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RESEARCH ARTICLE

Design and Implementation of Smart Environmental Air Pollution Monitoring System (SEAPMS) based on IoT

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ABSTRACT

A Smart Environmental Air Pollution Monitoring System (SEAPMS) based on internet of things (IoT) has been built for monitoring the concentrations of major air pollutant gases, as well as a fire extinguishing system for fire detection and prevention. Using a network of sensors, the SEAPMS detects gas concentrations such as carbon monoxide CO, carbon dioxide CO_2, methane CH_4, dust, smoke, temperature, and humidity. The sensors will collect data on numerous environmental characteristics and send it to particle photons, which will compare it to a predetermined threshold for each sensor then sends it to a special IoT platform known as UBIDOTS. UBIDOTS sends data to the cloud then they will be realized and virtualized to be displayed. The fire extinguishing system will activate when the smoke concentration exceeds its threshold limit value.

Key words: Internet of things, Smart Environmental Air Pollution Monitoring System, Particle photon, Sensors, UBIDOTS, Message Queuing Telemetry Transport

INTRODUCTION

According to the American Social Medical Association for Industrial Health, air pollution is defined as the presence of impurities or pollutants that have fallen into the air, whether by nature or man, in sufficient quantity and time to disturb the many people exposed to this air, causing harm to public health and property of humans, animals, and plants.[1] Acidification, global warming, ozone layer depletion, and climate change are all environmental repercussions of air pollution, resulting in dryness and vegetation damage.[2] Air pollution promotes respiratory problems such as asthma, pneumonia, and bronchitis in humans. Pregnancy exposure to high levels of air pollution causes miscarriage, early delivery, autism, and asthma in children.[3] As a result, demand for air pollution monitoring (APM) systems is increasing. The conventional air automatic monitoring system is distinguished by very sophisticated equipment technology, huge bulk, instability, and expensive cost. Due to the high cost and weight, large-scale installation is unfeasible. This system is only available for installation in key monitoring locations of a few significant enterprises.

This paper provides a way for overcoming the drawbacks of standard monitoring systems and detection methods while simultaneously cutting test costs by merging internet of things (IoT) technology with APM. The IoT is a more exemplary new path in the field of IT, a revolution in the conversion of data from things to things, from human to human, and from human to things. It was created in 1998 and Kevin Ashton first introduced the term "IoT" in 1999.[4] IoT architecture consisting of three layers, as shown in Figure 1, application layer, network layer, and perception layer. The application layer uses smart cloud computing technologies to extract valuable information from a large amount of data processing and also provides a link between IoT and users.[5,6] The network layer deals with network operations, while the responsible sensing layer is assembling the information.[7]

There are many reasons explained in Table 1 for choosing this APM technology.

Over the past few decades, there has been a rapid surge in the development of APM systems. The applications of these systems are regarded as robust, and they are always a challenge for inventors. These systems must be well-designed to

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Table 1: Traditional and IoT based of monitoring air pollution differences[8]

Parameter	Conventional	IoT APM
Coverage	Low	High
Cost	High	Cheap
Power consumption	High	Low

APM: Air pollution monitoring, IoT: Internet of things

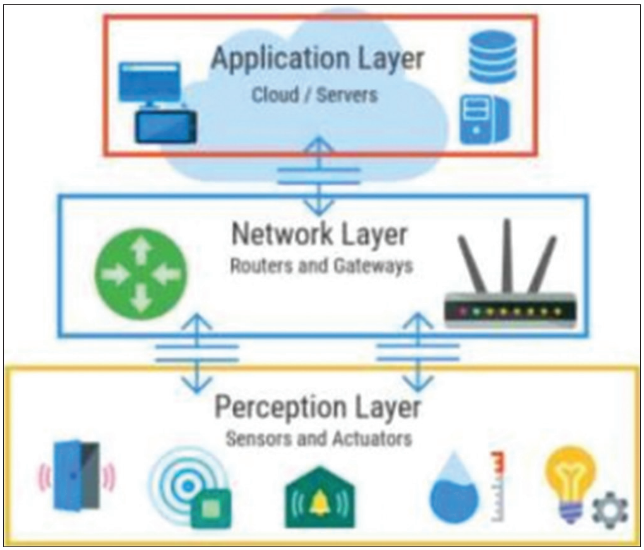

Figure 1: Internet of things architecture[5,6]

meet time restrictions while executing complicated jobs.[9]

The Smart Environmental APM System (SEAPMS) in this research contains two parts; the first part is the hardware components and the second part is the software programs. The sensors are programmed using the Particle IDE program and the programming language (C++). The data should be available in real time on the UBIDOTS IoT platform, the structure of the system is shown in Figure 2.

The rest of this paper is structured as follows: Section 2 discusses the background and related works, while Section 3 describes the system design analysis. Section 4 describes implementation of the system, Section 5 shows the analysis of the fire extinguishing system design, Section 6 shows the implementation if the fire extinguishing system design, Section 7 shows the system's flowchart where Section 8 shown the results, and finally, Section 9 shows the conclusion.

BACKGROUND AND RELATED WORKS

We discovered through a review of previously designed APM systems and fire extinguishing

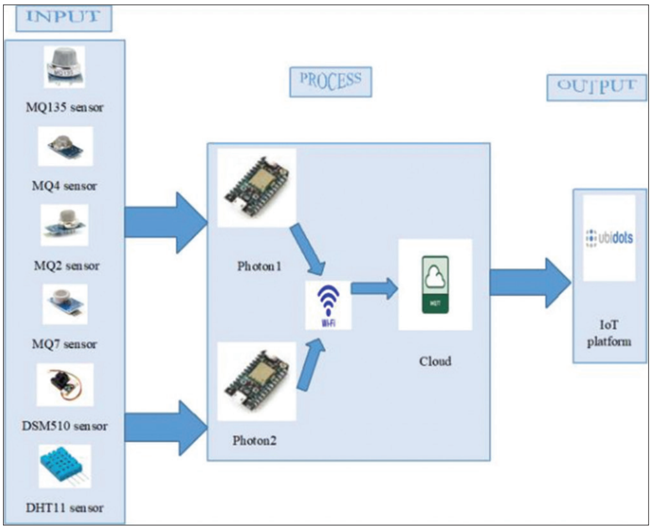

Figure 2: The proposed SEAPMS structure

systems that Manna *et al*.[10] designed an APM system based on IoT to measure pollution on streets and track vehicles that pollute beyond a predetermined limit by combining a wireless sensor network (WSN) based on IEEE 802.15.4 and electrochemical toxic gas sensors, as well as the use of a radio frequency identification (RFID) tagging system. Continuous air quality monitoring and the use of multiple gas sensors, such as carbon monoxide, sulfur dioxide, nitrogen dioxide, methane, and so on. The locations that had a high volume of traffic were identified to be monitored. For each location, the RFID reader communicated with Arduino and sends the RFID tag number that it was read and data were printed on a terminal or sent the data to a server.

Dong *et al*.[11] created a wireless automatic fire alarm system with low-power consumption to provide rapid fire detection and alarm as well as state supervision of fire-fighting capabilities. Zheng *et al*.[12] designed an APM system based on IoT technology using low-power area network, which is established on the IEEE 802.15.4 k regulation, is used to get ubiquitous communication between the monitoring nodes and the access point. A particulate matter (PM) sensor was utilized to measure PM 2.5, as well as a temperature and humidity sensor. Sensors, a microcontroller unit, and a battery make up the air quality monitoring node.

Kumar and Jasuja[13] suggested a real-time independent air quality monitoring system based on IoT that contains several sensors such as the DSM501A PM sensor, the DHT22 and BMP180, which provide digital outputs for measuring temperature, humidity, and pressure, MQ9 and MQ135 are analog sensors that detect carbon monoxide and carbon dioxide. The sensors are linked to an Arduino board, and the Raspberry Pi (a main node) was linked to the Arduino Uno through a USB cable. The system's software was built of an IDE (Integrated Development Environment). The Message Queuing Telemetry Transport (MQTT) protocol is critical in developing connection between devices and users.

Barot *et al*.[14] described an IoT-based air quality monitoring system that detects indoor and outdoor air pollutants, including PM10, PM2.5, carbon monoxide, temperature, and humidity, ESP8266 microcontroller was equipped with Wi-Fi to smooth MQTT protocol, the system also included a DHT22 sensor, an electrochemical sensor ZE07-CO for carbon monoxide, and an SDS021 sensor unit for PM10 and PM2 5 readings.

The literature analysis shows that most systems differ in microcontroller type and sensors type that is used for the simulation of a practical circuit. Most of the studies used Arduino or Raspberry Pi or ESP8266 as a microcontroller and used WSN technology. The aim of the research is to design and develop a SEAPMS as well as a fire extinguishing system based on IoT using a particle photon microcontroller and then sending the evaluated data over the internet to the UBIDOTS cloud to store, visualize, and analyze data. The system's most essential advantages are its low cost with long life time, small size unit, low-power consumption, efficiency, eco-friendliness, and the ability to achieve real-time results at several places.

ANALYSIS OF THE SEAPMS DESIGN

Figure 3 shows the SEAPMS elements, correct interconnections, and the actual position of each item. Particle photons, MQ-2 sensor, MQ-4 sensor, MQ-135 sensor, MQ-7 sensor, DHT 11 sensor, and DSM501A sensor are among the equipment and components used in this project.

Particle photon

The particle photon is a single microcontroller development board with the added feature of having a built-in Wi-Fi module that we can control and program over the internet using the Particle cloud.[15] It is a combination of the ARM Cortex M3 microprocessor and the Broadcom Wi-Fi chip in a tiny compact module that employs the C/C++ programming language. As illustrated in Figure 4, it contains 18 general purpose input-output pins, which are utilized for connecting particle photons to other general-purpose devices by coding them according to the desired function, while the sensors acquire actual data and send it to the photon.[16]

MQ4 gas sensor

MQ4 sensor is shown in Figure 5 which has high levels of methane sensitivity in a wide range, suitable for low cost, and long-term use, and it has simple driver circuitry.[17]

MQ2 gas sensor

MQ2 gas sensor shown in Figure 6 can be used as a digital or analog sensor, for smoke detection, it uses the analog pin of the sensor for a scope of 200–5000 ppm.[18]

MQ7 gas sensor

This sensor is ideal for measuring carbon monoxide (CO) gas, as illustrated in Figure 7. CO

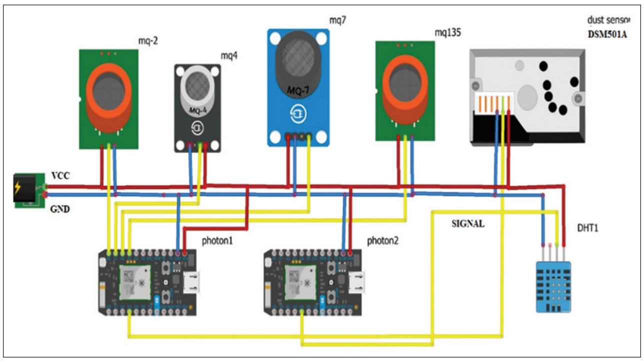

Figure 3: Circuit pin diagram of the implemented hardware of the SEAPMS

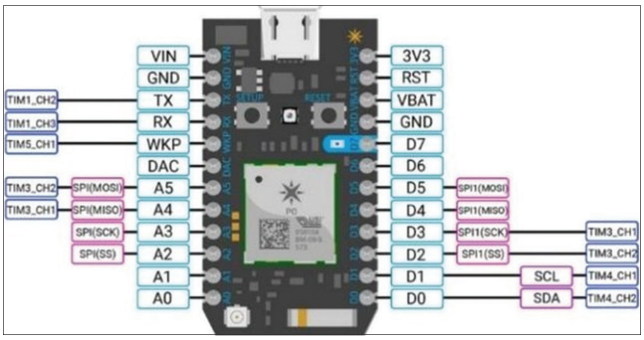

Figure 4: Photon pin diagram[16]

concentrations ranging from 10 to 10,000 ppm can be estimated. This sensor's performance is measured in terms of analog resistance. It includes six pins, four for signal extraction and two for internal line heating. Its benefits are long life, low cost, and simple drive circuit.[19]

MQ135 gas sensor

MQ135 shown in Figure 8 is used to measure carbon dioxide CO_2 emissions in the air. Because of its wide detection range, it has rapid reaction, high sensitivity, long life, and stability.[20]

DSM501A dust sensor

In Figure 9, it can detect particles with a diameter >1 micron. The built-in sensor warmer will automatically inhale air. It is compact in size, light in weight, and simple to install and use.[21]

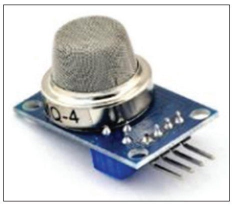

Figure 5: MQ4 sensor

Figure 6: MQ2 sensor

Figure 7: MQ7 sensor

Figure 8: MQ135 sensor

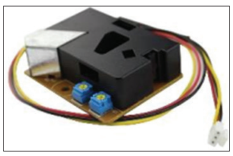

Figure 9: DSM501A

DHT11 temperature and humidity sensor

The DHT11 sensor measures and serializes humidity, and temperature values over a single wire. It has four pins, one of which is used for serial communication of data.[22] The sensor reads analog signals from the physical environment and converts these signals into digital signals.[23] DHT11 temperature and humidity sensor are shown in Figure 10.

UBIDOTS is a platform for IoT

UBIDOTS is the IoT platform employed in this research. It is an IoT application builder with data analytics and visualization. Each UBIDOTS user has an API credential, which includes a unique authentication for each user to be included in the program. The system is then networked, and the data measurements collected by the hardware are transferred to this IOT platform.[18] The UBIDOTS log-in process is depicted in Figure 11. The particle photon takes data from the sensor and transmits it through a communication protocol known as MQTT to the UBIDOTS cloud, once the platform has been modified, it receives hardware information and displays a variable within the platform, representation of the system in UBIDOTS is shown in Figure 12.

This is accomplished through the use of variable names in the code; once the data are represented as a variable, it is shown as a widget in the dashboards. Data can be viewed to users in the form of a table, indication, or graph. Events can also be used to send alert messages or e-mails to users.

MQTT Message Queue Transport Remote Service, which is an ISO-based open-source messaging protocol file that works on the TCP/IP network layer, MQTT is a powerful tool that employs the publish-subscribe (pub/sub) structure, as shown in Figure 13. It was created in 1999 by Andy Stanford-Clark and Arlen Nipper and has since been popular for IoT due

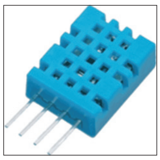

Figure 10: DHT11 sensor

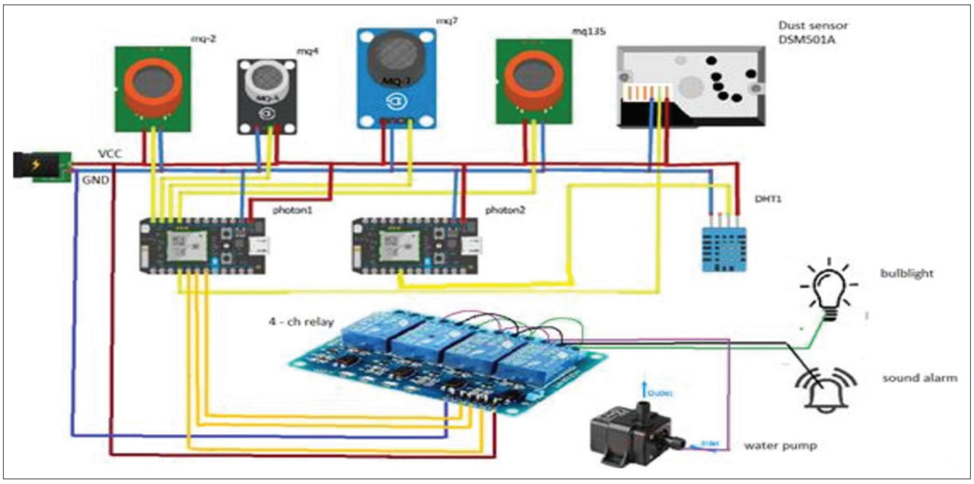

Figure 11: Circuit pin diagram of the implemented hardware of fire extinguishing system

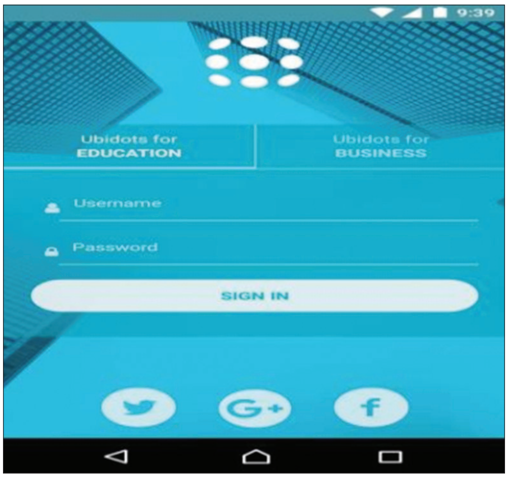

Figure 12: UBIDOTS log in[24]

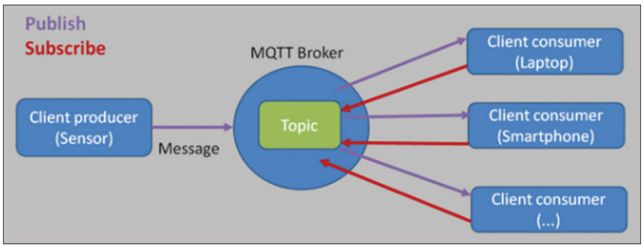

Figure 13: MQTT protocol working principle[25]

to low-cost processors and quick internet access.[24] For IoT devices, the MQTT protocol works on two types of controls, the first of which publishes data from MQTT clients to MQTT brokers on a specific subject. The second is a subscription to which the MQTT client can subscribe to the topic,[25] it enables real-time data transmission and reception while leaving a tiny footprint on the network system and the device itself.

IMPLEMENTATION OF THE SEAPMS

Connecting the electrical circuit is shown in Figure 14, the Particle IDE platform was used to

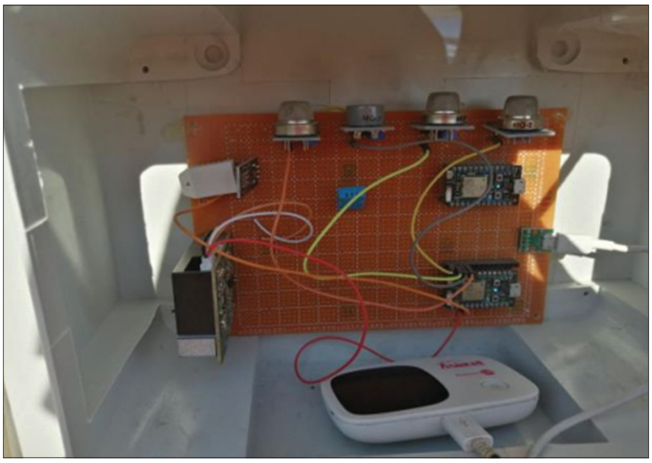

Figure 14: The electrical circuit of the SEAPMS

generate the main system code and download the necessary libraries. The IDE platform will upload the code to the board. The IDE environment uses C/C++ languages. The data were collected using the various sensors mentioned above. Calibrated sensors have produced an analog output voltage proportional to the pollutant concentration of gas. The concentrations collected will be compared to the TLV of each sensed gas, thus, if the sensed concentration is above the TLV, the event created by UBIDOTS sends alarm messages to the smartphone, g-mail, and telegram application so that a warning message is sent to the competent authorities concerned to take the effective steps to prevent the worsening of the air pollution problem because it affects the lives of all living organisms, the first of which is human beings. The Wi-Fi module then transmits the measured data value to the server through the internet and is configured to transmit the measured data to the UBIDOTS platform. UBIDOTS provides access to data measurement through any computer with internet access capabilities.

All data are in the photon, and it compares each gas concentration to its specific threshold limit value (TLV), as shown in Table 2 that clarifies the TLV specified for this research is relative to the TLV for the Occupational Safety and Health Administration.

ANALYSIS OF THE FIRE EXTINGUISHING SYSTEM DESIGN

Governments are currently interested in smart fire-fighting systems, which will be a future development trend for intelligent fire defense. By recognizing concealed risks in real time, this technique can take emergent measures to successfully protect users' lives and property.

The system depends on the previously designed SEAPMS, where after measuring the percentage of smoke inside the room or building if the smoke exceeds the TLV set for it, the relay will automatically sound and lights an alarm and operates the sprinkler that sprays water in the designated area to put out the smoke or fire.

Figure 11 depicts the pieces of the fire extinguishing system, as well as the appropriate connections and the actual position of each item. MQ2 sensor, 4-Channel relay, bulb and sound for alert, and a water pump are among the equipment and components utilized in this project.

MQ2 smoke sensor

This sensor is explained previously in paragraph (3.3) of the first designed APM system.

Four-channel relay

The four-channel relay module is a low-level relay interface board that contains four 5 V relays as well as the associated switching and isolating components, allowing for simple interfacing with a microcontroller or sensor while using a few components and connections. Figure 15 depicts a 5 V four-channel relay interface with a 15–20 mA driver current required for each channel. It appears to be simple to install and repair, and it has high-current relays that function at AC250V 10A or DC30V 10A.[27]

Table 2: Thresholds table[26,27]

Parameter	Set TLV	OSHA TLV
CO	25 PPM	50 PPM
CO_2	3500 PPM	5000 PPM
CH_4 [TLV]	1500 PPM	2000 PPM
Smoke	50	100
Dust	10,000	15,000
Temperature	55°C	75°C
Humidity	60%	75

OSHA: Occupational Safety and Health Administration, TLV: Threshold limit value

Water pump

The water pump is shown in Figure 16 powers the sprinkler, which sprays water in the designated area to extinguish the smoke or fire.[28]

Light bulb and Alarm

Light bulb and alarm shown in Figure 17 are used in the event of a high level of smoke, where the automatic extinguishing system activates the light

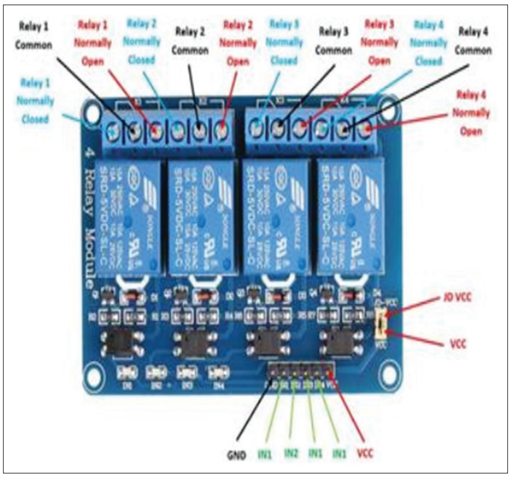

Figure 15: Four-channel relay layout[27]

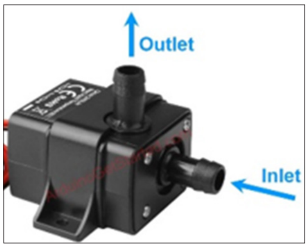

Figure 16: Water pump pinout[28]

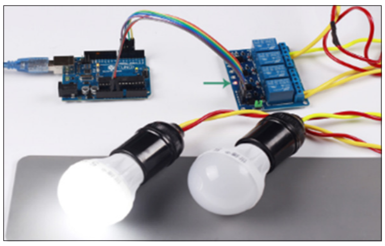

Figure 17: Light bulb and alarm[29]

and alarm sound as a warning signal, followed by the spray system, where the relay sprays water in the designated area to avoid the risk of burning.[29]

IMPLEMENTATION OF THE FIRE EXTINGUISHING SYSTEM

Connecting the electrical circuit is shown in Figure 18

SYSTEM'S FLOWCHART

The concentrations collected will be compared to standard thresholds of each sensed gas, thus, if the sensed concentration is above the threshold, the event created by UBIDOTS sends alarm messages to the smartphone, g-mail, and telegram application so that a warning message is sent to the competent authorities concerned to take the effective steps to prevent the worsening of the air pollution problem. Because it affects the lives of all living organisms, the first of which is human beings. Moreover, if the concentration is less than the threshold, this means that there is no environmental problem to worry about and we will continue collecting data from sensors. The Wi-Fi module then transmits the measured data value to the server through the internet and is configured to transmit the measured data to the UBIDOTS platform. UBIDOTS provides access to data measurement through any computer with internet access capabilities. The data collected from the sensor have been converted into a string and the information sent to the remote server has been modified. The system's flowchart is shown in Figure 19.

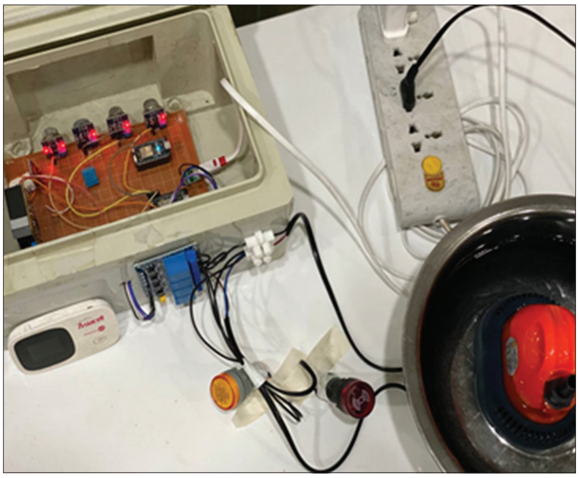

Figure 18: The electrical circuit of the APM with the fire extinguishing system

EXPERIMENTS AND RESULTS

The monitoring results of different sensors on the UBIDOTS platform are shown in the graphs below. The shown concentrations of pollutants are calculated in the study sites which included many different areas and the results were as follows:

The environment of the generators

The systems were tested in a generator environment for 5 days in a crowded area with a large number of houses (400–450) are located as shown in Figure 20; the results were as follows in Figure 21 and dashboards as shown in Figure 22:
The concentrations of some air pollutants for the study area were measured weekly in conjunction with work generated and for the period January 22, 2021, until January 28, 2021, by taking daily readings over a 24 h, the generator selected for the study is working at a rate ranging between 12 and 20 h a day and estimation of pollutant concentration in units of parts per million (ppm). The emissions of the generators were measured against the direction of the wind to find out the farthest distance, they were concentrated pollutants. Note that the ranged temperatures pollutants were measured are between 2°C and 22°C, the humidity is between 14% and 84%.

Air pollution in a natural environment (a garden)

The system was used to measure outdoor pollution for 5 days away from the generator mentioned above 250 m, as shown in Figure 23, and the results and dashboards were as follows in Figures 24 and 25, respectively:
The results show that the concentration of all gasses decreased significantly when moving away from the emission source of the generator.

Landfill (sanitary landfill)

In the sanitary landfill shown in Figure 26, there is an anaerobic tolerance of the organic materials that make up the waste materials that lead to the emission of biogas. It is made up of 40–60% methane gas and the proportion of the remaining gasses is carbon dioxide, the other is

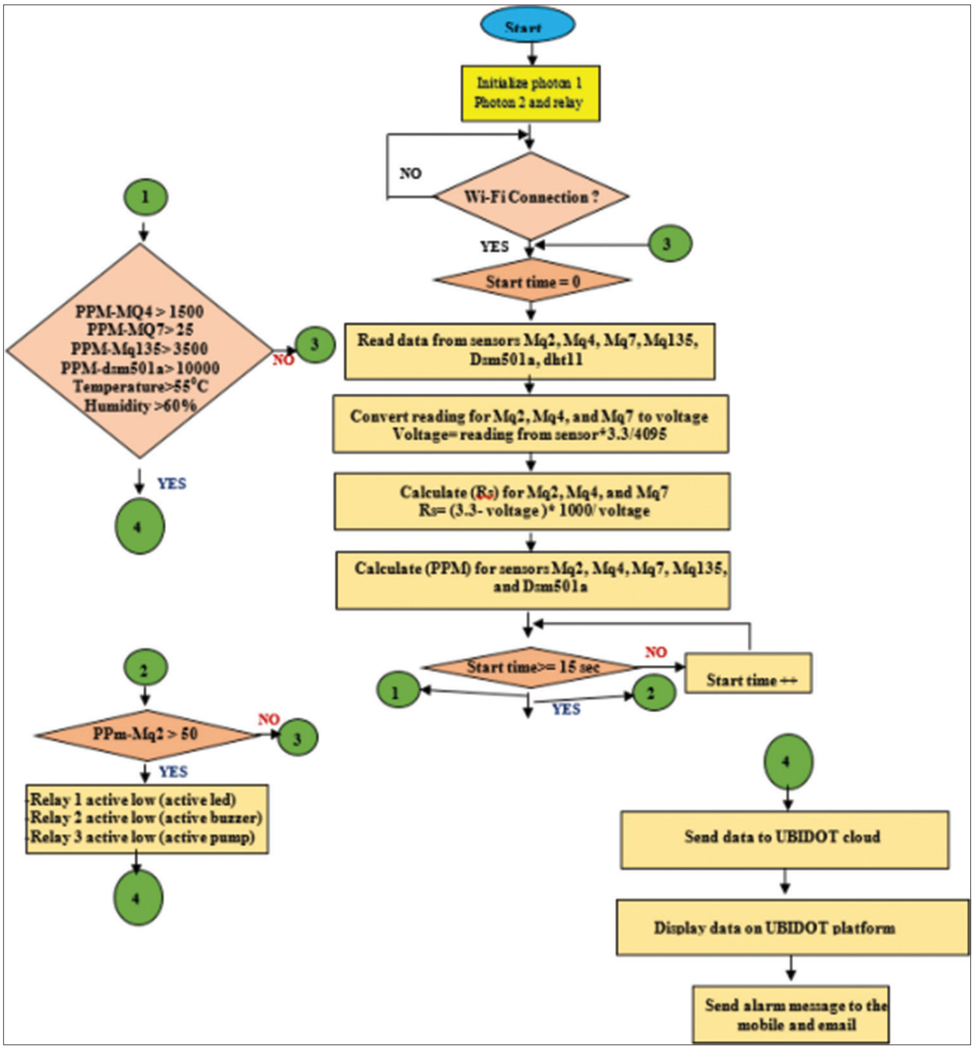

Figure 19: Flowchart of the system

Figure 20: Designed systems at generator

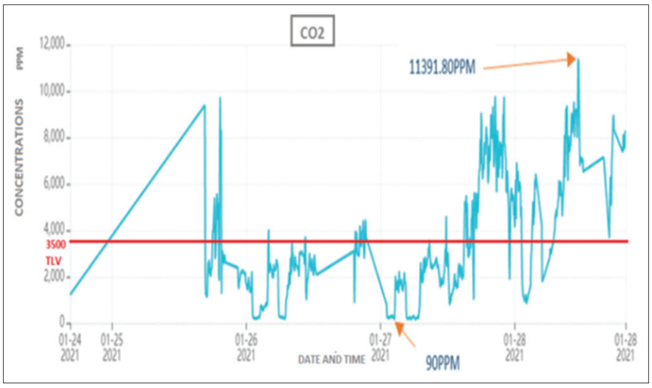

Figure 21: CO_2 concentrations at generator

carbon dioxide; the results and dashboards were as follows in Figures 27 and 28, respectively:

Gas plant

In a gas plant shown in Figure 29, we got the following results and dashboards shown in Figures 30 and 31, respectively:

The smallest concentration was carbon monoxide gas CO because it was not detected in all locations, this is a good thing, cause and it is a heavy and very dangerous and toxic gas, and inhaling quantities of it that may lead to inevitable death.[30]

The UBIDOTS dashboard gives us historical statements that can be showed anytime, anywhere. These reports indicate the human readable dates, like: January 26, 2021, 07:40:13 and the readable value of each measured gas from sensors. For

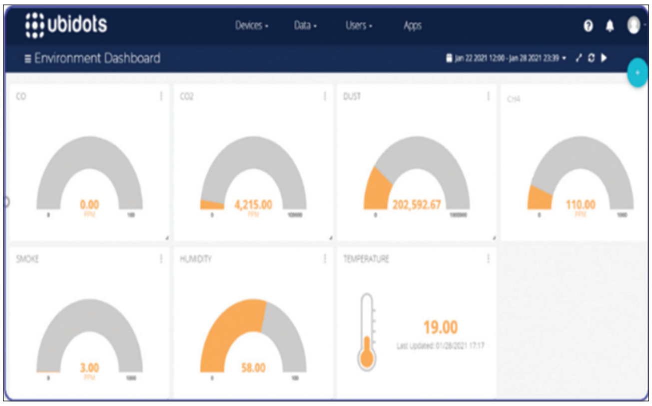

Figure 22: Generator’s dashboards

Figure 23: Garden designed systems

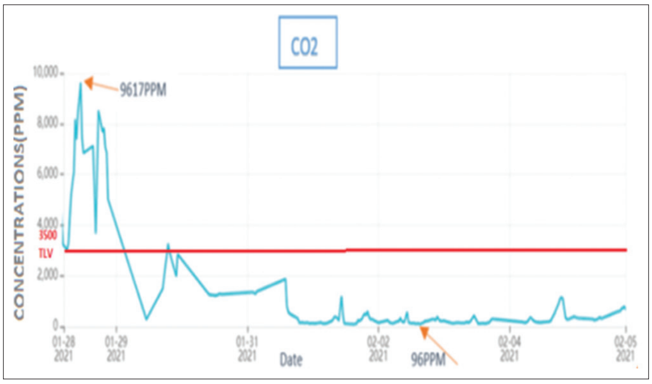

Figure 24: CO_2 concentrations in a garden

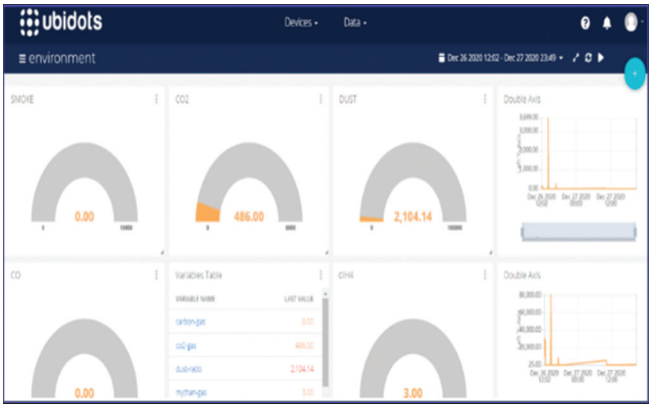

Figure 25: Garden’s dashboards

Figure 26: Landfill (sanitary landfill) designed systems

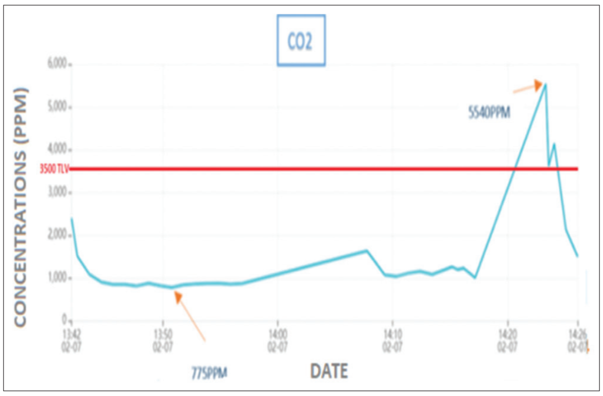

Figure 27: Outdoor CO_2 concentrations

Figure 28: Outdoor dashboards

Figure 29: Systems at a gas plant

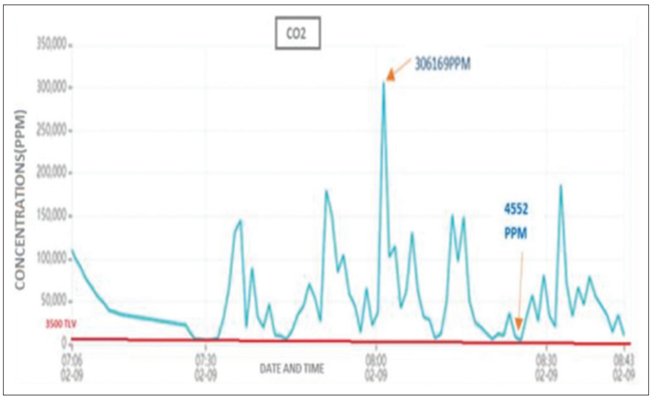

Figure 30: CO_2 concentrations at a gas plant

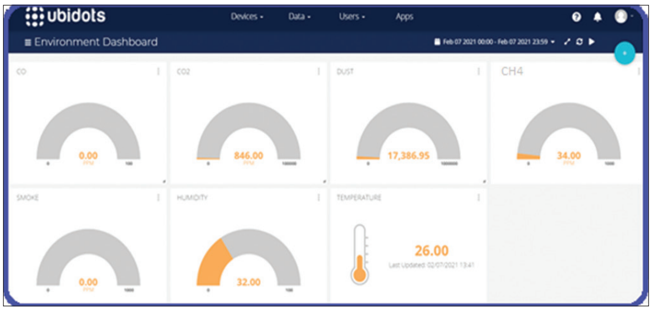

Figure 31: Dashboards for a gas plant

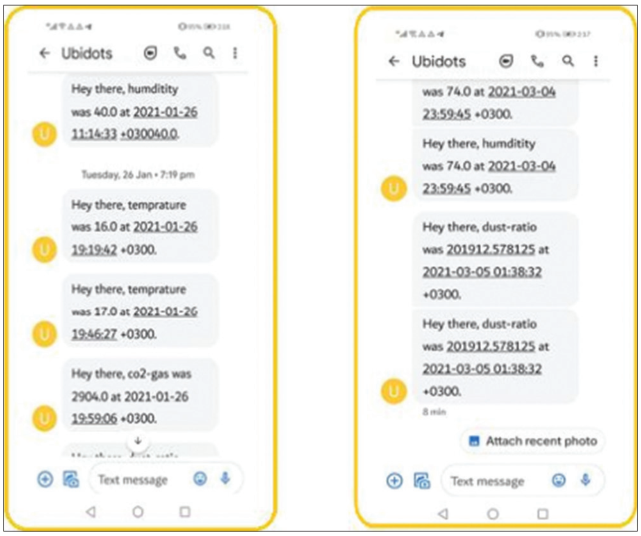

Figure 32: UBIDOTS messages on smartphone

user feedback, the following messages shown in Figure 32 will be received from programmed UBIDOTS on smartphones to ensure that the concentrations of gasses do not exceed the specific threshold for each of them.

CONCLUSION

In this paper, a SEAPMS and a fire extinguishing system were implemented in different locations for the detection of harmful concentrations of different gases, based on IoT technology.

The SEAPMS is important for sending warning messages to the relevant responsible authorities to avoid the risk of harming all kinds of life-giving creatures, and the fire extinguishing system will send a sound and a light alarm and sprays water if smoke gas exceeds its specific threshold, the monitored gas included carbon dioxide CO2 which is monitored using MQ135, methane CH4 which is monitored using MQ4, CO which is monitored using MQ7, dust is monitored using DSMA510 dust sensor, and smoke which is monitored by MQ2.

Data were continuously transmitted and displayed on the UBIDOTS platform through particle photon in real time we can obtain data on a daily, weekly, and monthly basis. The systems are already used in homes, car parks, gardens, factories, landfills, and gas plants, and can be used anywhere and anytime needed for real-time readings.

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