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**REVIEW ARTICLE**

# Design and Implementation of Smart Air Pollution Monitoring System Based on Internet of Things

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## ABSTRACT

An internet of things (IoT)-based environmental air pollution monitoring (APM) system for monitoring concentrations of major air pollutant gases in Mosul, Iraq, has been built. The system employs low-cost air quality gas monitoring sensors with Particle Photon. This device detects gas concentrations such as carbon monoxide CO, carbon dioxide $CO_2$, methane $CH_4$, dust, smoke, temperature, and humidity. The sensors will gather data and send it to particle photons, which compare it with threshold for each sensor then sends it to the IoT platform known as UBIDOTS. UBIDOTS sends data to cloud where they can be realized and virtualized before displaying. The suggested system's major goal is to provide a low-cost, real-time monitoring system based on IoT that can be shown and displayed whenever and wherever needed, and it has been tested in numerous sites throughout Mosul city.

**Key words:** Air pollution monitoring, Internet of things, MQTT, particle photon, Sensors, UBIDOTS

## INTRODUCTION

The presence of particles, biological molecules, or other harmful chemicals in the earth's atmosphere creates air pollution, which causes illness, human casualties, and damage to other living organisms such as animals and food crops, as well as the natural or constructed environment. Air pollution can be caused by either artificial or natural sources.

According to different studies, about 225,000 people die from diseases, caused by care missions in Europe every year.[1]

Mosul city which is known as the second biggest governorate in Iraq, it is noted that there are a large number of cases of increased polluted gasses caused from combustion of fuel in cars, factories, generators, burning fuel in homes for cooking, and heating purposes.

Air pollution is an important determinant of health and convincing evidence links air pollutants with the risk of disease, including premature death even at relatively low pollutant concentrations.[2]

Pregnancy exposure to high levels of air pollution causes miscarriage, early delivery, autism, and asthma in children.[3] Figure 1 shows the effects of air pollution on the human body.

The internet of things commonly abbreviated as the word (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 "Internet of Things" in 1999.[5] The IoT is the most widely used in various internet based mobiles, vehicles, sensors, and other hardware devices. This can be integrated with the various machine learning and deep learning algorithms to improve the performance of the system. Each factor is unambiguously diagnosable through its installed framework anyway is prepared to interoperate inside the present web foundation. Specialists gauge that the IoT can include essentially fifty billion articles by 2020. The origination of the IoT ended up a standard in 1999, through the Auto-ID Center at college and associated showcase investigation distributions.[6]

IoT architecture consist of five layers as shown in Figure 2, perception layer network layer, middleware layer application layer, and business layer. The perception layer comprises physical objects that are monitored/controlled by sensor and actuator devices, with the primary goal of sensor data collecting and command actuation.

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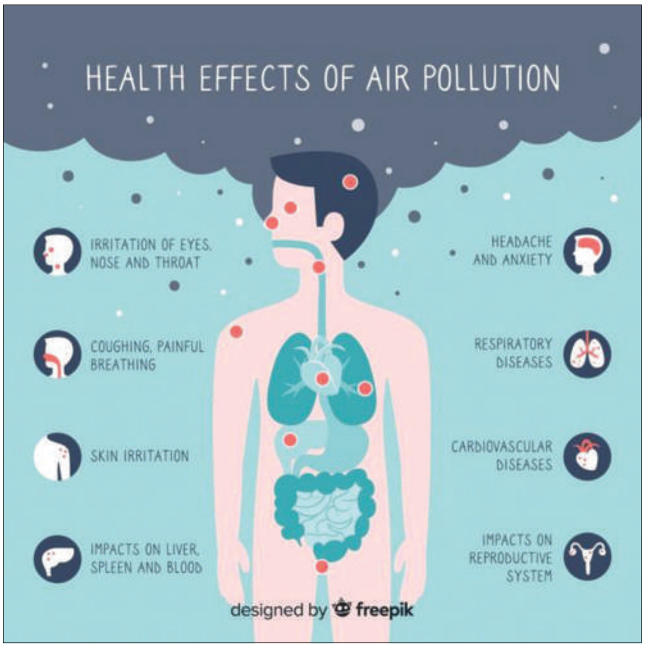


**Figure 1:** Effects of air pollution on the human body[4]

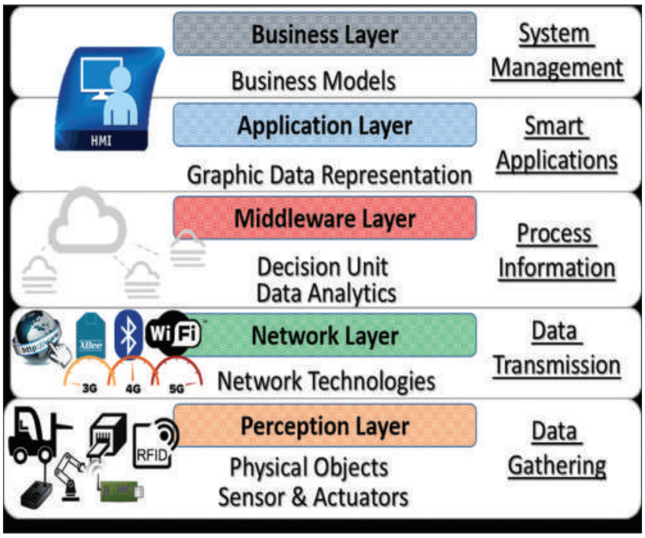


**Figure 2:** Internet of things architecture[7]

The sensor data are subsequently communicated to the Middleware layer through the Network layer, which is distinguished by a variety of network protocols. The Middleware layer is where information is processed, where it is stored and analyzed using advanced data analytics approaches.

The primary goal is to establish an autonomous decision-making process that sends actuation orders back to physical objects to perform activities that alter the overall conditions of the physical environment. The information gathered/analyzed can be displayed to an end user through the application layer, which may also be used to operate the total system. Finally, the business layer enables system administrators to manage and strategically govern the IoT platform's overall operation.[7]

When reviewing past APM systems, we discovered that Souvik Manna and others introduced an air pollution system with a wireless sensor network (WSN), which is seen as an effective use of IoT to deal with automobile pollution. Pollution may be gathered throughout city streets and evaluated with WSN, Arduino Uno, RFID, and MQ sensors to monitor carbon monoxide, sulfur dioxide, nitrogen dioxide, and methane. Using the quality index (AQI), and an algorithm will be implemented to collect data, remove duplicates, filter and summarize useless readings in a simpler form, and develop Mobile Discovery Net (MoDisNet) using GUSTO sensor technology to monitor and analyze pollution in real-time based on traffic conditions, emissions, and ambient pollutant concentrations.[8]

Bedoui and others used WSN, and Zigbeeunder LABWIEW environment to measure hydrogen, sulfide gas, humidity and temperature. The results demonstrate the efficacy of this technology in terms of detection speed and real-time reaction with minimal cost and power due to the utilization of ZigBee with WSN. The system consists of three steps: The initial step is data capture, followed by wireless transmission, and ultimately by data processing. Stations can be replaced with a tiny portable metering system that contains several sensors to improve it.[9]

GaganParmar and others proposed a system that combined low-cost air quality monitoring nodes and semiconductor gas sensors with Wi-Fi modules. It monitors gas concentrations such as CO, $CO_2$, $SO_2$, and $NO_2$. The system was low-cost pollution control system, fast response, low maintenance, and production capacity, continuous measurements, small-sized wireless sensor gateway node and database server, and a web server all packed in one package.[10]

Landge and Harnebuilt a model begins with sensors capable of sensing, calculating, and connecting data in a network. It measures PM2.5, temperature, and humidity, and then wirelessly transmits the monitored data to the server over Wi-Fi. Carbon monoxide (CO), carbon dioxide ($CO_2$), nitrogen dioxide ($NO_2$), methane ($CH_4$), hydrogen sulfide ($H_2S$), and ammonia sensors were included in the functional circuit ($NH_3$), and particulate matter (PM), ESP8266, ATCommand Library.[11]

Kumar *et al*. created a portable air quality monitoring system that allowed for real-time data analysis. Three sensors are used: The MQ9 gas sensor, which detects carbon monoxide, the MQ2 sensor, which detects smoke, and the PMS3003 G3 particle sensor, which detects PM2.5 and sends this detection data to the Node MCU as a processing unit, which stores and restores data through Hypertext Transfer Protocol (HTTP) over the Internet. The circuit includes the following components: A bread board, a PMS3003G3 particle sensor, connecting wires, 180 and 330-ohm resistors, MQ9 and MQ2 gas sensors, a 3.3–5 v boost converter, an analog multiplexer 4051, an OLED display, and a Battery Charger Board for Li-ion batteries.[12]

Patil recommended employing an embedded wireless computer system to monitor air and noise pollution levels in an industrial environment. This concept can be adapted and used in any infrastructure environment. Circuit in use: Raspberry Pi, humidity, temperature, and dust level sensors, Arduino Nano which is linked to a Wi-Fi module as well as temperature, humidity, gas, and dust sensors.[13]

The literature analysis shows that most APM systems differ in microcontroller type and sensors type that is used for the practical circuit. Most of the studies used Arduino or Raspberry pi or ESP8266 as a microcontroller and used WSN technology.

The main objective of this research is to design and implement a smart air pollution monitoring (APM) system and to test the system at different locations in Mosul city, based on IoT using a particle photon microcontroller then sending the measured data over the internet to the UBIDOTS cloud to store, visualize, and analyze information. The system's most essential properties are low cost with a long life span, small size unit, low power consumption, efficiency, eco-friendliness, and the ability to achieve real-time results at different locations, such as homes, industries, car parks, and data gathered remotely by UBIDOTS which is an appropriate IoT platform thus any connected individual can access data at any time and from any location where the internet is accessible.

The remainder of the paper is as follows, with section 2 explaining the proposed framework's system description. Section 3 discusses implementation and working concepts. Section 4 discusses the project's results. Section 5 contains the conclusions. Section 6 contains references.

## SYSTEM DESCRIPTION OF THE FRAMEWORK

### Components

The proposed system consists of the hardware components as follows:

1. Particle photons as a microcontroller
2. MQ4 sensor for methane gas measurement ($CH_4$)
3. MQ2 sensor for smoke detection.
4. Carbon monoxide (CO) gas sensor MQ7
5. MQ135 carbon dioxide sensor gas ($CO_2$)
6. Dust detector (DSM501)
7. Temperature and humidity sensor DHT11.

### The system's overall structure

The system is divided into two sections. The first part is the previously described physical components, and the second portion is the software applications. The sensors are programmed with the (Particle IDE) program and the (C ++) programming language. The sensors are connected to the photon, which collects data and delivers it to UBIDOTS, where it is analyzed and virtualized for display, the structure of the system is shown in Figure 3.

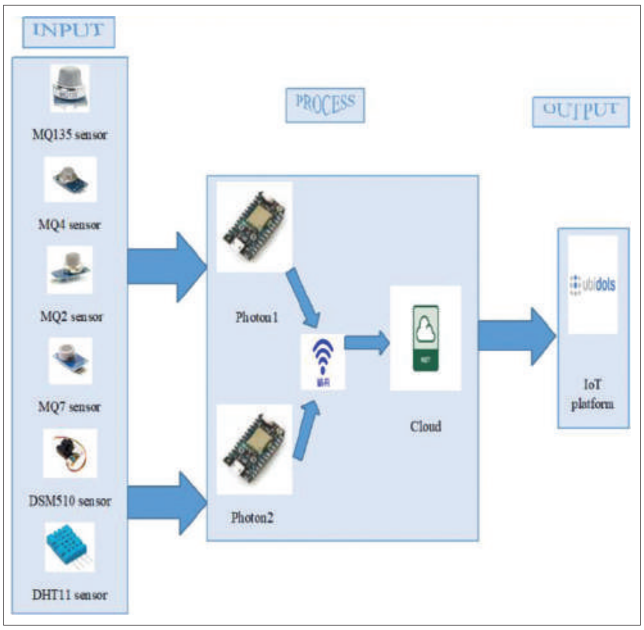


**Figure 3:** The proposed system structure

## WORK DESIGN AND THEORY

### Particle photon

Particle Industries Inc. offers the Photon IoT device, which is a compact (37 × 20 mm) open source module that combines an ARM microcontroller and a Wi-Fi chip.[14] It has 18GPIO peripherals that enable photon to be linked with different devices by coding it to special functions, Photon makes a great IoT device, allowing remote controlling or data gathering from possibly multiple connected sensors etcetera.[14] It is shown in Figure 4.

### MQ4 gas sensor

Figure 5 shows that the MQ4 sensor (5) has high Methane sensitivity over a wide range, is low-cost and long-term, and has simple driving circuitry.[15]

### MQ2 gas sensor

MQ2 gas sensor as shown in Figure 6 it can be used as a digital or analog sensor, for smoke detection it uses the analog pin of the sensor for scope of 200–5000 ppm.[16]

### MQ7 gas sensor

As illustrated in Figure 7, this sensor is ideal for carbon monoxide (CO) gas. CO concentrations ranging from 10 to 10,000 ppm can be computed. This sensor's performance is measured in terms of analog resistance. It contains six pins, four for signal extraction, and two for internal line heating. Its advantages include extended life, low cost, and a simple drive circuit.[17]

### MQ135 gas sensor

MQ135 shown in Figure 8 is a device that measures carbon dioxide $CO_2$ emissions in the atmosphere. It has a quick reaction time, excellent sensitivity, and a long life and is stable due to its wide detecting range.[18]

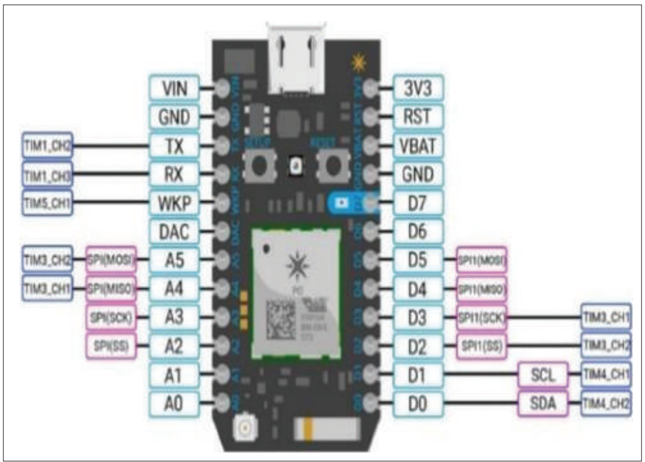


Figure 4: Particle photon pin diagram


**Figure 6:** MQ2 smoke

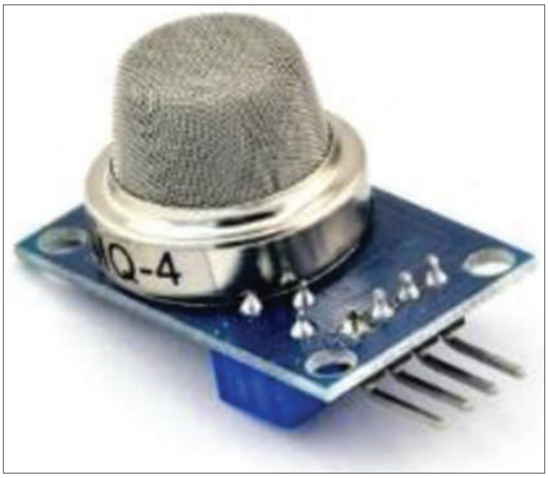

**Figure 5:** MQ4 methane


**Figure 7:** MQ7 CO sensor.

### DSM510 dust sensor

The diagram depicts it in Figure 9. The particle counting hypothesis underpins the DSM501 theory.[6] It can detect particles larger than 1 μ in diameter. The built-in sensor warmer will automatically inhale air. It is tiny in size, light in weight, and simple to install and operate.[17]

### DHT11 temperature and humidity sensor

The DHT11 is a humidity and temperature sensor, it produces aligned advanced yield. DHT11 can be associated with microcontrollers such as Arduino, Raspberry Pi, and so on. DHT11 is a minimal effort temperature and dampness sensor. It gives high unwavering quality and long haul dependability.[19]

The encapsulated form of DHT11is a single row of 4 stitches of which is used for serial communication of data. Single wire and serial interface make the system integration simply and easily.DHT11 has a 3–5.5V power supply voltage,[20] it is shown in Figure 10.


**Figure 8:** MQ135 $CO_2$ sensor

### The IoT platform UBIDOTS

UBIDOTS is the IOT platform employed in this research. It is an application builder for the IoT that includes data analytics UBIDOTS Platform (also known as the UBIDOTS IoT Application Development Platform) Platform in IoT ONE) debuted in January 2013, a year after its provider business UBIDOTS was acquired originally established.

The UBIDOTS Platform is also said to be able to "scale from one device to 1,000s with assurance." Particles and UBIDOTS vary depending on their application (devices and traffic) UBIDOTS established its Education program in 2018 to provide enthusiasts and students with easy access to the IoT world. The obvious advantage of all open source systems is the open source code and the ability to modify it. Parts or entire components can be edited. Some of these platforms have additional features that make them stand out.[21]

Each UBIDOTS user has an API credential that includes a specific authentication for each user to be included in the code, and then the system is connected and the data measurements obtained by the hardware are sent to this IOT platform.[16] Figure 11 depicts the UBIDOTS log in process. The particle photon collects data from the sensor and sends it to the UBIDOTS cloud using the MQTT communication protocol; after the platform has been changed, it gets hardware information and displays a variable inside the platform; a representation of the system in UBIDOTS is displayed in Figure 12. This is accomplished through the use of variable names in the code; once the data is represented as a variable, it is displayed as a widget in the dashboards. Data can be displayed to users in the form of a table,

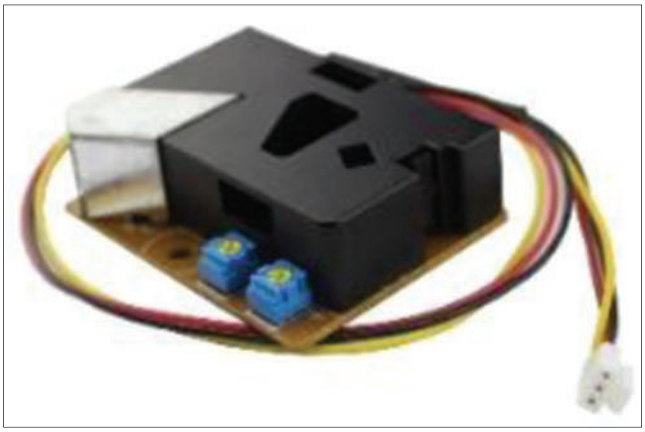

**Figure 9:** DSM501A

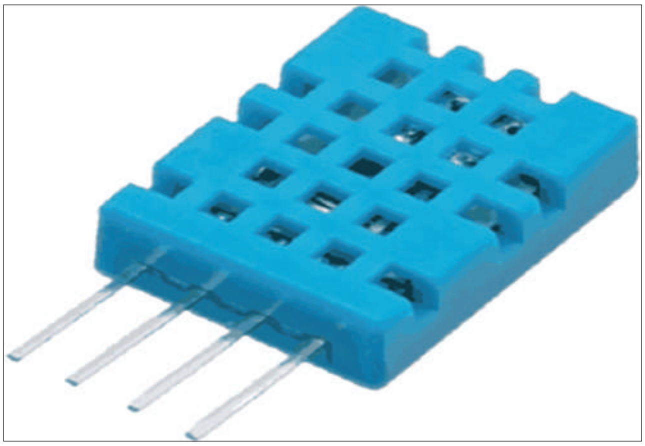

**Figure 10:** DHT11 sensor

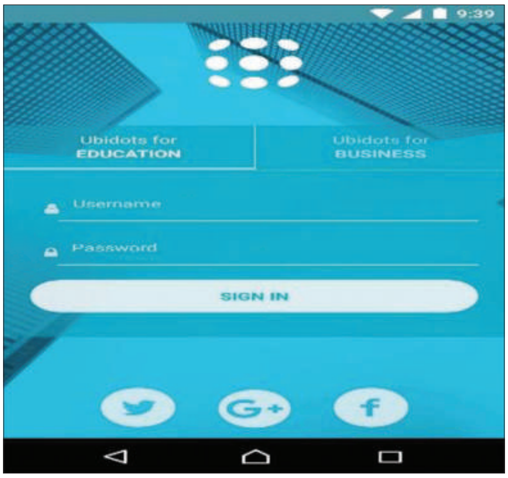


**Figure 11:** UBIDOTS log in Kodali *et al*.[16]

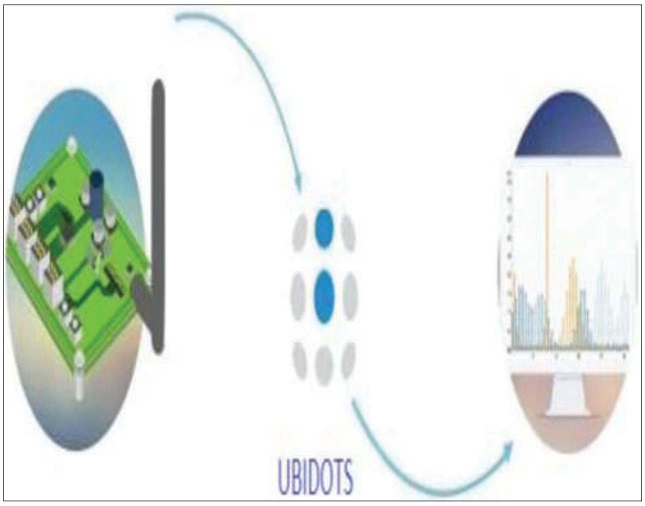


**Figure 12:** System representation in UBIDOTS[16]

indication, or graph. Events can also be used to send alert messages or e-mails to users.

MQTT: Message Queue Transport Remote Service, is a protocol built specially for "machine-to-machine" communication. MQTT protocol runs over TCP/IP and has a data packet size with a low overhead minimum (> 2 bytes) so that power consumption is also kept to a minimal architecture as shown in Figure 13. This protocol is data-agnostic, capable of transmitting data in a variety of formats such as binary data, text, XML, or JSON, and it employs a publish/subscribe architecture rather than a client-server approach.[22]

## IMPLEMENTATION OF THE SYSTEM

### Hardware

Connecting of the electrical circuit of the system is show in Figures 14 and 15.

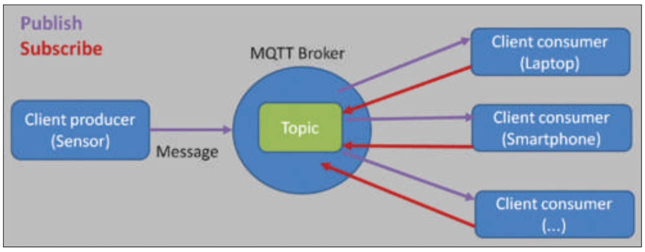


**Figure 13:** MQTT protocol working principle[23]

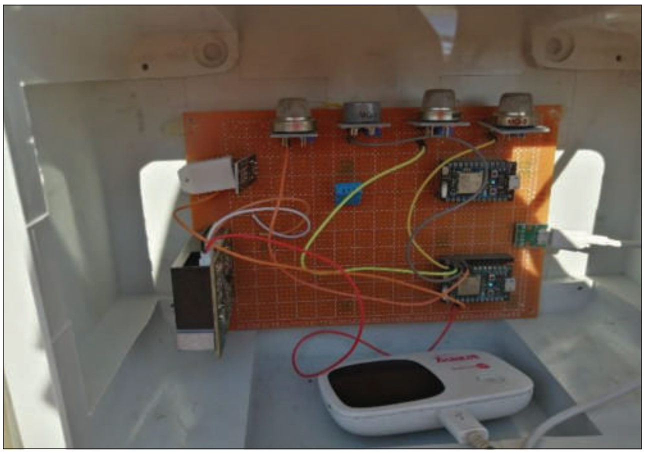

**Figure 14:** Real circuit of the system

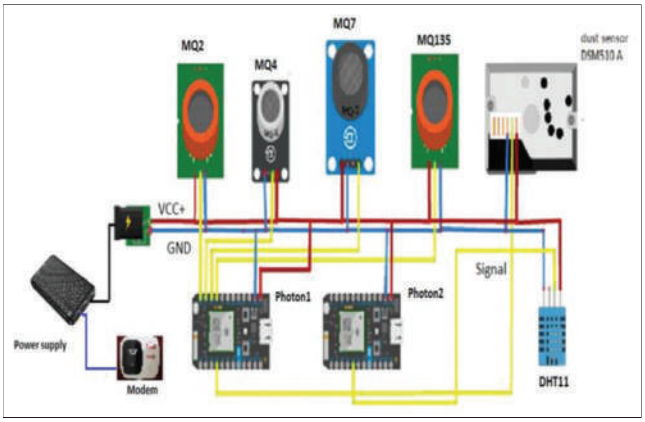


**Figure 15:** The electrical circuit of the system

### Software

To generate the primary system code and download the required libraries, the particle IDE platform was utilized. C/C++ programming languages are used in the IDE environment. The above-mentioned sensors were used to acquire the data. Calibrated sensors provided an analog output voltage that was proportional to the pollutant content in the gas, the obtained concentrations will be compared to standard levels for each sensed gas, thus, if the sensed concentration is above the threshold, the event created by UBIDOTS sends smartphone alerts to the relevant authorities, urging them to take immediate action to prevent the air pollution situation from increasing. The Wi-Fi module subsequently sends the measured data value to the UBIDOTS platform's server. UBIDOTS allows data measurement to be accessed from any computer with internet connectivity.

Code

```
void loop()
{if!clientMQTT.isConnected())     {clientMQTT.
connect(5); }
duration = pulseIn(pin, LOW);
lowpulseoccupancy+= duration;
endtime = millis();
int adc_mq2=analogRead(mq2);
int adc_mq4=analogRead(mq4);
int adc_mq7 = analogRead(mq7);
```

Steps for putting the system into action:

1. Connect sensors to particle photon.
   Then they will sense all gases and give the Pollution level in PPM (parts per million).
   PPM: is an abbreviated form for "parts per million" and can alternatively be written as milligrams per liter (mg/L) and is frequently used to identify pollution concentrations in the air (as a volume fraction).
2. Data are gathered from sensors
3. Compare data with a predetermined threshold
4. Data are transmitted to UBIDOTS
5. The cloud handles data processing
6. The user can obtain data and alarm messages through smartphone or online; the methods are depicted in Figure 16.

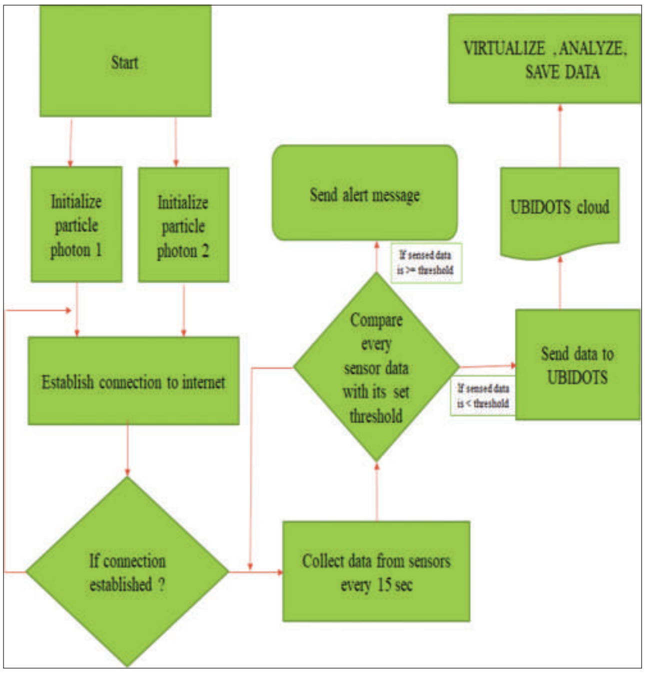


**Figure 16:** Designed system flowchart

## RESULTS AND DISCUSSION

Monitoring results of different sensors on the UBIDOTS platform are shown in the graphs below. There are five variables used in Photon 1 and two variables used in Photon 2. The X-axis on the dashboards represents the date and time, and the Y-axis represents the gas concentrations in (ppm), displaying the data of the sensors that each sensor has its own variable and widget.

The air pollution concentrations shown are measured in three study areas: the first is the environment of generators in Mosul's residential neighborhoods, the second is the measurement of air pollution in the natural outdoor setting, and the third is the landfill (sanitary landfill) in the Kokjeli area of the Nineveh Governorate Municipality.

## THE ENVIRONMENT OF THE GENERATORS IN THE RESIDENTIAL NEIGHBORHOODS OF THE CITY OF MOSUL

Figures 17 and 18 show APM and UBIDOTS dashboards at a generator.

We evaluated our system in a generator setting for 5 days in the Zohour district, which is renowned as a congested region with a significant number of houses (400–450). The findings are shown in Figure 19.

**Figure 17:** APM at thea generator

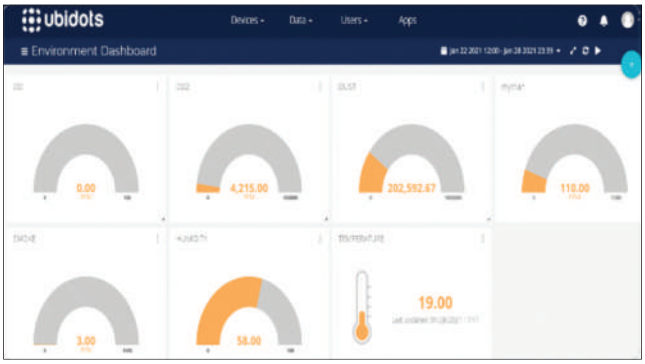


**Figure 18:** UBIDOTS dashboards for generator

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 period, the generator selected for the study is working at a rate ranging between 12 and 20 h a day. It should be noted that the pollutants were measured at temperatures ranging from 2 to 22°C with humidity ranging 14 to 84%.

## AIR POLLUTION IN NATURAL OUTDOOR ENVIRONMENT

Figures 20 and 21 show APM and UBIDOTS dashboards for outdoor pollution.

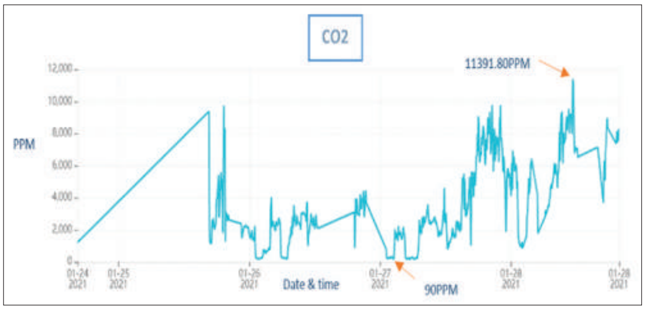


**Figure 19:** $CO_2$ concentrations generator

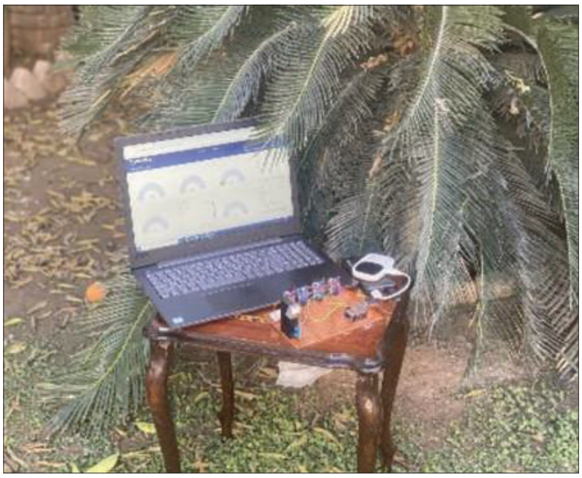

**Figure 20:** APM at the garden

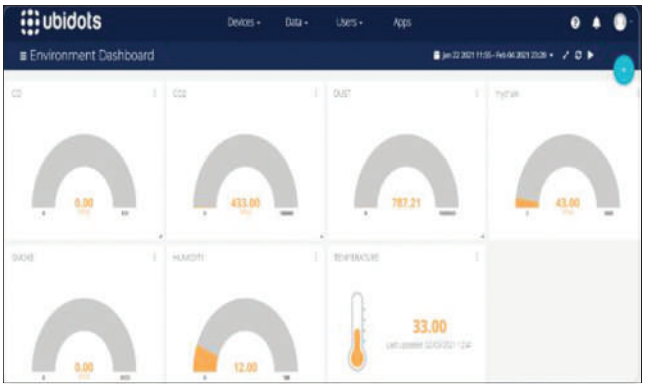


**Figure 21:** UBIDOTS dashboards for outdoor pollution

The equipment was utilized to monitor outdoor pollution for 5 days away from the above-mentioned generator (250 m), with the findings shown in Figure 22:

The results reveal that when one moves away from the generator's emission source, the concentration of all gasses decreases dramatically.

## LANDFILL (SANITARY LANDFILL) IN THE KOKJELI AREA OF THE NINEVEH GOVERNORATE MUNICIPALITY DEPARTMENT

Figures 23 and 24 show APM and UBIDOTS dashboards for sanitary landfill in Kokjeli area.

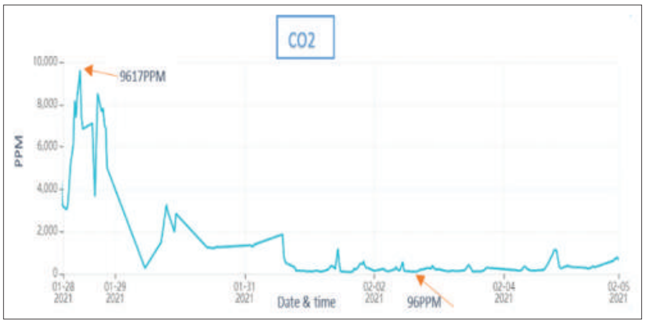


**Figure 22:** $CO_2$ concentration for outdoor pollution

**Figure 23:** APM at sanitary landfill in Kokjeli area


**Figure 24:** UBIDOTS dashboards for sanitary landfill in Kokjeli area

**Table 1:** The main results

| Location | Dust PPM Min-Max | CO2 PPM Min - Max | Methane PPM Min - Max | CO PPM Min - Max | Smoke PPM Min - Max | Temperature °C | Humidity % |
|---|---|---|---|---|---|---|---|
| *At the generator* | 8330.0125–36102.032 | 90–11391.80 | 6.6–323.80 | 0–0 | 0–259 | 12–22 | 14–84 |
| *At a garden* | 1710.05176–148990.2188 | 96–9617 | 9.71–255.63 | 0–0 | 0–67 | 40–42 | 80–90 |
| *In the sanitary landfill* | 5965.2098–61002.032 | 775–5540 | 32–223 | 0–0 | 0–8 | 23–27 | 32–42 |


**Figure 25:** $CO_2$ concentrations for sanitary landfill in Kokjeli area

Figure 25 shows $CO_2$ concentrations for sanitary landfill in Kokjeli area.

There is bacterial absorption of the organic elements that make up the waste materials in the sanitary landfill, which results in the release of biogas. It is composed of 40–60% methane gas, with carbon dioxide accounting for the remainder of the gasses. Researchers see that the largest amount of carbon dioxide gas is at the first site near the generator, which was 11391 ppm, and that all polluting gas concentrations have raised in the generator area.

Carbon monoxide gas CO had the lowest concentration because it was not identified in any of the three sites, which is a good thing because it is a heavy, deadly, and inhaling large amount of it can lead to death. The results are shown in Table 1.

The UBIDOTS will provide us with record declarations that we can view at any time and from any location, as an excel table or as other types of widgets.

These reports indicate human readable date, like: 5/12/2020 08:56:25 and the readable value of each measured. These reports are being used to track air pollution in different spots as needed by virtualizing and analyzing data that come in contact with the sensor, and to send alerts to the relating concerned authority through Google account or web applications chosen for this research, to avoid any danger threatening life forms of all kinds.

For user interaction, the following signals will be received through programmed UBIDOTS on smartphones to guarantee that gas concentrations do not exceed the specific thresholds for each of them as in Figure 26.

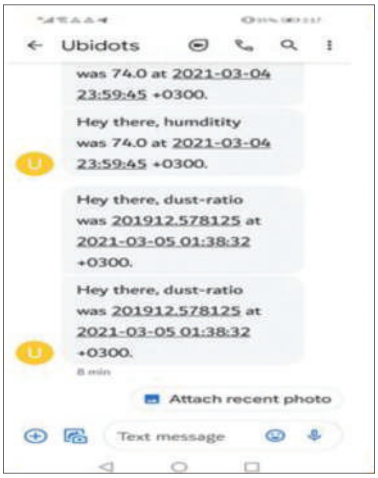


**Figure 26:** UBIDOTS messages on smartphone

## CONCLUSION

In this paper, the APM system was designed in various sites in Mosul city for the detection of harmful concentrations of different air pollutant gases, based on IoT technology, the system is essential for sending warning messages to the appropriate authorities to avoid hurting all types of life-giving species. We chose three settings for this paper: the environment of generators in Mosul's residential areas, the measurement of air pollution in the natural outdoor environment, and finally the dump (sanitary dump) in the Kokjeli area of Nineveh Governorate Municipality. Carbon dioxide CO2 was monitored using MQ135, Methane CH4 was measured using MQ4, CO was monitored using MQ7, dust was detected using a DSMA510 dust sensor, and smoke was measured using MQ2. Data are continuously transmitted and displayed on the UBIDOTS platform via particle photon in real time; we can obtain data on a daily, weekly and monthly basis. The system is already used in homes, car parks, gardens, factories, landfills, and gas plants and can be used anywhere and anytime needed for real-time readings. These data can be collected, analyzed and made early warning by the responsible and related authorities.

## FUTURE WORKS

1. System can be implemented in more locations such as oil refineries, gas plants, and hospitals.
2. Using solar cell instead of the power supply to store energy and ensure its continuity
3. Using more sensors to measure more different pollutant gases such as ozone $O_3$ and nitrogen oxide $NO_2$.

## ACKNOWLEDGMENT

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