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A Smart Fire Detection System using IoT Technology With Automatic Water Sprinkler

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Article Info	ABSTRACT
	House combustion is one of the main concerns for builders, designers, and property residents. Singular sensors were used for a long time in the event of detection of a fire, but these sensors can not measure the amount of fire to alert the emergency response units. To address this problem, this study aims to implement a smart fire detection system that would not only detect the fire using integrated sensors but also alert property owners, emergency services, and local police stations to protect lives and valuable assets simultaneously. The proposed model in this paper employs different integrated detectors, such as heat, smoke, and flame. The signals from those detectors go through the system algorithm to check the fire's potentiality and then broadcast the predicted result to various parties using GSM modem associated with the system. To get real-life data without putting human lives in danger, an IoT technology has been implemented to provide the fire department with the necessary data. Finally, the main feature of the proposed system is to minimize false alarms, which, in turn, makes this system more reliable. The experimental results showed the superiority of our model in terms of affordability, effectiveness, and responsiveness as the system uses the Ubidots platform, which makes the data exchange faster and reliable.
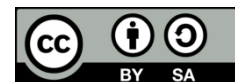
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1.   INTRODUCTION

Nowadays, fire incidents have become a critical issue [1-3], which must be dealt with on time without any unnecessary delay to avoid the loss in lives and belongings [4-10]. It is considered a fire situation when the monitored temperature exceeds 50° C. In critical places such as hospitals, schools, and banks, personnel's arrival time to come for help in fire hazards is around 15 minutes [11]. The statistics show that there are 475,500 structural fires annually in the United States, causing 2,950 civilian deaths, 12,775 civilian injuries, and $7.9 billion in property damage [12]. According to the National Fire Protection Association (NFPA), two-third of U.S. household fires occur in premises with no working smoke alarms, alarms with no proper maintenance, or misplaced alarms [13]. The appropriate allocation of fire alarms with a proactive warning could save lives and reduce property losses [14], [15]. Particularly, there are many types of fire alarms as heat detectors and smoke detectors [16]; studying these types helps to decide which type is more suitable for home or store. For instance, heat detectors are classic options [17] when the temperature reaches a certain level. Thus, it is more suitable for applications that rapid response is not required or in an environment where smoke detectors cannot be placed like frozen areas. Heat detectors have a lower false alarm rate but still slower in response because the temperature rises slowly [19]. With all these lacks, smoke detectors remain better than heat detectors [18].

Smoke alarms will more likely detect fires before it really starts. Smoke comes when the energy of an object is consumed due to the loss of Carbon Dioxide (CO2) from heat [20]. Smoke detectors are classified into three types: ionization, photoelectric, and combination. All these types can be studied further in instruments and measurement books. In this study, we will highlight a brief description of ionization. In brief, ionization is a radioactive material that receives radiation from the fire. It enters the ionization chamber, which is an air-filled space between two electrodes and permits a small, constant current between the electrodes. This type is the best for fast fires or fires caused by bombs or accidents [21].

The concept of Internet of things (IoT) nowadays is applied in many applications ranging from the smart industry [33], smart agriculture [34] to smart healthcare [31], and smart home application [32]. Home automation is an area where IoT has several advantages [35-37]. In the case of remote plant locations, for example, technology enabling remote operation and maintenance will benefit; autonomous inter-appliance such that devices are mutually aware of the information exchange, thereby minimizing engineering costs in handling all devices involved. Nowadays, fires can get out of control because people intend to save money rather than installing proper fire alarm systems. Some problems are still on, such as affordability, effectiveness, and responsiveness [22-24]. Previous related works such as Network-Based Real-time Integrated Fire Detection and Alarm (FDA) System with Building Automation [25] have been done to overcome these problems.

Considering the aforementioned challenges, this study focuses on building an advanced fire alarm using heat and smoke alarms. The system reads the flame, heat, and smoke data using IoT, analyzes these data, and then quickly triggers the automatic water sprinkler. Thus, this study's importance is to provide a low-cost fire alarm system considering the affordability, effectiveness, and responsiveness.

Many studies have been conducted to address these issues like [26-28]; however, fire detection issues are not addressed properly since these systems rely on machine vision, where the algorithms need more images to train, and the detection rate is not satisfactory. Other approaches like [29,30] suffer from some limitations, mainly slow time responses and low accuracy. Thus, this paper aims to minimize false alarms, provide faster response, and a new IoT approach than previous studies that used mostly Node-Red. The contribution is as follows: (1) To determine which combinations and algorithms of sensors can accurately and quickly detect fires, (2) We have designed and then developed a system that detects fire and activates the fire alarm, (3) the proposed system evaluates the situation and initiates an automatic water sprinkler where the water unit was designed separately, and (4) the system analyses the collected data using Ubidots platform which results in a faster response. Thus, the highlighted four points make the proposed system superior in terms of affordability, effectiveness, and responsiveness.

The remainder of this paper is organized as follows. Section 2 gives an overview of the methodology adopted for the proposed research and described the experimental model. Results are discussed in Section 3 while; the conclusion and the future work are given in Section 4.

2. RESEARCH METHOD

Smart Fire Detection System with Automatic Water sprinkler has been developed to solve the slow response issue of fire accidents. The inputs provide readings for the system to analyze, such as sensors and Wi-Fi module that works as a transmitter for the sensor readings. Temperature, gas, and flame sensors are inputs. The readings from the inputs are displayed on the web page. Outputs like LED and Buzzer indicate a fire. The water system is lunched with a 12V water pump powered by Arduino and Controlled by a 5V relay. The sprinkler head is the outer of the water output. An ultrasonic sensor is used to measure the tank level and inform the need for refilling. Moreover, batteries are suppling the circuitry and the pump. The pump is 12V that cannot get powered by an Arduino. Relay is used as a switch to control the 12v motor that pumps water required from the tank. In addition to the microcontroller used, a Multiplexer is also used to deal with Analog and Digital lack of pins.

2.1 Block Diagram

According to Figure 1, in case of fire, flame, temperature, and gas sensors send continuous readings to the Arduino. Updated readings are sent into a Wifi module that translates the data into a graphical and statistical manner. A web page created to analyze the data and a response extracted conditionally to launch a water sprinkler as shown. Batteries feed the system as a back-up source while the primary Alternating Current (AC) source function.
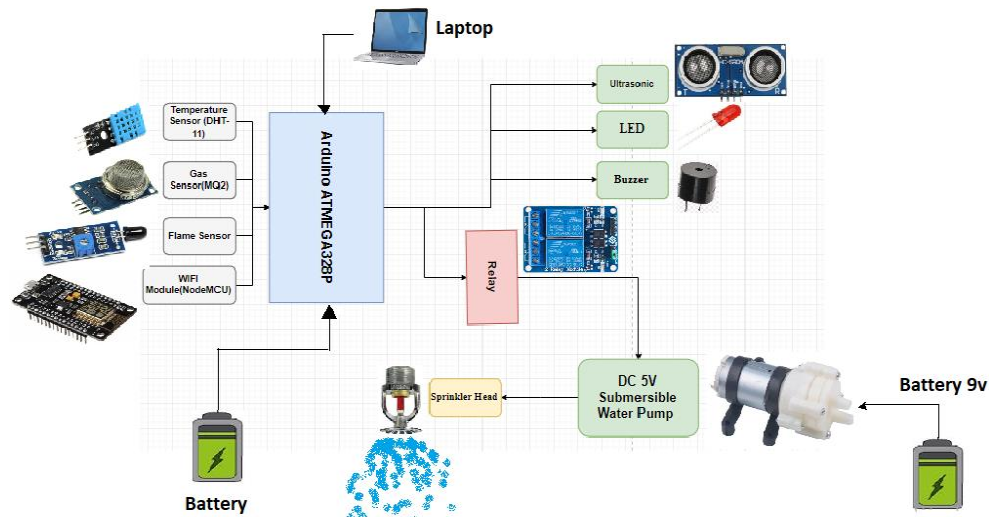
Figure 1. Block Diagram of Smart Fire Detection System with Automatic Water Sprinkler

2.2 Flowchart

Figure 2 depicts the proposed fire detection system with an automatic water sprinkler. As described in the figure, the Arduino Mega controls the sensors to extract reading from the surroundings. Each indicator for these readings has a threshold to check the potentiality and criticality of fire. For example, the temperature exceeds 80C, CO2 exceeds 30%, and/or flames detection. Smoke and flame, indicators of fire criticality, represent the extra needed readings to see fire plus, if one sensor does not work, then back up reading is required. If the above thresholds are met, the water system would be activated to stop the danger. The 12V pump sucks water from the tank to pass into the sprinkler head through the pipe. An ultrasonic sensor reads the water level on the tank. The feedback is linked to IoT updates that control the water pump with other sensors that detected fire. Besides, LED and Buzzer are used in the system as visual evidence to show danger. NodeMCU stores data and display continuous reading on a smartphone.
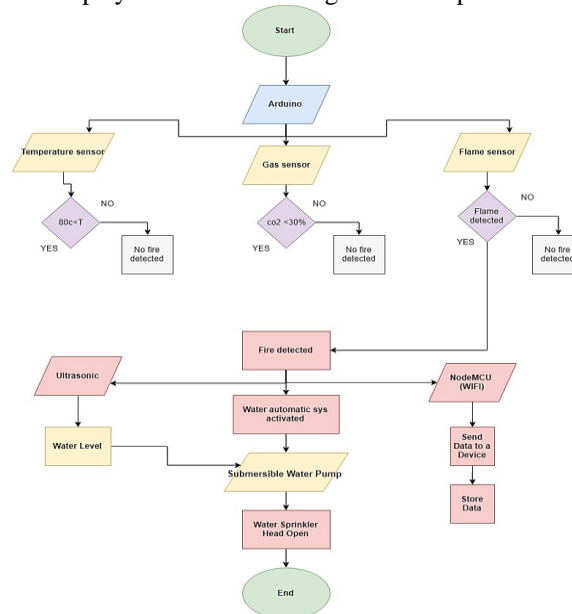

Figure 2. Flowchart of the Proposed System

2.3 Placements of the sensors (Real life application)

Figure 3 depicts the proposed prototype of a fire detector system in which a room is equipped with Gas, Temperature, and flame sensors propagated to ensure fast readings, water sprinklers are equally distributed, a router of the Global System for Mobile Communications (GSM) module is added, and accessories such as LED and Buzzer. The prototype is a testing stand for fire with an emergency backup of the water system.
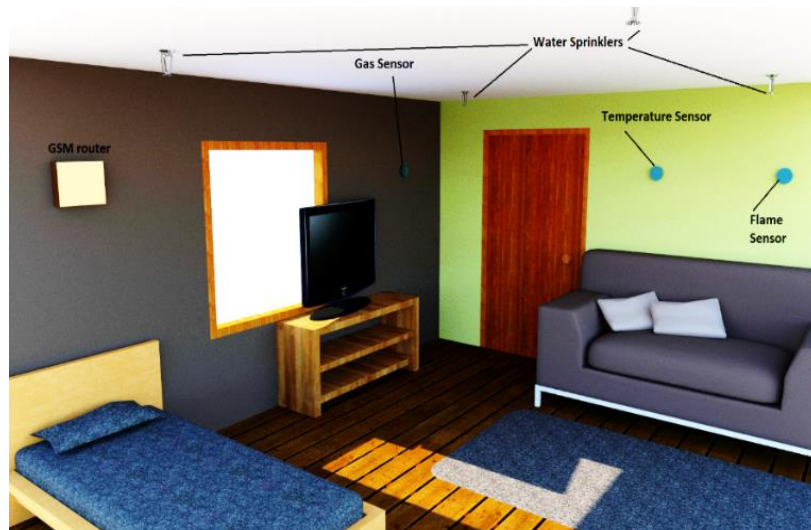
Figure 3. Components Placements in Real-Life with the additional GSM router

3.   RESULTS AND DISCUSSION

In this section, several tests have been conducted to carry out the objectives of the study and get more accurate values with precision. Therefore, efficiency becomes higher with accurate readings; thus, the testing is conducting on seven elements because a smart fire detection system is a life linked matter, so accuracy matters.

3.1. Flame Sensor

A flame sensor is programmed to detect light that falls into a specific range of wavelengths. The sensor follows the visible spectrum. Specifications indicated that the range of detection is acceptable up to 33cm. The changes are between distance and wavelength values; the more the distance, the more the nm increase. The accuracy is higher when the distance is closer. Accuracy is higher when the distance is lower. In 5cm, the reading is 26, which is far from 100; less than 100 fire is detected. In 30cm, the reading is 97, which is critically close to 100, and sensors vary within close range, so it can go more than 100 in thunder moment and not detecting fire due to sensitivity. Figure 4 illustrates the flame sensor detection result.
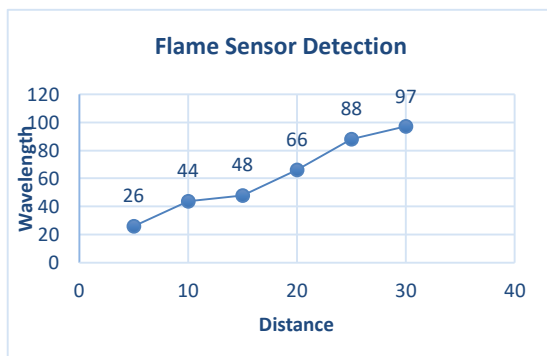

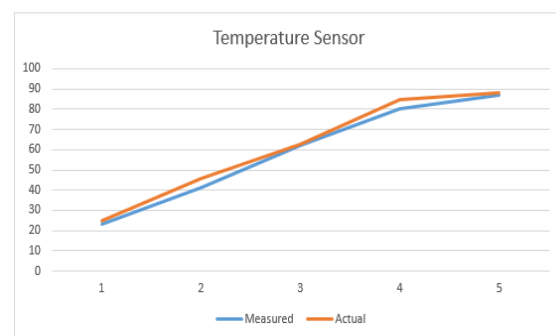Figure 4. Flame Sensor Detection results.

Figure 5. Result of temperature sensor accuracy

Furthermore, the experimental result indicates that the distance is proportionally linked with wavelength. Ideally, the flame sensor would be more accurate if it is placed within a range of 10cm to 15cm from the targeted point.

3.2. Temperature Sensor

Table 1 demonstrates the accuracy of the temperature sensor; the results are compared with infrared thermometer readings. By using a lighter near the sensor to raise the temperature, the reading was conducted. The readings accuracy does not follow a pattern because the sensor is linked to formula and voltage varying from the microcontroller.

Table 1. Accuracy of temperature sensor

Measured Temperature	Infrared Thermometer Reading	Error%= $\frac{Actual-Measured}{Actual}x100$	Accuracy%(100-Error)
23 $C°$	25$C°$	8%	92%
41$C°$	45.5$C°$	9.89%	90.1%
62$C°$	62.6$C°$	0.96%	99.04%
80$C°$	85$C°$	5.9%	94.1%
87$C°$	88.2$C°$	1.36%	98.6%

Figure 5 indicates that results are accurate and can be used practically. Due to the voltage varying and formula used to convert the voltage into temperature, the results can be affected by the delay, so the water pump is not linked to a temperature reading.

3.3. Gas Sensor

Table 2 shows that any increment in voltage means rising in gas concentration. MQ-5 can detect Co, methane, and alcohol. The sensor function according to its sensitivity by using a formula to convert the voltage into estimated numbers of gas concentration. The sensor's accuracy is hard to tell because the reading is based on converting voltage into a percentage by using a mathematical approach. Accuracy can be justified to be acceptable, taking self-observing even though no referencing point is taken.

Table 2. Experimtal result Gas Sensor

Voltage Gas	Concentration (Co) %
0.45	7%
0.9	10%
1.6	19%
2.2	29%
2.8	33%

3.4. Automatic Water System

The delay time is tested according to the response time of the flame sensor. The water pump is connected into a relay switch; if a flame is detected, a delay is counted to switch on the relay that activates the water pump. The flame sensor detects lights wavelengths that are less than 100nm. Once fire detected, the relay switch on. The water pump activated and suck water from the tank and release it into the water sprinkler. The tested part is how many seconds it took the relay to switch on after fire is detected. Figure 6 illustrates the automatic water sprinkler unit design. Therefore, the experimental response time results obtained over the distance is demonstrated in Figure 7.
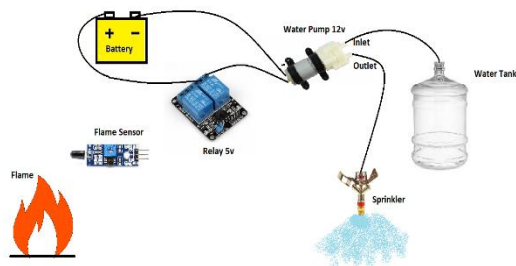

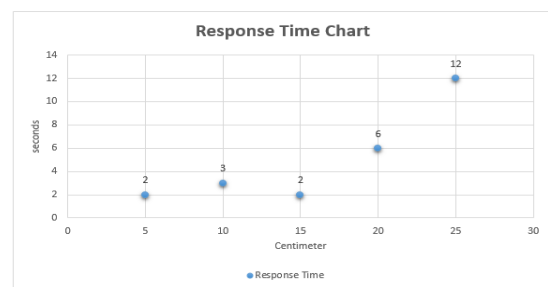Figure 6. Automatic Water System Working Diagram   Figure 7. Response time Vs Distance

Therefore, Hsu *et al.* [38] have developed a kitchen fire detection system with the same sensors employed in this study. However, the system was mainly functioning to warn the residents with loud sounds if a flame was detected and let them monitor the kitchen stove using the Line app to reduce the loss. In Hsu *et al.* [38] work, no automatic water sprinkler unit was involved, making the system not sufficient and reliable to minimize the fire or turn it off. A different system was proposed by [40], where the authors used temperature, flame, Carbon Monoxide (CO), and humidity sensors. The system is designed to notify the owner using SMS;

however, their system has an average delay of less than 30 seconds to achieve its desired functionality. While the proposed approach in this study obtained an average response of 5 seconds

3.4. Integrated System

Table 3 demonstrates that six types of testing were conducted in a continuous attempt to observe the sensors' changes. Six continuous readings have been carried out to establish firefighting. In the beginning, the flame sensor was exposed to flame. However, no fire was detected due to response time. All the testing is continuous and studied every 5 seconds. In testing 2, 3, and 4, the fire was detected and dealt with a water sprinkler that stops when the flame sensor is 1024. Moreover, the water level is monitored with the response time.

Table 3. Expermental results of the system

NO	Flame Reading	Temperature Reading	Gas Concentration	Status	Water Sprinkler	Water Tank Level	Response Time
1	1024	30.4 C°	3%	No Fire	OFF	100%	None
2	34	56.2 C°	12%	Fire	ON	88%	2 Seconds
3	22	64.5 C°	22%	Fire	ON	53%	3 Seconds
4	10	68 C°	66%	Fire	ON	33%	2 Seconds
5	1024	39 C°	35%	No Fire	OFF	20%	4 Seconds
6	1024	31.2 C°	21%	No Fire	OFF	20%	None

3.5. Results and Prototyping

The software results are shown on the Arduino window and the Ubidots platform. Figure 8 displays the readings on the Ubidots dashboard that linked to Arduino coding from the sensors. The readings came from temperature, gas, flame, ultrasonic, and battery. There are three indicators for temperature, gas, and flame sensors; the temperature goes from 0 Celsius to 100 Celsius. The gas sensor takes two displays; one is an indicator for the voltage, one for gas percentage. Ultrasonic gives water level percentage by measuring the distance of water from the container cap. The battery percentage is measured with the voltage divider rule, and it is displayed on the dashboard.

Figure 8. Expermintal result of IoT with Ubidots

When a flame sensor detects light that ranges from 760nm to 1100nm, fire is detected, and data are collected into the IoT platform of Ubidots. Ubidots sends SMS messages into a signed phone number to alert the user that there is a fire threat, as shown in Figure 9 (a). Therefore, the authors in [39] have proposed a fire detection system based IoT using a gateway protocol and flame sensor with Arduino. However, the system was designed to warn the property owner via email if a fire was detected, unlike our system, which alerts the property owner by sending direct SMS messages. Also, there is no automatic water sprinkler unit implemented. This approach is time-consuming and not sufficient compared to the proposed approach in this study.

Figure 9 (b) illustrates the developed experimental model front view, which shows three units integrated with a solid metallic prototype. The joints are eight to support the corners and edges. The water tank is placed on top to make use of gravity when water flows to the bucket. The testing chamber will carry the

flame, gas, and temperature sensors. The water unit will carry two containers for water and a water pump attached to the water sprinkler. The electronics will form the brain of the operation with IoT included.
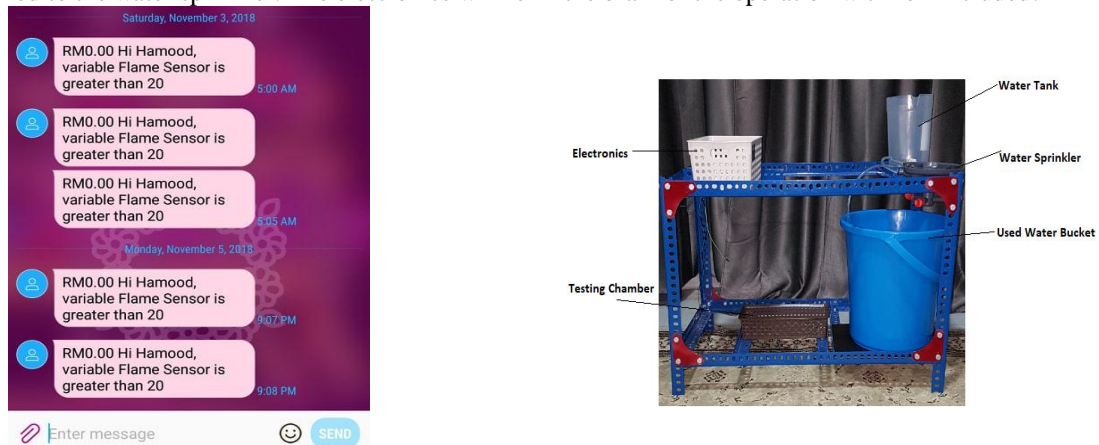

Figure 9. (a) Sending SMS message into a signed phone number to alert the owner of properties; (b) The developed experimtal model.

4. CONCLUSION

The fire detection systems proposed in the literature served fire stopping with no care of the responsiveness. Thus, this study considers the existing issues and build an efficient and effective fire detection system based on IoT technology, gas, temperature, and smoke sensors to collect the data accurately and rapidly. The continuous readings sent over WIFI modules to the central unit to analyze the data and trigger the water sprinkle. This system structure enhances the efficiency and effectiveness of fire detection. Moreover, using the Ubidots platform in this system made the data exchange faster and reliable. However, this study's proposed approach obtained an average response of 5 seconds to detect the fire and alert the property owner. Meanwhile, the water pump activated to suck water from the tank and release it into the water sprinkler to minimize the fire until the property owners and emergency services reached. Hence, the proposed system overcame the challenges of the issues of affordability, effectiveness, and responsiveness. The proposed system still needs further enhancements. Thus, one of the enhancement directions is integrating machine learning with the system to predict the potentiality of fire based on the collected data from different sources. Machine learning may help the operators find and overcome the vulnerabilities in their building to prevent fire instead of detection only.

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