Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System

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Abstract*—Fire detectors and monitoring systems are proven to save many lives making it a promising investment. It is undeniably recognized that one of the most effective preventive methods to prevent catastrophic fire accidents is having a fire detector. However, there are only limited fire mitigation devices that are implemented for urban residential areas. This led to the development of the Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System that aims to acquire fire data such as heat, rate of temperature rise, smoke, combustion gas, and location of the nodes. The Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System is a low-cost fire detector and monitoring device that has the ability to track and record the amount of temperature and gas concentration in its coverage area. Multiple tests were conducted, and it was proven through the Unpaired Two Sample T-Test Results that there is an average percentage error of 0.7775% between the temperature and gas concentration readings of the Digital sensors compared to the sensors used in our prototype. Hence, the system can accurately detect fire data statistics with 30 seconds delay which is faster than conventional smoke detectors.

***Keywords*—fire detection, outdoor monitoring, ESP8266, wireless mesh network, IoT**

I. INTRODUCTION

A. Context

Fire is one of the most dangerous disasters that may occur. It can happen anywhere and at any moment, whether at home, schools, buildings, offices, etc. In residential areas, it can lead to several casualties, such as destroying not only houses and belongings but also the livelihood and life of the inhabitants. From 2013 to 2018, a thousand recorded fire incidents occurred in the Philippines, and most of them happened in Metro Manila. This disaster resulted in a loss, particularly in properties, livelihood, and life. Since most fire hazardous incidents happen in urban residential areas as the risk is higher compared to rural areas, the law obligates owners, buildings, structures, and facilities to provide fire safety construction, protective and warning systems such as firewalls, sprinklers, and fire alarms. The current systems for fire detection include several types of sensors and detectors that are used in buildings and facilities. The proposed system is a wireless mesh network that detects temperature and gas outdoors, specifically in urban residential areas.

B. Review of Previous Research

The three common elements that make up the fire triangle are oxygen, heat, and fuel. The proportion of these anticipates the nature of fire [1]. Aside from these, several things to the fire's origin. Some of it is caused by negligence or carelessness triggering hazardous materials such as the combustion of cellulose materials, liquids, and gas such as foam, rubbers, plastics, paint, LPG gas leak, a lighted cigarette, a burning candle, and overheated electrical appliance [2], [3]. There are three stages in monitoring fire, these are; pre-fire, which entails establishing the best course of action in preventing the occurrence of a fire; during the fire, which involves identification of the location of the fire and performing the firefighting reaction; and post-fire, which involves damage mitigation and assessment [4]. Traditional sensors used for fire monitoring are not for outdoor areas, cannot locate the region of the fire, and are only used inside commercial and industrial households [5]. Some of them are in practice as of today, but some are becoming out-of-date. Through the years, these techniques continuously evolved with the integration of advanced technology, some of which are the application of machine learning, neural networks, and wireless sensor networks [5], [6].

C. Gap or Missing Information

The existing fire detection system uses a variety of sensors, processing units, and alarms. Currently, there are five fire-sensing technologies that are used in fire detection and monitoring systems: heat sensing, gas sensing, smoke sensing, flame sensing, and miscellaneous sensing. These technologies have their merits, such as detecting different temperature measures, and types of gas, smoke, and flame. However, drawbacks cannot be avoided in the existing types of systems. These types of sensors provide multiple sensing techniques, but they usually suffer late detection of fire, limited mobility, duration of operation, thermal distance problems, IR blocking, and thermal reflection. Moreover, some of them such as IR sensors or any type of visual sensors, are costly and high maintenance [7]. Some systems are wired, increasing the cost and complexity of installation [8]. Intrinsically, finding a better solution is opted to be the answer. The researchers propose a low-cost IoT-based wireless mesh network system that eliminates the need for vision-based sensors and manned surveillance.

D. Statement of Purpose

This study aims to develop a wireless fire detection and monitoring system connected via the Internet of Things that could detect the incidence of fire in urban residential areas using the ESP8266 mesh network. Specifically, the study aims: (1) to design a technology that can acquire fire data such as heat, rate of temperature rise, smoke, combustion gas, and location of the nodes from the wireless mesh sensor network interfaced with the ESP8266 microcontroller; (2) to employ a graphical user interface (GUI) used to display sensors readings, fire-analysis status, and a global system for mobile communications (GSM) platform to alarm and transmit an emergency alert message to the fire authorities; and (3) to validate the wireless sensor network by measuring its accuracy and detection-to-notification delay.

E. Statement of Value

The proposed technology attempts to address the issues of the previous fire detection methods in urban residential areas. This will be an unmanned near real-time monitoring system that will observe the location of each sensor node by means of wirelessly detecting and measuring heat, smoke, combustion gas, and location for signaling prospective residential fire. Through the integration of IoT, the response alarm for the potential occurrence of this fire detection system to fire will be faster and more accessible since data will be sent and stored immediately to the host making it more efficient when it comes to damage mitigation. Lastly, it will also be low cost since ESP8266 is a cost-effective wireless mesh network.

E. Scope and Delimitation

The primary focus of this proposal is to construct a fire detection and monitoring system that can measure the heat, smoke, and combustion gas, and provide the location of the incidence of fire. After that, the system can notify and direct the authorities to the point of a potential fire. However, the system is unable to determine and prevent the cause of the fire as it is designed only for detection and monitoring of the current status of the coverage area where the system is located. The system's range to detect potential fire is limited only to the total area coverage of each sensor node. Multiple sensor nodes can be added to the sensor network to increase the coverage area and implement it over longer distances for an optimum detection range. There are no visual sensors used in the system since it is an unmanned detection system. Therefore, there is no visual projection of the area. Lastly, the system is for fire detection and monitoring only. Hence it cannot eliminate the fire itself.

II. Review of Related Literature and Studies

This chapter entails a completed and published a synthesized collection of studies that provide and support concepts, ideas, generalization, and information that are befitting in this study. This will also serve as a guide for the researcher in familiarizing details similar to the present study. Moreover, additional information in this chapter includes a thorough discussion of different fire detection techniques and studies about appropriate equipment effective for detection, such as sensors and networks.

A. Fires

Fire is one of the most dangerous phenomena that could happen in a community as it could eliminate properties, livelihoods, and lives. The average temperature of a flame is around 320~400 ° C and can go to 1100~1200℃ [5]. In a six-year period from 2013 to 2018, there were 94,399 reported fire incidents in the Philippines with a loss of 22.88 billion pesos in assets, 5,131 total number of injuries, and 1,517 total number of deaths. On average, there are 33 fire incidents per year with an average loss of 4.60 billion pesos in assets, 855 injuries, and 253 in fatalities. Most of these incidents came from the National Capital Region (NCR), which contributes 28.61% of the total fire incident in the Philippines. That is 27,011 fire incidents with a loss of 4.6 billion pesos in assets, 1,823 injuries, and 476 deaths [9]. In the city of Manila, there are 2,316 fire incidents reported. One of the major causes of fire in the city of Manila is due to faulty electrical connections. A faulty electrical connection is the highest cause of fire with 58%. Other causes include LPG/cooking, cigarette butt, unattended fire, neglected appliances, and under investigation cause. The reason why some cities have faulty electrical connection is due to the informal settlements and old electrical wiring in the city [10].

Table 2.1. Fire Incidents, By Region

Region	Fire Incidents	Injuries	Deaths
Region I	4,889	94	36
Region II	1,308	60	27
Region III	8,944	455	157
Region IV – A	10,090	525	172
Region IV – B	1,323	69	23
Region V	2,504	33	11
Region VI	8,435	497	57
Region VII	4,871	300	99
Region VIII	1,546	119	47
Region IX	2,100	139	43
Region X	5,517	241	97
Region XI	5,440	223	97
Region XII	3,265	173	55
ARMM	489	68	31
CAR	2,188	124	27
CARAGA	1,402	63	30
NCR	27,011	1,823	476
NIR	3,077	125	32
Total	94,399	5,131	1,517
Average/Year	15,733	855	253

Table 2.2. Asset Losses Due to Fire, By Region

Region	Lost Assets (In Million Pesos)	Average/Year (In Million Pesos)	Share to Total (%)
Region I	260.3	52.1	1.1
Region II	333.0	66.6	1.4
Region III	2,366.3	473.3	10.3
Region IV – A	3,985.2	797.0	17.3
Region IV – B	500.7	100.1	2.2
Region V	279.3	55.9	1.2
Region VI	865.0	173.0	3.8
Region VII	421.5	84.3	1.8
Region VIII	546.5	109.3	2.4
Region IX	903.2	180.6	3.9
Region X	962.4	192.5	4.2
Region XI	4,348.9	869.8	18.9
Region XII	788.2	157.6	3.4
ARMM	179.6	35.9	0.8
CAR	395.3	79.1	1.7
CARAGA	539.3	107.9	2.3
NCR	4,941.5	988.3	21.5
NIR	375.3	75.1	1.6
Total Average/yr.	22,991.3	4,598.3	100.0

B. Classifications of Fire

Fires are categorized by class according to the National Fire Protection Association (NFPA). The portable fire extinguisher standard, NFPA 10, specifies the pertinent graphics and letter designations that correspond to these classes.

This categorization of fire is based on the combustible materials that may catch fire, allowing for the planning of precautions against various types of flames. The NFPA fire classifications are shown in Table 2.3 [11], [12].

Table 2.3. NFPA Classification of Fire

Class	Symbol	Fuel Type	Description
A		Solid materials	wood, paper, fabric, rubber, or plastics
B		Flammable liquids or gasses	petroleum, gasoline, kerosene, paint, alcohol, ether, or propane and butane
C		Electrical fire	Electrical failure from appliances, electronic equipment, bad wiring, or space heaters
D		Metallic fire	aluminum, potassium sodium, titanium, zirconium, magnesium
K		Cooking or grease fire	such as cooking grease, oil, or vegetable and animal fat

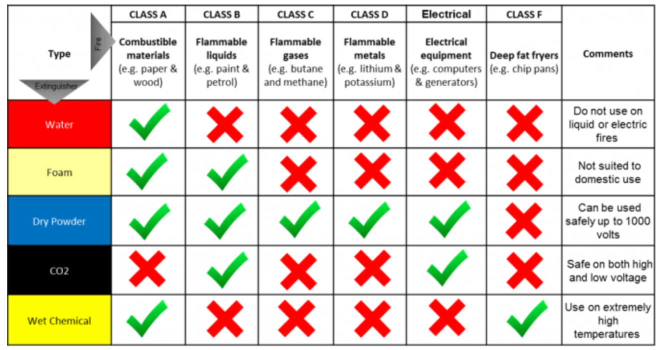

Fig. 2.1. Fire Classification Chart

C. Fire Detection Techniques

There are various fire detection systems used in the market since there are numerous possible causes of fire. Most of these detection systems are smoke and temperature sensors. According to the study of Bogue, optical, ionization, photodetectors, temperature sensors, thermal imaging, and visual surveillance are the commonly used sensing techniques used when detecting fire parameters such as smoke particulates, flame, heat, and combustion products. Table 2.4 shows these sensing techniques [13].

Table 2.4. Common Fire Sensing Techniques

Characteristics	Measured Variables	Sensing techniques
Smoke	Particulates	Optical, ionization, visual surveillance, etc.
Flames	Light	Photodetectors, visual surveillance
Heat	Temperature or rate of temperature rise	Point and linear, temperature sensors, thermal imaging
Combustion products	Gases	Carbon monoxide sensors

Currently, there are two sensing techniques available for early fire detection. These are Visual and Non-visual. This section of the study discusses the two sensing techniques [7].

1. *Visual Sensing Technique*

Forest fire statistics acquired from detection systems serve as an input to a detection system that will alert fire personnel and help aid in determining the fire's origin and behavior, such as the site of ignition, spread speed, temperature, and distance [14]. Visual sensing techniques, notably camera-based techniques, are one of the most prevalent ways of detecting fires where these conditions apply. Visual sensing techniques include infrared and optical cameras and sensors.

Visual sensing technique uses visible and IR cameras to detect the presence of smoke and fire. In some studies, the use of visible or IR cameras can detect flames and smoke in a large area. Smoke is one of the elements of fire that appears and can be noticed first when a fire occurs. Camera sensors detect not only the presence of flames or smoke but also the presence of a person. These visual sensors and cameras can capture image signals with different formats that are analyzed via image processing. This can be a staffed system or a convolution neural networks-based algorithm. Compared to a conventional sensor, the vision-based sensor can cover a large area and it can capture detail such as shapes, size, color, growth, location, degree of burning and dynamic texture [7].

2. *Nonvisual Sensing Technique*

Camera-based techniques provide visual input of the area. It is an expensive system to operate because it is used as a surveillance system and has more features to offer. An inexpensive and alternative way to detect fire is by using nonvisual sensing techniques. Most nonvisual sensors are analog. These techniques fill the gaps of visual sensing techniques of response time and cost. A photoelectric sensor measures smoke by light scatters. This sensor can detect fire fast at a relatively low cost.

Aside from flame and smoke, nonvisual sensing techniques can detect heat and gas. Heat sensor is used to measure the thermal energy in the surrounding. There are three types of heat sensor such as fixed temperature, rate of rise, and rate of compensation. These sensors are activated when a set threshold is exceeded. Gas sensor is used to detect the presence of gas such as CO2, LPG, CO and HCN. These types of gas are mostly present and responsible for fire casualties. Compared to visual sensing, the particles must reach the sensor to be activated and it covers less area. However, to expand the coverage, an additional sensor node can be added [7].

D. Sensors

1. BME280 Environmental Sensor

Fig. 2.2. BME280 Environmental Sensor

BME280 is an environmental sensor that has an integrated pressure, humidity, and temperature sensor. The integrated environmental unit is compact and designed for efficiency. The integrated temperature sensor has been optimized for low noise and high resolution. It has a fast response time, high accuracy over wide temperature ranges, and can be used for ambient temperature measurements. The sensor can measure from –40℃ up to 80℃ with a resolution of 0.1℃ and deviation of ±0.5℃. In addition, the sensor has a range of 0~100%RH, resolution of 0.1%RH, deviation of ±2%RH for Humidity and 300~1100hPa for pressure.

2. MQ-2 Gas Sensor

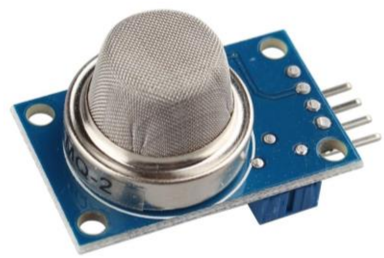

Fig. 2.3. MQ-2 Gas Sensor

MQ-2 gas sensor is one of the gas sensors that belong to the semiconductor type of MQ sensor series. It is a metal oxide gas sensor also known as a chemiresistors because its detection is based upon the change of resistance of the sensing material when the gas meets the material. It is one of the most used gas sensors because it is a low-cost gas sensor that is suitable for different applications. Using a simple voltage divider network, different gas concentrations can be detected. It works on 5V DC.

The MQ-2 sensor is typically used in gas leakage detection for houses, workshops, commercial buildings, fire and safety detection systems. The gases it can detect are LPG, Smoke, Alcohol, Kerosene, Hydrogen, Methane, Butane, and Carbon Monoxide concentrations anywhere from 200 to 10000ppm, but they are unable to distinguish between gases. Thus, they cannot tell which gas it is [15].

E. Wireless Sensor Network

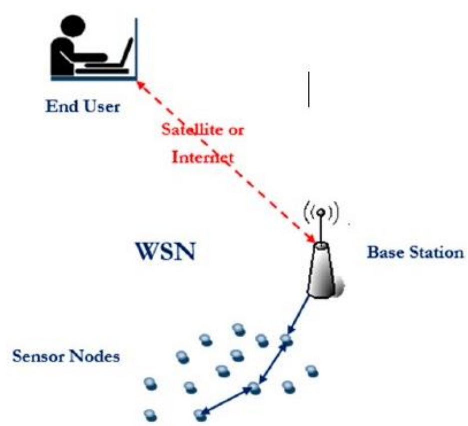

Fig. 2.4. An Architecture of a Wireless Sensor Network

A wireless sensor network or WSN is a group of sensor nodes that are placed in a dispersed location. A sensor node collects information from the environment through the sensors within its range. The information collected is then converted and processed to become a digital signal. Then, the digital signal is transmitted from node to node and/or directly to a selected sink point called the base station. The base station acts control center for the data and sends the collected data through the internet. All transmission and connections are done wirelessly [16].

Wireless sensor networks are used in a variety of applications, namely in healthcare, environmental, industrial, and urban. A wireless sensor network has a capability to acquire data connectively from various sensor nodes that are positioned in a wide area without a need of wire making it inexpensive and low maintenance. The advantage of a WSN is that it is compact, yet it has great sensing, processing and communication capability making it popular in these industries [8], [16].

In a wireless sensor network for fire detection, the sensor node is responsible for sensing, processing, and transmitting collected information from the environment. Most fire detection systems rely on two parameters: smoke, and temperature. The reason being that in a fire incident, gas and steam are to appear first then a sudden change in temperature arises. Hence a gas sensor and temperature sensor are used for early fire detection system [2]. The advantage of using sensor node for early fire detection is it can detect fast and accurately ambient readings, nodes can be added or removed without disrupting the whole network, and the information can transmit through multiple paths thus it can handle a high amount of data communication traffic [8].

F. Different Types of Network Topologies

When designing a communication system, it is ideal for its characteristics to be low in complexity, low-cost, and has high reliability. Identifying the appropriate type of topology is necessary to have an effective model that can conserve the energy of individual nodes in a wireless sensor network while also guaranteeing its coverage and graph connectivity.

Sensor nodes are compact, self-contained pieces that function automatically. It comprises a programming system, storage and communication subsystems, a power source, and a variety of sensors. These sensor nodes are significant in receiving and transmitting the gathered data from its surroundings and forwarding it through the network to a destination that can store the variables and make them available to the network of the end-users.

In some sensor network environments, the deployment of sensor nodes is encountered to be not functional or defective. Hence, the sensor network must be fault-tolerant to sustain the network. Practically, the wireless sensor network architecture is constantly changing dynamically. It is continuously subjected to alteration. However, it is not a desirable approach to increase it by replacing depleted sensors with new ones. Designing a specific and efficient topology is essential in developing a solution to this challenge. Topology control addresses issues such as determining which nodes in a network are interconnected to attain maximum transmission, calculating the lowest transmission power for an individual node for energy conservation, and connecting the nodes using the shortest algorithm for minimal-energy level [17].

The basic and common among all network architecture of a wireless sensor network can be classified into three topologies that are defined in the IEEE 802.15.4 standard. These topologies are the (1) star network, (2) cluster-tree network, and (3) mesh network [18]. These topologies are functional in fire detection and alarm systems, but each has its own set of benefits and drawbacks.

The first topology is the star network topology. It is the simplest of the three topologies [19]. It consists of coordinator and end devices wherein the end device is directly connected to the coordinator device [20]. Since it is a centralized network, nodes can be conveniently added or removed without causing any disruptions to the network. It consumes a small amount of electricity and is commonly used in a small number of ZigBee terminal routing node connections. The downside of this topology is that the network has only one data routing path and is entirely reliant on the local center's operation. As a result, when the local center fails, the entire network fails as well [8]. Figure 2.4 shows a sample of a ZigBee star network topology [18].

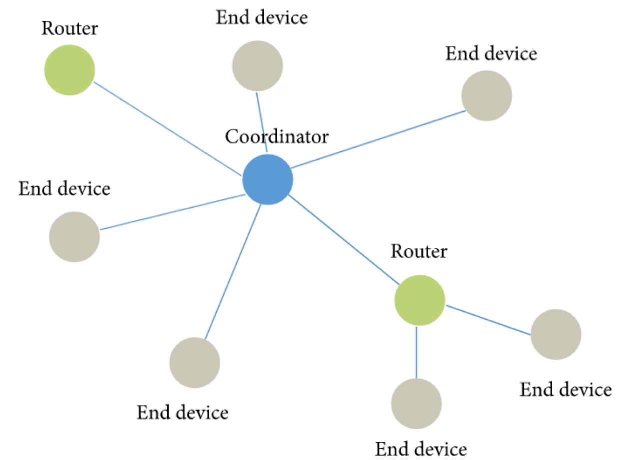

Fig. 2.5. Star Network Topology

The second type of topology is the cluster-tree network. It can support more nodes than a star network and can also be expanded as needed [18]. Communication is based chiefly on grading strategies that use a routing device to transfer data now and then. Since each node is interconnected, they can interact with one another. It is mainly made up of coordinators, routers, and end devices [20]. The downside of this topology is that the information is only transmitted through a particular network channel. If routing nodes fail, the corresponding terminal nodes will recreate the network from the ground up [19]. If the routing node is paralyzed, the entire subnetwork below it will also be paralyzed. Figure 2.5 shows a sample of a ZigBee cluster-network topology [18].

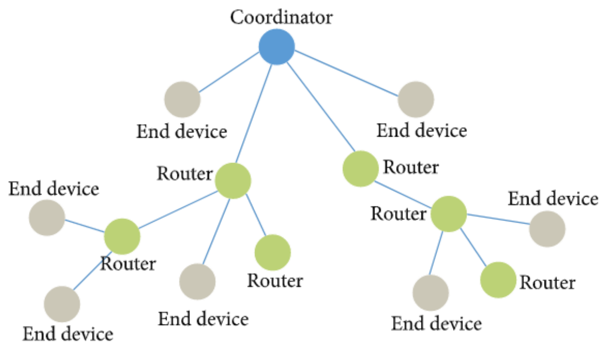

Fig. 2.6. Cluster-Network Topology

The third type of topology is the mesh network. It can be referred to as multi-hop communication. Each node in this network can communicate with other nodes within its range. Since all routers will be interconnected, even if one node fails, the network will be able to recover on its own because of its coping technology [20]. One of this topology's advantages is that data transmission from one node to another lies with its neighboring nodes. When two nodes are unable to interact directly with one another, the data is passed across the nearby nodes as a bridge. Hence, regardless of the occurrence of faulty nodes, relaying data to other nodes is significantly more manageable as it automatically determines the best possible pathway to the network, which reduces message delay and improves system reliability. Because of its flexibility to adapt to a vast number of detectors, mesh topology tops the centralized network, making it more ideal for FDAS [8]. To its disadvantage, it necessitates more storage space. Figure 2.6 shows a sample of a Zigbee mesh network topology [18].

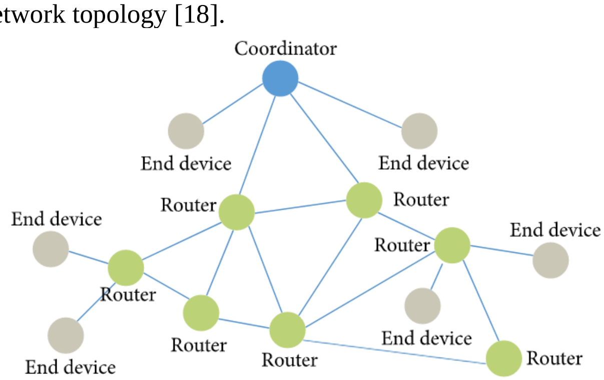

Fig. 2.7. Mesh Network Topology

According to the study of S. Soijoyo and A. Ashari that compared node failure parameters such as data traffic sent, data traffic received, delay, throughput, and packet loss, the star topology has a more stable measurement of throughput, packet loss, and most minuscule amount of uncertainty compared to the cluster-tree and mesh topology because its nodes are less than the other two making its data delivery accuracy better. However, the cluster-tree and mesh network topology trump the star topology in their ability to accommodate more nodes making it efficient for acquiring and delivering data from a broader range and farther area of location [21].

According to the study of Yu Xi Guan, Zheng Fang, and Tian-ran Wang, mesh network technology can be used in several types of fire alarm and risk assessment systems such as electrical fire monitoring systems, forest fire detecting systems, firefighting response, and fire safety management. It monitors the fire in real-time, which reduces the hosts' burden by making the process instant and convenient as opposed to traditional fire risk assessment, which requires manual work. [22].

G. Fire Detection System interfaced with an ESP8266 NodeMCU Wi-Fi Module

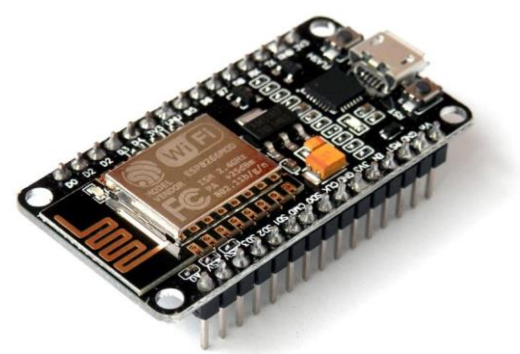
Fig. 2.8.1 ESP8266 NodeMCU Wi-Fi Module

The NodeMCU is an Arduino-type board that runs on the ESP8266 module. The ESP8266 NodeMCU Wi-Fi Module is a low-cost open-source platform that uses simple hardware and software that uses the Wi-Fi protocol to link things and send data. It can be accessed and programmed using the Arduino IDE (Integrated Development Environment), a ready-made software used to write and upload the computer code to the physical board. [23]. Due to its wide working temperature range, it can perform consistently in extreme operating conditions. It is specifically engineered for portable devices, wearable technology, and IoT applications. It utilizes a combination of patented technologies to achieve low power consumption. Three modes of operation are available in the power-saving architecture: active mode, sleep mode, and deep sleep mode. It permits battery-powered designs to run for extended periods of time [24]. Figure 2.8 shows the illustrative example of the NodeMCU, ESP8266 Wi-Fi Module that is based on the ESP- Modules.

There are three different types of Wi-Fi modules for the ESP8266 NodeMCU. First, it can operate as a station (STA) device that can connect to the Wi-Fi network. An access point (AP) connected to a wired network serves as a hub for one or more stations and provides Wi-Fi connectivity. Second, it can operate as a soft access point (soft-AP) to establish its Wi-Fi network for connecting other stations to the modules. Third, it can operate both in the station and soft access point mode simultaneously, enabling mesh networks to be built. [25].

Fig. 2.9.2 ESP8266 Operating in the Station Mode

Fig. 2.10.3 ESP8266 Operating in the Soft Access Point Mode

Fig. 2.11.4 ESP8266 Operating in both Station and Soft Access Point Mode

The ESP8266 NodeMCU Wi-Fi Module can be used in a variety of ways. It has been tested with different combination of technologies such as sensors, actuators, and variations of module devices [26], [27]. Moreover, it is mostly used for developing embedded Internet of Things (IoT) applications [28]. According to a study, it claims that projects that are interfaced with a microcontroller offer a portable module and low power consumption allowing the project to run for an extended period of time on a battery [29]. In some studies, most of these microcontrollers are used to develop an IoT – fire monitoring and alarm system for homeowners primarily to protect homes from any property loss or human loss from fire incident. The proposed system that was driven by the microcontroller was said to be economical and cheaper which can be deployed in all homes [27]. It was also used as a fire alarm system based on IoT (Internet of Things) technology. It was interfaced with a GSM module that aims to send an alert message or signal to the system of the authorities [30]. Furthermore, another fire warning system based on SMS Gateway in the residential area was designed that aims to detect the presence of fires using sensors whose data is then processed in a microcontroller in order to inform the hosts of the potential fire in residential areas and help reduce it [2].

H. Performance Assessment of the ESP8266 NodeMCU Wi-Fi Module in Wireless Mesh Network

In the rapidly expanding environment of the Internet of Things (IoT), the contribution of wireless mesh networks (WMNs) ranges from simple industry occupation to the most demanding industries and services, gathering and processing timely information and constantly aiming to provide near real-time information to assist decision-making. This module offers a useful alternative for this kind of application because they are a practical, affordable, and highly scalable tool [31].

According to the study of Santos, et.al., their project experimentally evaluated the performance assessment of the ESP8266 NodeMCU Wi-Fi Module that is connected in a wireless mesh network using the painlessMesh library. In order to assess the effect on network performance in terms of delivery ratio and one-way delivery time, several tests with various numbers of nodes, traffic loads, message payload sizes, and IwIP Variants were conducted out under unicast communication. They determined that 250 bytes messages consistently produced the highest performance, regardless of the number of sensor nodes in the network. Finally, it was feasible to draw the conclusion that there is high volatility, which may be explained by the painlessMesh library's management of the network topology [31].

I. MIT App Inventor

MIT App Inventor is a free, open-source, and cloud-based service that has a user-friendly interface used in developing mobile applications using a blocks-based programming language. More than a million users have used and accessed it globally using various web browsers. Users have two interfaces to edit: the design editor and the block editor. The design editors allow users to drag and drop interface to layout the interface of the application. The block editor uses color coded blocks like puzzles for the logic for their app in creating the program. With App Inventor Companion, users can test and adjust the interface of their app in real time.

According to the study of Munasinghe et.al [32], the MIT App Inventor can be used to analyze sensor data by adding the concept of Internet of Things (IoT). Moreover, users are able to build different applications. The MIT App Inventor project is continuing to push educational boundaries in the context of mobile app development. Its abstraction of hardware capabilities and reduction of complex logic into compact representations enables users to develop projects that address real-world problems quickly and iteratively.

J. ThingSpeak

ThingSpeak is a cloud-based IoT analytics platform that collects, presents, and examines real-time data streams. Users of ThingSpeak can send data from their devices, visualize real-time data instantly, and send warnings by using online services or social networks like Twitter and Telegram.

Preprocessing, visualization, and analysis may all be done by users inside ThingSpeak by writing and running MATLAB code. ThingSpeak enables engineers and scientists to prototype and build Internet of Things (IoT) systems without the need for servers or web development [33].

ThingSpeak has been used as a platform for real-time monitoring in numerous studies. A recent study by Jasareno et.al [34] has utilized ThingSpeak to send data and alerts for mobile-based temperature and humidity monitoring system in data centers. An essential element of an IoT system is an IoT service, and ThingSpeak is a platform for such applications with a wide range of functionalities. It is designed to be developed around a channel that may be used to store and process data gathered from "things."

III. METHODOLOGY

This chapter describes the overall operation and mechanism of the proposed fire system. It covers everything from monitoring and detecting potential fires to hardware components and analysis. The conceptual framework, system process flow, materials list, data gathering, data transmission, and system evaluation will be thoroughly discussed. This chapter also deals with how the system will be calibrated and tested to evaluate the device's accuracy, performance, reliability, and response time.

A. Hardware Development

This section covers the conceptual framework, system block diagram and the schematic diagram.

a. Conceptual Framework

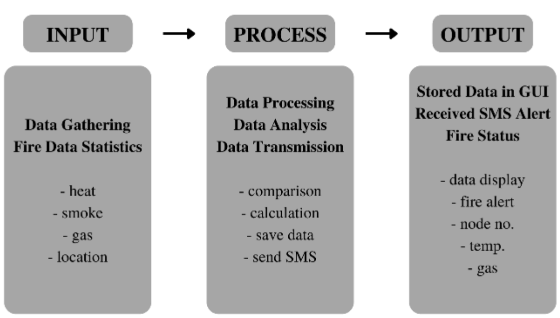

Fig. 3.1. Conceptual Framework

Figure 3.1 shows the conceptual framework of the study. The input of the system will be coming from the fire data statistics specifically temperature, smoke, gas, and location of each node. The process is divided into three stages: (1) the data gathering using each sensor nodes of the wireless sensor network interfaced with the Arduino Mega 2560 Rev3, (2) the data analyzation and transmission of fire data statistics including the location of the nodes through data processing algorithms such as comparing the obtained fire data with regular residential meteorological data and different data parameters that were gathered and processed for threshold checking, and (3) the data transmission of the obtained, gathered, processed, and analyzed fire information and node location through the use of GSM SIM800L Module and ESP8266 NodeMCU Wi-Fi Module. Lastly, the system will be able to save all the data in the GUI and transmit an SMS alert message if the analyzed data surpassed the gas, smoke, and temperature thresholds which will enable the local authorities to receive the approximate real-time information of the monitored location for fire prediction and detection through SMS Alert.

b. System Block Diagram

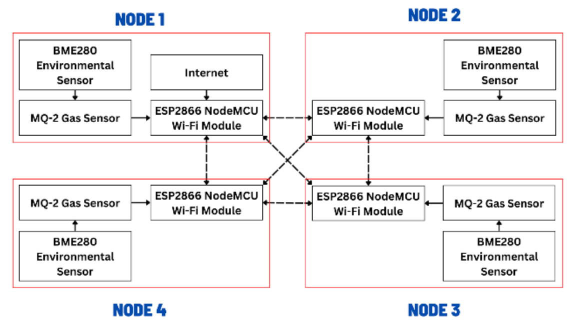

Fig. 3.2. System Block Diagram

Figure 3.2 shows the system block diagram of the whole prototype. In this study, the design of the system will be a Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System. The system components includes the ESP8266 NODEMCU Wi-Fi module, BME280 environmental sensor, and MQ-2 gas sensor. The ESP8266 NODEMCU Wi-Fi module will serve as the main microprocessor that will process the data gathered by the two sensors. This will also enable each node of the system to be interconnected wirelessly and communicate its data with each other through its mesh connection. It will provide the access to the GUI of the system through Wi-Fi. Lastly, the GUI created through the ESP8266 NODEMCU Wi-Fi module is responsible in sending the alert message.

c. Schematic Diagram

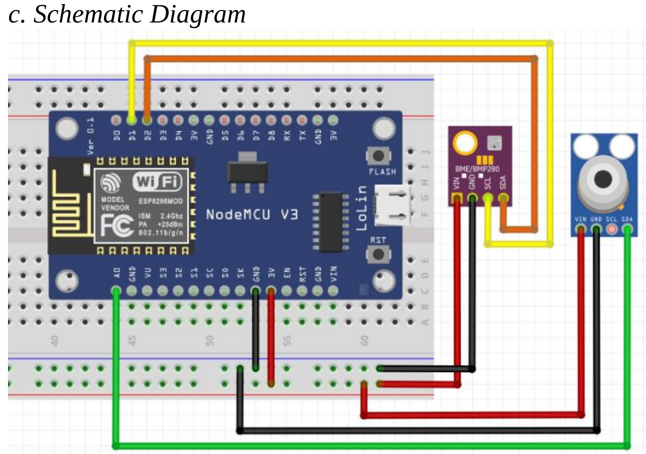

Fig. 3.3. Breadboard Circuitry Diagram

Figure 3.3 shows the breadboard circuitry diagram of a node in our whole prototype. Specific colors were assigned to the pins of each component to easily identify its connection to the microcontroller. Black indicates ground while Red indicates the voltage source. The ESP8266 NodeMCU Wi-Fi Module serves as the microcontroller designed to execute the whole operation based on the embedded codes and scripts stored in it. The BME280 environmental sensor will serve as the sensor that will read the temperature data obtained from the open environment. Its SCL pin is connected to the Digital Input 1 (D1) of the ESP8266 NodeMCU Wi-Fi Module through the yellow wire while its SDA pin is connected to the Digital Input 2 (D2) of the ESP8266 NodeMCU Wi-Fi Module through the orange wire. The MQ-2 gas sensor will serve as the sensor that will read the gas concentration data obtained from the open environment. Its A0 pin is conneceted to the Analog Input (A0) pin of the ESP8266 NodeMCU Wi-Fi Module.

B. System Process Flow

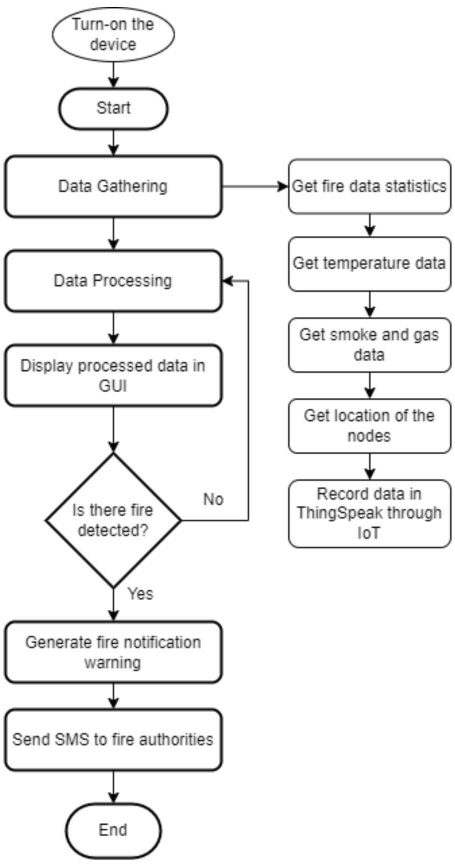

Fig. 3.4. System Process Flowchart

The process of a fire detection system starts by collecting the data from the sensors. Each sensor node is connected wirelessly via the mesh network of the ESP8266 NodeMCU Wi-Fi Module. The nodes consist of the temperature and gas sensor that detects the ambient air temperature and the presence of gas concentration within its vicinity. Once the fire data statistics are gathered, it will be recorded to the cloud which is the ThingSpeak through IoT. The recorded data will be processed and analyzed in the microprocessor of the ESP8266 NodeMCU Wi-Fi Module and GUI which is the MIT App Inventor through the codes embedded in it. The system requires two triggered parameters to declare a fire warning. The system will ask if there is a fire detected through the threshold set for the temperature and gas sensor. If there is a fire, the system will prompt a fire alert notification warning that will enable the user to send an SMS to the fire authorities along with the status and the location of the node. The system will continue to monitor the coverage area and notify as necessary.

C. Prototype Development

a. Prototype Design

The design of the prototype was made in SketchUp Pro 2021. The illustration for the final design is shown in Figure 3.6.

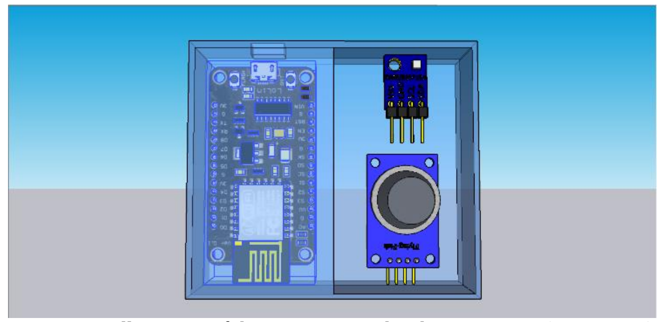

Fig. 3.5. 3D Illustration of the Prototype in SketchUp Pro 2021 (Front View)

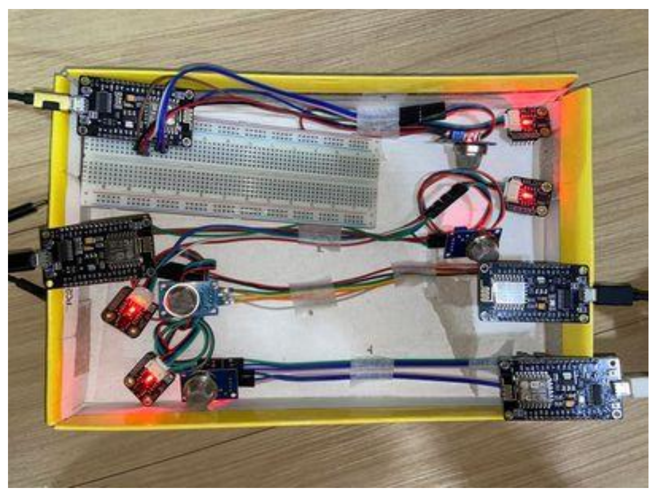

Fig. 3.6. Actual Prototype Design

Figure 3.6 shows the actual prototype of the Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System that was built based on Figure 3.5. The connections of the wirings are based on the breadboard circuitry diagram shown in Figure 3.3.

The whole prototype is powered by a laptop through a USB cable. As shown in the figure, it is composed of four fire monitoring and detector nodes wherein each node consists of one ESP8266 NODEMCU Wi-Fi module that serves as the microcontroller, one BME280 environmental sensor, and one MQ-2 gas sensor.

b. List of Materials

This section covers all the components with its specifications used in creating the prototype that will be developed as a fire detection and monitoring system. It includes the sensor nodes, base station, microcontrollers, and receiving units needed for the system [5], [14].

Table 3.1. List of Materials with their Specifications

ESP8266 NODEMCU WI-FI MODULE	
Microcontroller	ESP-8266 32-bit
Operating Voltage	3.3V
Input Voltage	4.5V – 10V
Digital I/O	11
Analog Input	1
Clock Speed	80Mhz – 160MHz
PWM Pins	4
UART	2
Wi-Fi Built-In	802.11 b/g/n
Temperature Range	-40°C – +125°C
BME280 ENVIRONMENTAL SENSOR	
Working Voltage	3.3V – 5V
Working Current	2mA
Working Temperature	-40°C – +85°C
Temperature Measuring Range	-40°C – +85°C resolution of 0.1°C deviation of ±5°C
Humidity Measuring Range	0 – 100% RH resolution of 0.1%RH deviation of ±2%RH
Pressure Measuring Range	300 – 1100hPa
Humidity Sampling Time	1s
Dimension	22 x 25mm / 0.87 x 0.98 inches
Weight	12g
MQ-2 GAS SENSOR	
Operating Voltage	5V
Concentration scope:	200ppm – 10000ppm 0.05mg/L – 10mg/L
Current Consumption	150mA
Operation Temperature	-10°C – +75°C

c. Bill of Materials

Table 3.2 indicates the materials required to create and operate the prototype. One of the components, notably the expensive high-end equipment like the laptop, is not readily available because of its high cost. If you don't have any means, you can borrow some from someone else.

Table 3.2. Bill of Materials

Quantity	Material	Type	Price (₱)
4 pcs	Microcontroller	ESP8266 NodeMCU WiFi Module	160.00
4 pcs	Gas Sensor	MQ-2	75.00
4 pcs	Environmental Sensor	BME280	1062.00
4 pcs	Breadboard	Solderless	64.00
2 set	Jumper Wires	Female to Male	64.00
2 set	Jumper Wires	Female to Female	64.00
		TOTAL	5,700.00

E. Data Gathering

Objective 1: to design a technology that can acquire fire data such as heat, rate of temperature rise, smoke, combustion gas, and location from the wireless mesh sensor network interfaced with the ESP8266 microcontroller.

1. Calibration

a. Temperature and Gas Sensor Calibration

The temperature and gas sensor will be calibrated using codes in Arduino IDE to ensure its accuracy in detecting the heat and gas.

For calibrating the BME280 environmental sensor, the BME280 environmental sensor is positioned pointing directly in an open environment together with a non-contact infrared digital thermometer to measure the normal outdoor air temperature. The test will be done in 20 trials with 30 seconds to 1 minute interval. The temperature of the sensor and the non-contact infrared digital thermometer will be recorded in Table 3.3 in Celsius.

The percentage error of the temperature values obtained from the non-contact infrared digital thermometer and BME280 environmental sensor will be calculated. Refer to equation 3.1. The temperature reading having the lowest percentage error be averaged and used to set the temperature threshold value of the BME280 environmental sensor.

$$\%Error = \frac{|\hat{y}_i - y_i|}{y_i} \times 100 \quad (3.1)$$

$$Ave.\ Error = \frac{\sum \%Error}{n} \quad (3.2)$$

Table 3.3. Temperature Sensor Calibration and Value Comparison

Outdoor Air Temperature				
Test	**Time**	**Infrared Digital Thermometer (°C)**	**BME280 Environmental Sensor (°C)**	**% Error**
1	2:30:48	28.20	28.00	0.7143
2	2:30:48	28.01	28.03	0.0714
3	2:31:03	28.12	28.10	0.0712
4	2:31:13	28.17	28.15	0.0710
5	2:31:23	28.22	28.19	0.1064
6	2:31:49	28.30	28.30	0

7	2:31:59	28.33	28.31	0.0706
8	2:32:09	28.35	28.31	0.1413
9	2:32:30	28.31	28.31	0
10	2:32:40	28.33	28.31	0.0706
11	2:32:50	28.29	28.30	0.0353
12	2:33:16	28.25	28.27	0.0707
13	2:33:26	28.23	28.26	0.1062
14	2:33:36	28.20	28.24	0.1416
15	2:34:02	28.16	28.21	0.1772
16	2:34:12	28.21	28.19	0.0709
17	2:34:22	28.19	28.17	0.0710
18	2:34:58	28.13	28.12	0.0356
19	2:35:08	28.11	28.11	0
20	2:35:18	28.11	28.10	0.0356
			Average Error	**0.1031**

For calibrating the Gas sensor, the MQ-2 gas sensor and digital gas sensor are positioned pointing directly in an open environment. The test will be done in 20 trials with 30 seconds to 1 minute interval. The gas concentration of the MQ-2 gas sensor and the digital gas sensor will be recorded in Table 3.4 in Celsius.

The percentage error of the gas concentration values obtained from the digital gas sensor and MQ-2 gas sensor will be calculated. Refer to equation 3.1. The temperature reading having the lowest percentage error be averaged and used to set the temperature threshold value of the MQ-2 gas sensor.

Table 3.4. Gas Sensor Calibration and Value Comparison

Outdoor Gas Concentration				
Test	**Time**	**Digital Gas Sensor (ppm)**	**MQ-2 Gas Sensor (ppm)**	**% Error**
1	2:30:48	333	334	0.2994
2	2:30:48	336	334	0.5988
3	2:31:03	334	334	0
4	2:31:13	335	333	0.6006
5	2:31:23	331	333	0.6006
6	2:31:49	332	333	0.3003
7	2:31:59	333	333	0
8	2:32:09	333	333	0
9	2:32:30	322	331	2.7190
10	2:32:40	329	332	0.9036
11	2:32:50	332	333	0.3003
12	2:33:16	330	330	0
13	2:33:26	331	330	0.3030
14	2:33:36	333	330	0.9091
15	2:34:02	332	330	0.6061
16	2:34:12	333	330	0.9091
17	2:34:22	332	330	0.6061
18	2:34:58	333	330	0.9091
19	2:35:08	330	330	0
20	2:35:18	331	330	0.3030
			Average Error	**0.5434**

b. Distance and Height Range Measurement

Both sensors will be tested to determine the amount of temperature and gas that can be recorded at a specific distance and height between each node. Since the test fire that we will use is far comparable to the actual fire of a house fire, the ratio of test detection will be smaller. Based on the standard test fire from the Bureau of Fire and Protection (BFP), a fire will be produced that will serve as the fire for calibration. There will be three classifications of fire according to its size will be used that will represent the actual residential fire. The size of fire will be based on what the BFP personnel will suggest. For the first stage (1), a small-sized fire will be used. For the second stage (2), a medium-sized fire will be used. For the third stage (3), a large-sized fire will be used.

The sensors will be positioned at different angles and direction in an open environment. The open environment is at an open field where the atmosphere has normal meteorological data away from people and structures. For the distance, the sensors will be put into trial within the distance range of 1m to 2.8m with an increment of 0.2m and will be checked every time. For the height, the sensors will be put into trial within the height range of 1m to 5m with an increment of 1m and will be checked every time. The sensors will be moved away from the subject for every 1m until it can't detect any heat or smoke at all. Once the measurement is done, the position of the sensor nodes will be positioned according to the smallest distance obtained. The measured temperature and smoke on the reading will be the sensor threshold value. The tables below show the sample testing table of results once the distance and height testing are done.

Table 3.5. Testing of Temperature Sensor Distance Range

Outdoor Air Temperature				
Distance (m)	**Time**	**Infrared Digital Thermometer (°C)**	**BME280 Environmental Sensor (°C)**	**% Error**
1m	22:02:16	33.21	33.6699	1.3659
1.2m	22:02:46	32.78	33.3100	1.5911
1.4m	22:03:16	32.41	32.25	0.4961
1.6m	22:03:46	32.38	31.7800	1.8880
1.8m	22:04:16	30.79	31.6299	2.6554
2m	22:04:46	32.15	31.1100	3.3430
2.2m	22:05:16	31.13	30.5599	1.8655
2.4m	22:05:46	30.86	30.1399	2.3892
2.6m	22:06:16	31.85	32.8901	3.1623
2.8m	22:06:46	32.83	33.4800	1.9415
			Average Error	**2.0698**

Table 3.6. Testing of Gas Sensor Distance Range

Outdoor Gas Concentration				
Distance (m)	**Time**	**Digital Gas Sensor (ppm)**	**MQ-2 Gas Sensor (ppm)**	**% Error**
1m	22:02:16	510	506	0.7905
1.2m	22:02:46	515	511	0.7828
1.4m	22:03:16	501	497	0.8048
1.6m	22:03:46	499	494	1.0121
1.8m	22:04:16	492	496	0.8065
2m	22:04:46	496	492	0.8130
2.2m	22:05:16	492	486	1.2346
2.4m	22:05:46	489	484	1.0331
2.6m	22:06:16	490	491	0.2037
2.8m	22:06:46	498	501	0.5988
			Average Error	**0.8080**

Table 3.7. Testing of Temperature Sensor Height Range

Outdoor Air Temperature				
Height (m)	**Time**	**Infrared Digital Thermometer (°C)**	**BME280 Environmental Sensor (°C)**	**% Error**
1m	22:45:37	33.85	33.60	0.7440
1.2m	22:46:07	33.10	33.6299	1.5756
1.4m	22:46:37	33.19	33.67	1.4256
1.6m	22:47:07	32.98	33.70	0.8308
1.8m	22:47:37	33.84	33.70	0.4154
2m	22:48:07	33.09	33.68	1.7517
2.2m	22:48:37	33.48	33.7099	0.6819
2.4m	22:49:07	33.19	33.75	1.6592
2.6m	22:49:37	33.48	33.75	0.8
2.8m	22:50:07	33.58	33.75	0.5037
			Average Error	**1.1694**

Table 3.8. Testing of Gas Sensor Height Range

Outdoor Gas Concentration				
Height (m)	**Time**	**Digital Gas Sensor (ppm)**	**MQ-2 Gas Sensor (ppm)**	**% Error**
1m	22:45:37	493	487	1.2320
1.2m	22:46:07	492	484	1.6529
1.4m	22:46:37	481	482	0.2075
1.6m	22:47:07	480	479	0.2088
1.8m	22:47:37	483	477	1.2579
2m	22:48:07	479	476	0.6303
2.2m	22:48:37	481	474	1.4768
2.4m	22:49:07	472	473	0.2114
2.6m	22:49:37	475	469	1.2793
2.8m	22:50:07	470	467	0.6424
			Average Error	**0.8799**

2. Experiment Setup

a. Experiment Setup

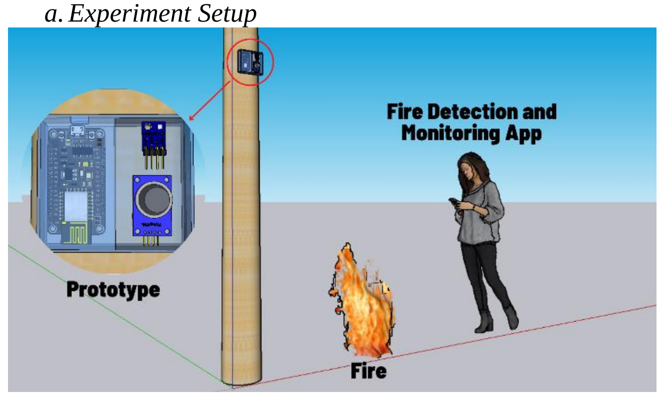

Fig. 3.7. Experiment Setup

The basic components that comprise the system test-fire are the sensor nodes, laptop, and cellphone. All testing and data gathering will be done in an open environment to ensure consistency with the parameters mentioned in the system calibration. This also ensures that the area monitored is close to the real residential setup when it is implemented.

The set-up starts with the sensor node where its position and threshold will be determined by system calibration. The system's capability to detect various temperatures will be measured. The readings of each sensor will be processed in the ESP8266 NODEMCU Wi-Fi module then processed data will be sent to the MIT App Inventor via IoT. Once the data reaches a fire warning, a message notification containing the status and location of the node will be sent to the phone of the user.

b. Distance and Testing Setup

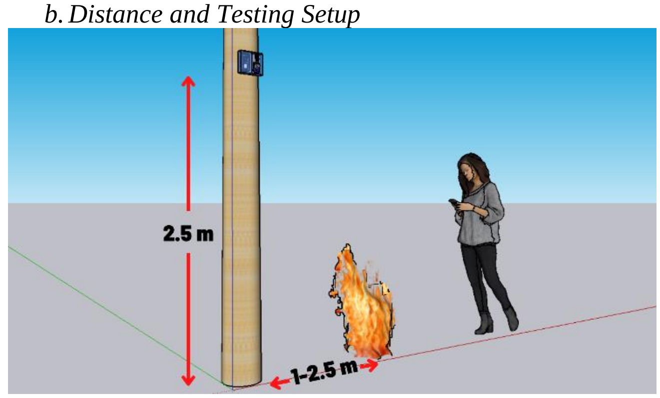

Fig. 3.8. Distance and Height Testing Set-up

c. Sample Test Area

Fig. 3.9. Sample Node Location Implementation

Figure 3.9 shows the sample node location implementation in a house in Greenland, Nangka, Marikina City. The figure shows the position of each node that is determined by the testing in distance. Each sensor nodes are wirelessly connected by the ESP8266 NODEMCU Wi-Fi module. The use of mesh network in this system allows each node to communicate with each other. An addition or removal of node or when a node fails, the network won't be disrupted as the data can find another best path. Other node will act as a bridge because data transmission also lies within its neighboring nodes.

E. Data Transmission

Objective 2: to employ a graphical user interface (GUI) used to display sensors readings, fire-analysis status, and a global system for mobile communications (GSM) platform to alarm and transmit an emergency alert message to the fire authorities.

1. MIT App Inventor SMS Notification

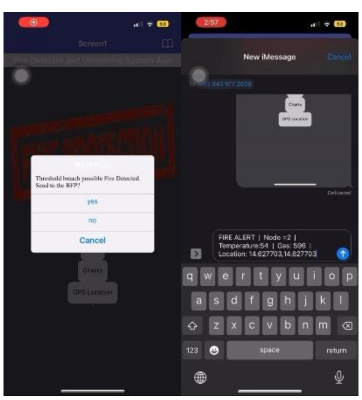

Fig. 3.10. SMS Notification by the MIT App Inventor

The MIT App Inventor will wirelessly transmit an alert notification indicating the sensor threshold are reached. The fire status, fire alert level, and coordinates of the fire detector sensor nodes from the device will be prompted to the message app of the user to manually send a message to the fire authorities. The message will show the exact time and date of occurrence as well as the message containing the corresponding fire statistics indicating fire. Manual sending of the alert message is used to avoid false alarm. When the multiple sensor nodes detect an exceeding parameter compared to the normal threshold value, it will first save the data then prompt the SMS:

FIRE ALERT | Node [Number of Node] | Temperature: [Temperature in Celcius] | Gas: [Gas in ppm] Location: [xx.xxxxxx], [xxx.xxxxxx]

2. Graphical User Interface (GUI)

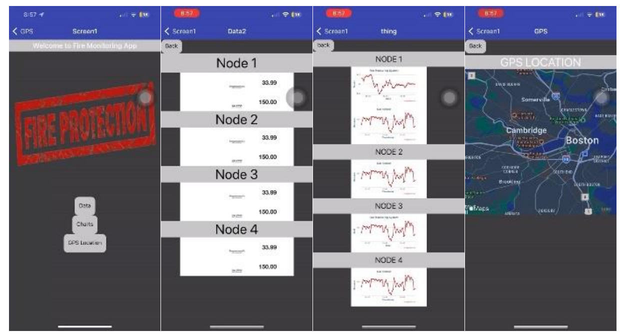

Figure 3.11 GUI using MIT App Inventor

Figure 3.11 shows the graphical user interface (GUI) of the proposed fire detection and monitoring system. The GUI of the system will show the data, graphs, and GPS location of each node. For the Data, the near real-time numerical values of the temperature and gas concentration of each node will be displayed. For the Graphs, the recorded temperature and gas concentration of each node will be displayed graphically which can be reviewed anytime. Lastly, the GPS location shows the exact position or location of the nodes where it is implemented.

F. System Evaluation

Objective 3: to validate the wireless sensor network by measuring its accuracy and detection-to-notification delay.

One of the last processes involves sending an alert message (SMS) through the MIT App Inventor to the receiver in order to inform and give an initial warning of the occurrence of fire. The overall system testing will be carried out to verify the working principle of the fire detector and monitoring device. It will be tested for its response time and accuracy to register and receive data through sensors and transmitter that will be processed in the ESP8266 NODEMCU Wi-Fi module.

The test will be carried out with multiple trials in order to verify if the device can measure each fire data parameter accurately. The parameters involved are the device node number, temperature and smoke sensor, location coordinates of the node, fire status, and response to the receiver, accuracy, and time. The testing phase will have 1 telephone number as recipient.

In testing the accuracy of the system, the temperature and gas parameter obtained from each nodes will be compared to each other to determine whether the parameters are detected accurately. Tale 3.8 shows the sample temperature and smoke accuracy testing table. A series of test fire will be produced at different location near a certain node.

Table 3.9. Temperature and Gas sensor Accuracy and Detection-to-Notification Testing Table

Test 1: Fire is near node 1 and 2									
Node	**Node 1**		**Node 2**		**Node 3**		**Node 4**		**SMS**
Time	**T**	**G**	**T**	**G**	**T**	**G**	**T**	**G**	
23:00:07	✓	✓	✓	✓	X	✓	✓	✓	✓
23:00:37	✓	✓	✓	✓	✓	✓	✓	X	✓
23:01:07	✓	✓	✓	✓	✓	X	✓	X	✓
23:01:37	✓	✓	✓	✓	✓	✓	✓	X	✓
23:02:07	✓	✓	✓	✓	✓	✓	✓	✓	✓
23:02:37	✓	✓	✓	✓	X	✓	✓	✓	✓
23:03:07	✓	✓	✓	✓	✓	✓	✓	✓	✓
23:03:37	✓	✓	✓	✓	✓	X	X	✓	✓
23:04:07	✓	✓	✓	✓	✓	X	✓	✓	✓
23:04:37	✓	✓	✓	✓	✓	✓	X	✓	✓

Table 3.10. Temperature and Gas sensor Accuracy and Detection-to-Notification Testing Table

Test 2: Fire is near node 3 and 4									
Node	**Node 1**		**Node 2**		**Node 3**		**Node 4**		**SMS**
Time	**T**	**G**	**T**	**G**	**T**	**G**	**T**	**G**	
23:30:23	X	✓	X	X	✓	✓	✓	✓	✓
23:30:53	✓	✓	✓	✓	✓	✓	✓	✓	✓
23:31:23	✓	X	X	✓	✓	✓	✓	✓	✓
23:31:53	✓	X	✓	✓	✓	✓	✓	✓	✓
23:32:23	✓	X	✓	X	✓	✓	✓	✓	✓
23:32:53	✓	✓	✓	X	✓	✓	✓	✓	✓
23:33:23	✓	✓	✓	✓	✓	✓	✓	✓	✓
23:33:53	✓	X	✓	X	✓	✓	✓	✓	✓
23:34:23	✓	✓	✓	✓	✓	✓	✓	✓	✓
23:34:53	X	✓	✓	✓	✓	✓	✓	✓	✓

IV. Presentation and Interpretation of Data

The presentation and interpretation of the prototype's data are covered in this chapter. The results of various tests relation to the objectives in Chapter 1 will be provided. This will establish how well the prototype is functioning and how dependable it is.

A. Two Sample T-Test

This study utilizes the Two-sample type of T-test which compares the results obtained from the digital temperature and BME280 environmental sensor, as well as the digital gas and MQ-2 gas sensor. Utilizing this type of test allows the researchers to determine whether there is a significant difference between the results obtained from comparing the sensors of the prototype to digital sensors.

B. Purpose of Two Sample T-Test

A t-test is a parametric test of difference which is used in comparing the means of two groups. It makes assumptions on whether the data are independent, are normally distributed, and have the same amount of variance on the group being compared. In this study, two-sample t-test will be used to compare the temperature sensors and the gas sensors. Two-tailed t-test will also be used to determine the sensors difference from one another.

C. Analyses and interpretations of collected data

Table 3.3 Temperature Sensor Calibration and Value Comparison

Table 3.3 shows the comparison results of the temperature readings of the BME280 environmental sensor and non-contact infrared digital thermometer in Celsius which is measured from 2:30:48 AM to 2:35: 18 AM with 30 seconds interval. Based on the computed values of percentage error, the highest % error is 0.7143 and the lowest % error is 0. Getting its average error, it resulted to a value of 0.1031 implying that the temperature readings of the BME280 environmental sensor is almost equal to the infrared digital thermometer.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.6904
   - By conventional criteria, this difference is considered to be not statistically significant.

2. Confidence interval:
   - The mean of Infrared Digital Thermometer minus BME280 Environmental Sensor equals 0.0120
   - 95% confidence interval of this difference: From -0.0485 to 0.0725

3. Intermediate values used in calculations:
   - t = 0.4013
   - df = 38
   - standard error of difference = 0.030

Table 3.11. Unpaired Two Sample T-Test Results of Table 3.3

Group	Infrared Digital Thermometer	BME280 Environmental Sensor
Mean	28.2110	28.1990
SD	0.0901	0.0988
SEM	0.0201	0.0221
N	20	20

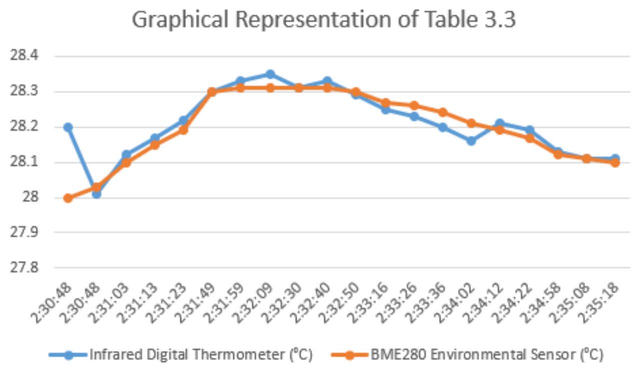

Figure 3.12 Graphical Representation of Table 3.3

Analyzing on the values of each parameter in the graph shown in Figure 3.12, it can be concluded that the value of the temperature readings of the BME280 Environmental Sensor is directly proportional to the temperature readings of the Infrared Digital Thermometer. At first reading, it can be seen that there is a 0.2 difference making this small value negligible.

Table 3.4 Gas Sensor Calibration and Value Comparison

Table 3.4 shows the comparison results of the gas concentration readings of the MQ-2 gas sensor and digital gas sensor in ppm which is measured from 2:30:48 AM to 2:35: 18 AM with 30 seconds intervals. Based on the computed values of percentage error, the highest percentage error is 2.7190% and the lowest percentage error is 0%. Getting its average percentage error, it resulted in a value of 0.5434% implying that the gas concentration readings of the MQ-2 gas sensor are almost equal to the digital gas sensor.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.8928
   - By conventional criteria, this difference is considered to be not statistically significant.
2. Confidence interval:
   - The mean of Digital Gas Sensor minus MQ-2 Gas Sensor equals 0.10
   - 95% confidence interval of this difference: From -1.39 to 1.59
3. Intermediate values used in calculations:
   - t = 0.1375
   - df = 38
   - standard error of difference = 0.737

Table 3.12. Unpaired Two Sample T-Test Results of Table 3.4

Group	Digital Gas Sensor	MQ-2 Gas Sensor
Mean	331.75	331.65
SD	2.84	1.66
SEM	0.64	0.37
N	20	20

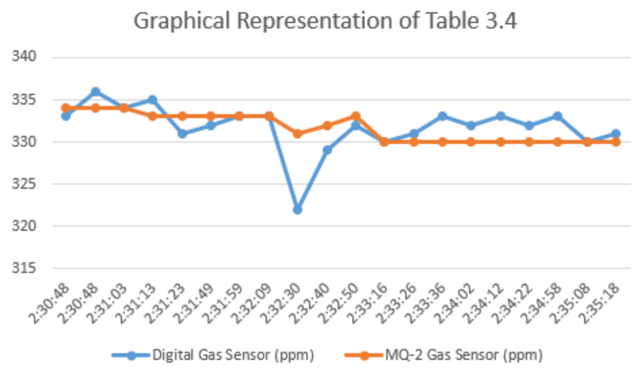

Figure 3.13 Graphical Representation of Table 3.4

Analyzing on the values of each parameter in the graph shown in Figure 3.13, it can be concluded that the value of the temperature readings of the MQ-2 Gas Sensor is directly proportional to the temperature readings of the Digital Gas Sensor. Even though there is a big difference in the values obtained at time 2:32:30, it can be neglected since almost all readings are approximately accurate and equal with each other.

Table 3.5 Testing of Temperature Sensor Distance Range

Table 3.5 shows the results of the temperature readings of the BME280 environmental sensor and non-contact infrared digital thermometer in Celsius measured at a specific distance from 22:02:16 AM to 22:06:46 AM with 30 seconds interval. Based on the computed values of percentage error, the highest percentage error is 3.3430% and the lowest percentage error is 0.4961%. Getting its average percentage error, it resulted in a value of 2.0698% implying that the temperature readings measured at a specific distance of the BME280 environmental sensor are almost equal to the infrared digital thermometer.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.9295
   - By conventional criteria, this difference is considered to be not statistically significant.
2. Confidence interval:
   - The mean of Infrared Digital Thermometer minus BME280 Environmental Sensor equals -0.042970
   - 95% confidence interval of this difference: From -1.048546 to 0.962606
3. Intermediate values used in calculations:
   - t = 0.0894
   - df = 18
   - standard error of difference = 0.479

Table 3.13. Unpaired Two Sample T-Test Results of Table 3.5

Group	Infrared Digital Thermometer	BME280 Environmental Sensor
Mean	32.039000	32.081970

SD	0.857923	1.246951
SEM	0.271299	0.394321
N	10	10

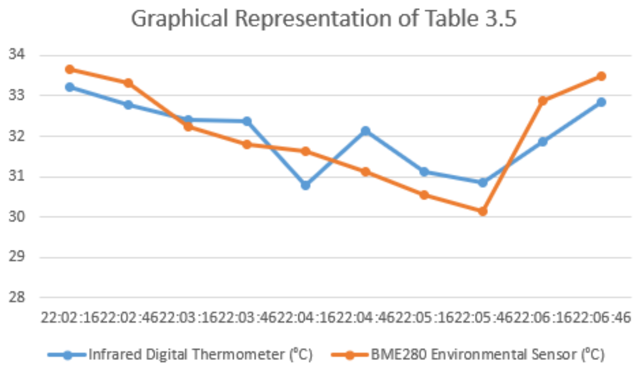

Figure 3.14 Graphical Representation of Table 3.5

Analyzing on the values of each parameter in the graph shown in Figure 3.14, it can be concluded that the value of the temperature readings of the BME280 Environmental Sensor is directly proportional to the temperature readings of the Infrared Digital Thermometer. The small difference in its values can be neglected since almost all readings are approximately equal with each other.

Table 3.6 Testing of Gas Sensor Distance Range

Table 3.6 shows the results of the gas concentration readings of the MQ-2 gas sensor and digital gas sensor in ppm measured at a specific distance from 22:02:16 AM to 22:06:46 AM with 30 seconds intervals. Based on the computed values of percentage error, the highest percentage error is 1.2346% and the lowest percentage error is 0.2037%. Getting its average percentage error, it resulted in a value of 0.8080% implying that the gas concentration readings measured at a specific distance of the MQ-2 gas sensor are almost equal to the digital gas sensor.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.5362
   - By conventional criteria, this difference is considered to be not statistically significant.

2. Confidence interval:
   - The mean of Digital Gas Sensor minus MQ-2 Gas Sensor equals 2.40
   - 95% confidence interval of this difference: From -5.59 to 10.39

3. Intermediate values used in calculations:
   - t = 0.6307
   - df = 18
   - standard error of difference = 3.805

Table 3.14. Unpaired Two Sample T-Test Results of Table 3.6

Group	Digital Gas Sensor	MQ-2 Gas Sensor
Mean	498.20	495.80
SD	8.59	8.43
SEM	2.72	2.67
N	10	10

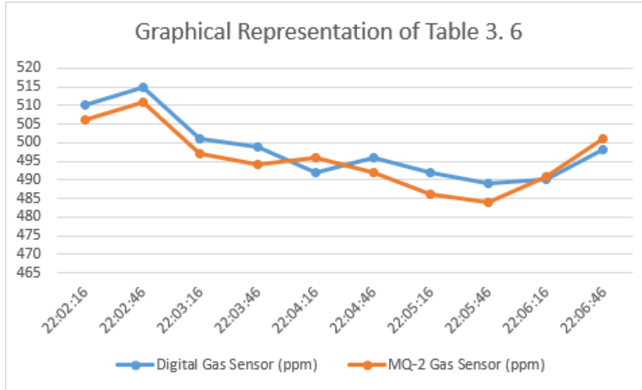

Figure 3.15 Graphical Representation of Table 3.6

Analyzing on the values of each parameter in the graph shown in Figure 3.15, it can be concluded that the value of the temperature readings of the MQ-2 Gas Sensor is directly proportional to the temperature readings of the Digital Gas Sensor. The small difference in its values can be neglected since almost all readings are approximately equal with each other.

Table 3.7 Testing of Temperature Sensor Height Range

Table 3.7 shows the results of the temperature readings of the BME280 environmental sensor and a non-contact infrared digital thermometer in Celsius measured at a specific height from 22:45:37 AM to 22:50:07 with 30 seconds intervals. Based on the computed values of percentage error, the highest percentage error is 2.1365% and the lowest percentage error is 0.4154%. Getting its average percentage error, it resulted to a value of 1.1694% implying that the temperature readings measured at a specific height of the BME280 environmental sensor is almost equal to the infrared digital thermometer.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.0056
   - By conventional criteria, this difference is considered to be not statistically significant.

2. Confidence interval:
   - The mean of Infrared Digital Thermometer minus BME280 Environmental Sensor equals -0.315980
   - 95% confidence interval of this difference: From -0.527307 to -0.104653

3. Intermediate values used in calculations:
   - t = 3.1413
   - df = 18
   - standard error of difference = 0.101

Table 3.15. Unpaired Two Sample T-Test Results of Table 3.7

Group	Infrared Digital Thermometer	BME280 Environmental Sensor
Mean	33.378000	33.693980
SD	0.313964	0.051044
SEM	0.099284	0.016142
N	10	10

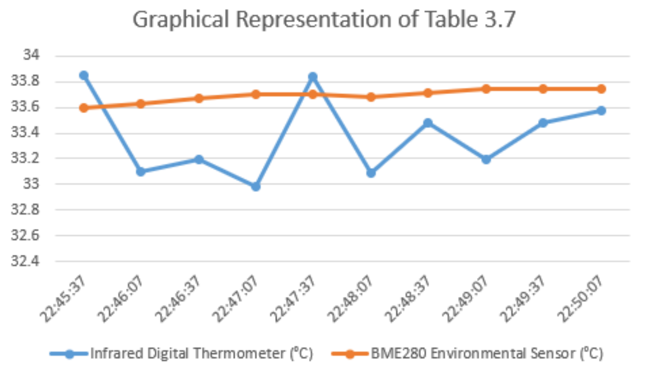

Figure 3.16 Graphical Representation of Table 3.7

Analyzing on the values of each parameter in the graph shown in Figure 3.14, it can be concluded that the value of the temperature readings of the BME280 Environmental Sensor is directly proportional to the temperature readings of the Infrared Digital Thermometer. It can be seen in the graph that there is a 0.2-0.8 difference in the obtained values from the two sensors. This small difference can be neglected since almost all readings are approximately close and almost equal with each other.

Table 3.8 Testing of Gas Sensor Height Range

Table 3.8 shows the results of the gas concentration readings of the MQ-2 gas sensor and digital gas sensor in ppm measured at a specific height from 22:45:37 AM to 22:50:07 AM with 30 seconds intervals. Based on the computed values of percentage error, the highest percentage error is 1.2793% and the lowest percentage error is 0.2114%. Getting its average percentage error, it resulted in a value of 0.8799% implying that the gas concentration readings measured at a specific height of the MQ-2 gas sensor are almost equal to the digital gas sensor.

Unpaired Two Sample T-Test Results:

1. P value and statistical significance:
   - The two-tailed P value equals 0.2395
   - By conventional criteria, this difference is considered to be not statistically significant.
2. Confidence interval:
   - The mean of Digital Gas Sensor minus MQ-2 Gas Sensor equals 3.80
   - 95% confidence interval of this difference: From -2.76 to 10.36
3. Intermediate values used in calculations:
   - t = 1.2166
   - df = 18
   - standard error of difference = 3.123

Table 3.16. Unpaired Two Sample T-Test Results of Table 3.8

Group	Digital Gas Sensor	MQ-2 Gas Sensor
Mean	480.60	476.80
SD	7.53	6.39
SEM	2.38	2.02
N	10	10

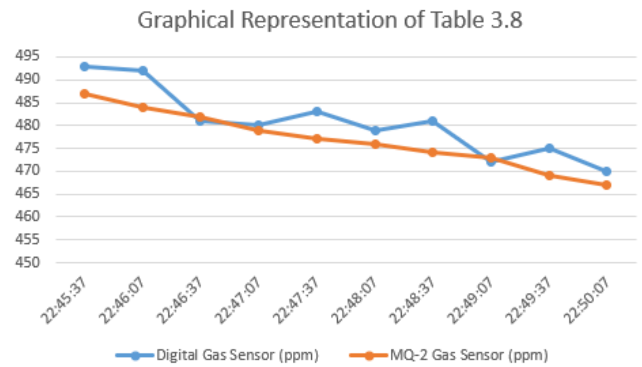

Figure 3.17 Graphical Representation of Table 3.8

Analyzing on the values of each parameter in the graph shown in Figure 3.17, it can be concluded that the value of the temperature readings of the MQ-2 Gas Sensor is directly proportional to the temperature readings of the Digital Gas Sensor. The small difference in its values can be neglected since almost all readings are approximately equal with each other.

V. Conclusion and Recommendation

This chapter evaluates the conclusion and propose recommendations to the prototype. The researchers will provide their overall findings and comprehensive evaluation to the entire prototype. This will determine the study's effectiveness and point up areas where the prototype needs improvement.

A. Conclusion

A Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System was developed. It can detect near real-time incidence of fire in urban residential areas using the ESP8266 mesh network connected via the Internet of Things.

The prototype was developed as a technology that can acquire fire data such as heat, rate of temperature rise, smoke, combustion gas, and location of the nodes from the wireless mesh sensor network interfaced with the ESP8266 microcontroller. Based on the interpretation of the obtained data, it can be concluded that our prototype can acquire these parameters while having a 0.7775% percentage error between the temperature and gas concentration readings of the Digital sensors compared to the sensors used in our prototype which are the BME280 Environmental sensor and MQ-2 Gas sensor among all tests that were conducted.

Researchers were also able to employ a graphical user interface (GUI) used to display sensors readings and fire-analysis status using the MIT App Inventor together with the cloud-based IoT analytics platform ThingSpeak. A global system for mobile communications (GSM) platform was also implemented and interfaced to the prototype using the MIT App Inventor whose purpose is to alarm and transmit the emergency alert message to the fire authorities once a fire is detected in the nodes.

Lastly, the researchers were able to validate connections between the wireless mesh sensor network by measuring its accuracy and detection-to-notification delay. It can be concluded that the fire is strongly detected by the node nearest to it. Even if one or two nodes doesn't match the readings of the node near the fire, the detection and notification of the prototype is still accurate since the node near the fire can accurately analyze its surroundings based on the data detected by the sensors.

B. Recommendation

The Wireless IoT-Based ESP8266 Mesh Network for Fire Detection and Monitoring System was developed only for detection and monitoring that is why it is unable to determine and prevent the cause of the fire. Therefore, it is recommended to add an additional function and module that can help extinguish the fire in its coverage area. The system's range to detect potential fire is limited only to the total area coverage of each sensor node that is why it is recommended to add more nodes to the sensor network to increase the coverage area and implement it over longer distances for an optimum detection range. Lastly, cameras or visual sensors can be added if visual sensing is desired.

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