) sensors readings
  2) the number of persons in the fireplace
  3) any sudden changes in the monitored zone
- The administrator can determine:
  1) the temperature at which an alarm should be triggered
  2) the humidity which an alarm should be triggered
  3) the smoke t which an alarm should be triggered
- The system will be able to:
  1) display the dashboard
  2) determine how many people are in a building fire.
  3) issue different alerts during the early stages of a fire emergency

2) Non-Functional Requirements:

- Usability: The system shall be easy and simple to learn and use
- Portability: The system can be used in any indoor environment such as buildings, workplaces, hospitals, etc.
- Accuracy: The system should be accurate to avoid any faulty fire alarm.

C. Hardware Requirements

To make a prototype of an internet-of-things enabled intelligent fire surveillance system, one needs a microcontroller [22], sensors and a wifi module [23] for sending data from sensors to the internet. In this case, a micro controller integrating wifi which is NodeMCU [24] was chosen. Also, sensors [temperature (DHT11) [25], smoke (MQ2) [26]], a light emitting diode (LED) [27], a buzzer [28] and jumper wires [29] were deployed.

D. Block Diagram

The block diagram below serves as the foundation for the intelligent fire continuous monitoring system (Fig. 3).

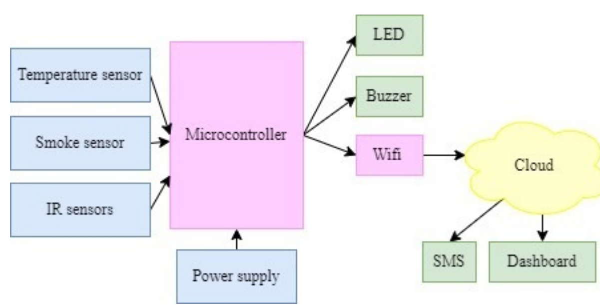

Fig. 3. Block Diagram.

The data issued from temperature, IR and gas sensors deployed in the monitored area are collected. Then transmitted to the microcontroller. Through wifi, sensors readings are displayed on a user-friendly dashboard. When readings are high and will cause a fire (cross a threshold), an alert message is sent to the building guard, a buzzer will beep accordingly and the LED will glow.

E. Circuit

Fig. 4 shows the circuit of the proposed smart system.

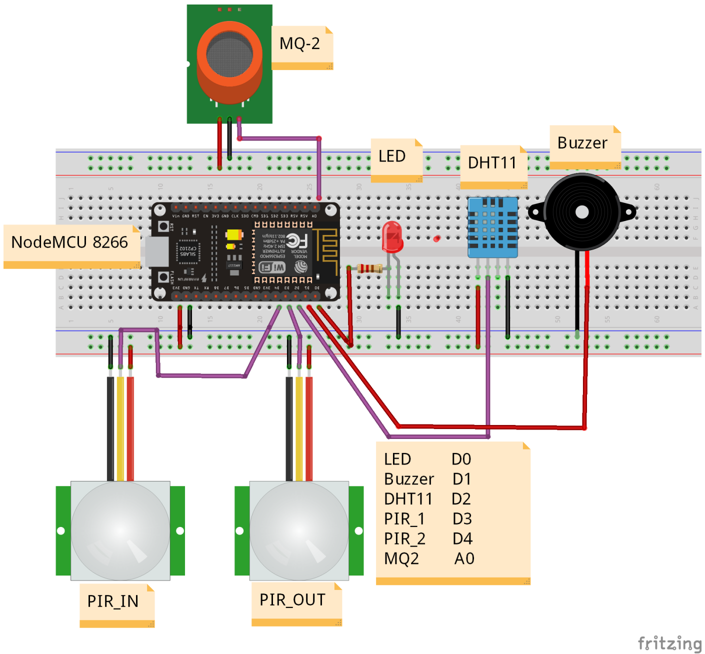

Fig. 4. Circuit Diagram.

F. Prototype

Fig. 5, Fig. 6, and Fig. 7 are a depiction of the exterior view, the exterior view without roof, and the interior view of the finalized system prototype, respectively.

Fig. 5. View of the Developed Prototype from the Outside.

G. Fire Detection

According to Algorithm 1, temperature and smoke data are collected, sent to the cloud. End users are notified in the event that any parameter has abnormally high level.

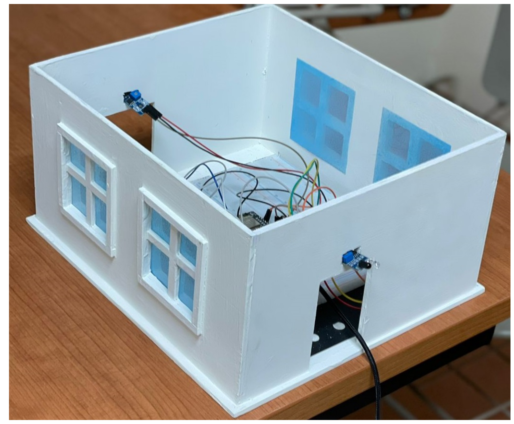

Fig. 6. View of the Developed Prototype from the Outside (without Roof).

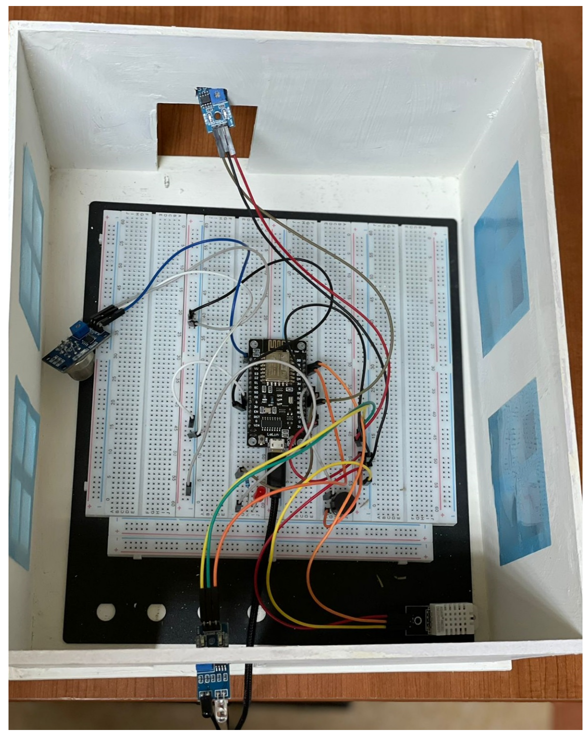

Fig. 7. A View of the Developed Prototype's Interior

IV. Results and Discussion

To visualize sensors' readings, Thingspeak [30] was used. ThingSpeak is a cloud service. This IoT analytics platform solution is really effective. The examination of real-time data streams is possible. Devices can continuously submit data to ThingSpeak. This can make instantaneous visualization of live data. It can also send alerts in emergency cases. The graphs below (Fig. 8, Fig. 9) show the results from the measured values taken from used sensors during an experiment conducted on site. In case of fire, an SMS is sent to the building guard automatically which can let him contacting firefighters immediately (Fig. 10).

Algorithm 1 Fire Detection

Require: Temperature sensor, Smoke sensor
Ensure: Warning notification
Initialization:
Set threshold for temperature T_{TH}
Set threshold for smoke S_{TH}
Capture temperature measured T from target environment
Capture smoke measured S from target environment
if ($T >= T_{TH}$) AND ($S >= S_{TH}$) **then**
Red light (LED)
sound alarm (Buzzer)
notify the building guard (SMS)
end if

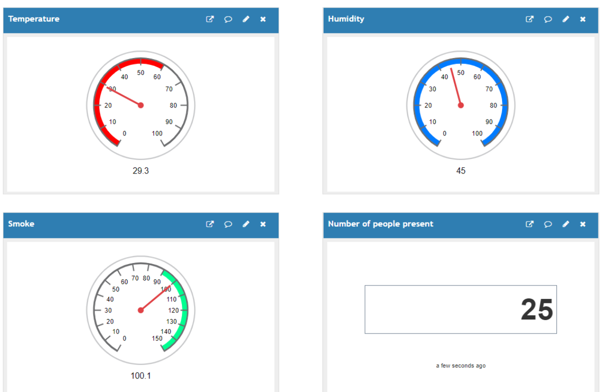

Fig. 8. Screenshot of the Continuous Monitoring in ThingSpeak.

V. Conclusion and Future Work

A cost effective smart fire system that provides real-time monitoring and data collection was deployed in this work. The suggested solution enables remote building status monitoring via a user-friendly dashboard that compiles sensor data into a single web page. A buzzer, a red light, and a message sent to the building keeper's mobile phone inform him whenever a collected parameter exceeds its threshold so that he can call authorities or firemen for assistance right away. The proposed technique has the important benefit of counting the number of persons at the building fire, which will speed up the evacuation procedure. Different scenarios have been successfully tested with the suggested system. The addition of an image processing method with a camera and real-time data analysis from sensors utilizing sophisticated algorithms can be considered as a future project. Another future work can be built around the deployment of a wireless sensor network to cover all the buildings existing in the campus. This can be performed by taking the advantages of the tremendous development that wireless communication technologies are experiencing today.

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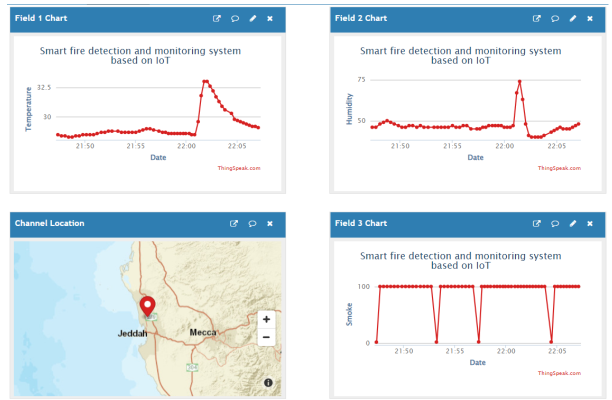

Fig. 9. Screenshot of Graphs Showing Sensors Readings.

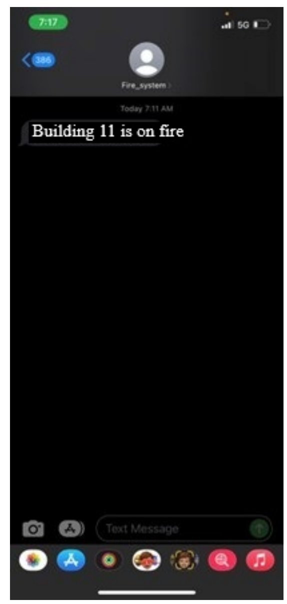

Fig. 10. SMS Sent in Case of Fire.

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