AIR PURIFICATION BY CHEMICAL PHOTOCATALYSIS BY MEANS OF TITANIUM DIOXIDE: A SMART AIR PURIFICATION SYSTEM

Fujai Muhammad Charieth[a]*, Haris Parengal[b], KM Ashifa[c], Sandeep Prabhakaran[d], Arya C F[e]

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Abstract. One of the most useful smart connected devices for projects and applications on any scale is the Internet of things (IoT). IoT devices connect people with their surroundings and environment and can be on any branch of study whether it is medical, engineering, chemical, etc. With the Arduino UNO System, this research created a pilot Smart Air purification system that not only detects harmful pollutants, but also purifies the air. Researchers hoping to overcome some of the shortcomings of current air purifiers with the developed model, like overpricing, lack of data, and portability. The developed model has an onscreen real-time data analysis, a wide-range MQ 135 Sensor, and a four-step decontamination and sterilization process. As of the stage of testing, the pilot model showed satisfactory results in the process of detection, where it detected ammonia, carbon dioxide, Sulphur, and all the stated detectable pollutants, even alcohol. The filtration unit has also shown promise, but has not yet been developed into a fully operational system, and the results of the filtration system are based on statistical and theoretical research.

Keywords: UV-C, Arduino UNO, TiO_2 (Titanium Dioxide), HEPA, MQ-135, Photocatalysis

[a]. Phase Markaz International, Markaz Main Campus, Kondotty, Malappuram, Kerala, India
[b]. Centre for Tropical Biodiversity Conservation, Ottathara, Kodur Post, Malappuram, Kerala, India
[c]. Istanbul Nisantasi University, Turkey
[d]. Botanical Survey of India, Southern Regional Center, Coimbatore
[e]. Indian Institute of Science, CV Raman Rd, Bengaluru, Karnataka, India

***Corresponding Author**

E-mail: fujai2003@gmail.com, ctbcindia@gmail.com, ashifakattur@gmail.com, sandeepbiologist@gmail.com, aryacf91@gmail.com

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INTRODUCTION

Air pollution is a major contributor to asthma, cancer, and other chronic diseases, causing the loss of millions of lives worldwide [1]. The WHO estimates that 99% of people live in areas where air quality exceeds WHO standards and most of them are in low-middle income countries. All of these issues are addressed by this research, which is portable, cheap, and best in class on filtration. This device can be installed in places ranging from indoors to outdoors, with various specs depending on the environment [2]. The smart device as the name states is a device that detects harmful pollutants in the environment in real-time, which sends the data to the user's device [3,4,5]. With the device, the primary benefit is that it helps clean the air by triggering a four-stage filtration system, including the primary filtration, HEPA filtration, UV-C filtration, and titanium dioxide filtration, since TiO2 is a great photocatalyst, which decomposes organic pollutants when exposed to light. In this regard, UV-C comes into play since TiO2 activates when it is exposed to UV-C light, making it a double filtration system in one unit where the UV-C source also acts as a disinfector. All these processes ensure the decontamination of all kinds of pollutants.

The project presents the concept, functional physical model of an air purification system for small public spaces or apartments. The purifier is controlled by a microcontroller of the Arduino UNO series. The model is equipped with a set of sensors which are used to determine the air quality. After exceeding the adopted threshold in the software, the system automatically starts the process of air filtering. The air purification system depends on the optical dust sensor readings as it senses the quality of air in the room and turns the air purifier On and Off accordingly. The body of the air purifier is made by wood and filters. The filters used are pre-filter, dust-filter & fine-filter. The purifier absorbs solid pollutants and reduces VOC pollutants. The system has been equipped with an LCD screen informing the user about the air parameters and the quality of air being purified [6].

Monika Singh Et al. 2019 [7] proposed an Air Pollution Monitoring System. This system uses an Arduino microcontroller connected with MQ135 and MQ6 gas sensor which senses the different types of gases present in the environment. It was then connected to the Wi-Fi module which connects to the internet and LCD is used to display the output to the user and buzzer alerts when the value crosses a certain limit. Their applications were industrial perimeter monitoring, indoor air quality monitoring, site selection for reference monitoring stations, making data available to users.

The main aim of building this project was to reduce the problems or diseases causing to human beings. So that they have built a project which is capable of doing it. The project is designed in a manner which could be useful and very easy to operate from anywhere, this is one of the main advantage of the project. Here they have used Internet of Things which helps to make this system more advance with the use of this very less energy will be used as we can control it from anywhere, this makes it more convenient to use. Just with a click on your mobile phone the system can be controlled easily, hence this system proves to be a great work [8].

METHODOLOGY

In this design, the basic functionality of air purification is implemented. Standard air purifiers typically use HEPA Filtration and UV Filtration, which is sufficient for most air cleaning applications, but this air purifier uses a more advanced method called photocatalysis. It is a catalysis process that is activated in the presence of light for removing the harmful compound Sulphur, a metal or steel material is coated with TiO_2 (one of the best-known photocatalysts), whose activity is then activated by UV light, UV light being used since Titanium Dioxide operates at its best in the UV spectrum [9].

Titanium dioxide (TiO_2) has been long regarded as one of the more promising photocatalysts to remove environmental pollution and generating hydrogen from water under sunlight irradiation via photocatalysis. TiO_2 is environmentally benign and thus is considered a 'green' catalyst.

The main sensor unit mainly consists of an MQ-135 sensor- this sensor has a steel exoskeleton, which houses the main sensor unit, the when current passes through the sensor it heats the element this current is known as the heating current. Due to the heating effect, when gases come in contact with this element the gases gets ionized, giving a fluctuation in the resistance of the current being flown thus this value is taken as the value of the threshold. This sensor is used as it is one of the best sensors for hazardous gas detection and has a wide range of gases it can detect.

The whole unit works as a collaborative system with the aim to minimize loss of electricity but without compromising maximum efficiency output. The main unit or the sensor unit detect the increase or presence of hazardous or unfavourable gases in the atmosphere, which when increases beyond a set threshold initiates the filtration unit.

The below sets of the equation were used to determine the Revolutions Per Minute (RPM), CFM (Cubic Feet Per Minute, which is the volume of air moved per minute.) and Fan Rpm required. The below equations are to be used to have the highest efficiency possible for the purification process CFM formulas are used so as to determine whether the fan is capable of pushing or purifying the air in a given set area or volume, whether it is a closed or open environment.

$$Fan\ RPM = MotorRPM \times \frac{d}{D} \tag{1}$$

$$CFM = Room\ Volume\ \times \frac{AirChanges_{perhour}}{60} \tag{2}$$

$$CFM_2 = CFM_1 \times \frac{RPM_2}{RPM_1} \tag{3}$$

$$CFM = Velocity \times duct\ area(in\ sq.ft) \tag{4}$$

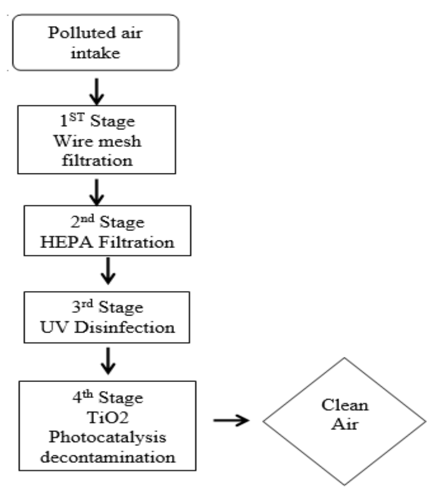


Fig. 2. Stages of filtration

The device will be idle at the start-up stage, as the device aims to reduce electric consumption. The main sensory unit, with the calibrated sensors in motion, starts sensing for any presence of pollutants and unwanted gases. When the threshold spectrum is exceeded, the LEDs and buzzers will be indicating the presence as well as the LCD display, the filtration unit will start its process with further instructions and all the values or information will be seen on the user's phone by Bluetooth through any serial monitor displaying app.

After identification of the pollutant, with the help of a simple servo motor, the mechanism filtration unit is given electricity by a simple servo switch, the air suction pump starts its work by taking in the air at a desired pace and moves to the 4 stages of filtration

A) STAGE 1

The air is passed through the primary filter, which is a wire mesh use to filter larger particles about the size of , the wire mesh is of any material but preferable heat-treated metals are used.

B) STAGE 2
The air then passes to the secondary filtration, this is where the HEPA filter is present, this filter helps get rid of particles about the size of 0.3 microns, which helps get rid of most harmful compounds. This unit also has a UV lamp present as HEPA filters have the tendency for microbial growth which can be avoided by this method

C) STAGE 3
This is the UVC sterilization unit, though the entire filtration process has a UV setup, this one is to be stronger and more powerful to finalize the decontamination process and to kill any germicidal or viral particles present in the air so as to also prevent the spread of airborne diseases.

D) STAGE 4
This is the final stage of filtration and this is an enclosed unit that has the presence of TiO_2 coated metals. This metal is present to initiate a photocatalysis process, which is the desired process to get rid of sulphur, TiO_2 Photocatalysis compound was chosen because this compound is the best in its class, showing maximum efficiency. TiO_2 is a photocatalysis as it requires light to start its process mainly UV light which is why UV will be present in this enclosed chamber.

After the final stages of filtration, the expelled air is fresh and decontaminated. All these stages are of utmost importance so as to gain the maximum clean output of air. Usually, only the first 3 filtration stages are present in most commercial air purifiers but the addition of photocatalytic decontamination enhances the freshness and purity of the air

Circuit Diagram

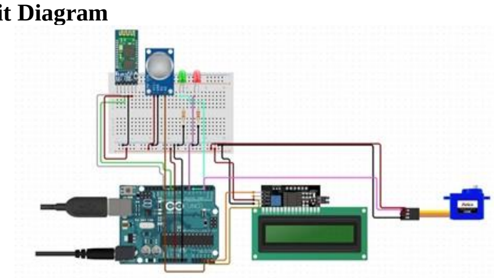


Fig. 3. Circuit connections for the detection and control unit

The Fig.3 shows the circuit diagram required and used for the main control and detection unit. The I2C Display can be replaced with a bigger graphic display with a touchscreen interface for more advanced control over the entire unit. An ESP 8266 IOT device which is a wireless Wi-Fi unit for direct access to the internet for a more advanced IOT system, a potential replacement for the HC 05 Bluetooth module.

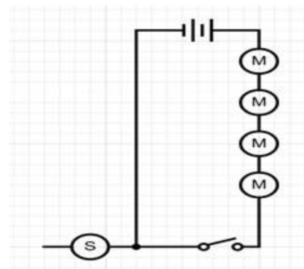


Fig. 4. Circuit Diagram for the motor system with a servo switch

The Fig.4 shows the connection of the fan or the air suction unit, it consists of 4 brushless or brushed motors with a battery with required voltage, the whole circuit will be a closed unit to power up the filtration system only when the value exceeds the desirable threshold.

Arduino Codes

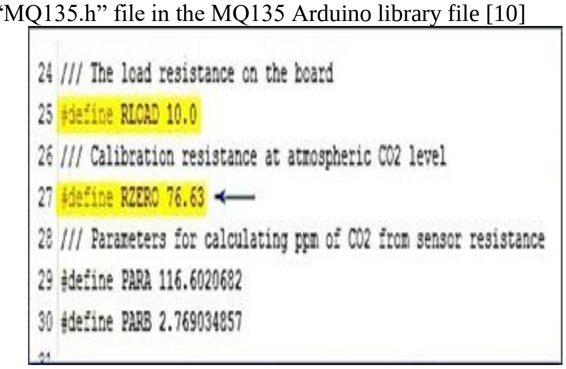
1) Code for MQ 135 Calibration

MQ-135 gas sensor calibration is done at first by finding the value of Ro in fresh air, and then using that value to find Rs through the formula: Rs = (Vcc/VRL-1)x RL. The sensor requires a 24 hour preheat to have the most accurate reading of the value, this can be done by connecting the sensor to the Arduino in the 5v pin, as the sensor requires a minimum of 5v input voltage supply to work, after the circuit completion the sensor is kept in a closed environment with fresh air for a maximum of 24hr.

After the 24hr preheat, the following code is run in the Arduino IDE to complete the calibration process and to find the value of Fresh air:

```
#include "MQ135.h"
const int ANALOGPIN=0;
MQ135 gasSensor = MQ135(ANALOGPIN);
void setup(){
Serial.begin(9600);
}
void loop(){
float rzero = gasSensor.getRZero();
Serial.println(rzero);
delay(1000);
}
```

The resultant or the RZERO value is inserted in the "MQ135.h" file in the MQ135 Arduino library file [10]



```
24 /// The load resistance on the board
25 #define RLOAD 10.0
26 /// Calibration resistance at atmospheric CO2 level
27 #define RZERO 76.63
28 /// Parameters for calculating ppm of CO2 from sensor resistance
29 #define PARA 116.6020682
30 #define PARB 2.769034857
```

Fig. 5. Calibrated RZERO value in Arduino IDE

2) Code for the Main detection unit

The code is only for the main detection system and not the filtration system :

```
#include <LiquidCrystal_I2C.h>
#include <MQ135.h>
#include <MQUnifiedsensor.h>
#include <MQ135.h>
#include <LiquidCrystal_I2C.h>
#include <hd44780.h>
#define ANALOGPIN A2 // Define Analog PIN on Arduino Board
#define RZERO 76.63 // Define RZERO Calibration Value
MQ135 gasSensor = MQ135(ANALOGPIN);
int redLed = 12;
int greenLed = 8;
int buzzer = 10;
int smokeA0 = A0;

// Your threshold value : This is the value of the calibrated clean air, the values can vary
int sensorThres = 100;
LiquidCrystal_I2C lcd(0x27, 16,2);
void setup() {
 lcd.init();
 lcd.begin(16,2);//Defining 16 columns and 2 rows of lcd display
 lcd.backlight();
 Serial.begin(9600);
 delay(100);
 pinMode(redLed, OUTPUT);
 pinMode(greenLed, OUTPUT);
 pinMode(buzzer, OUTPUT);
 pinMode(smokeA0, INPUT);
 Serial.begin(9600);
}
void loop() {
 float Gas = gasSensor.getPPM();
 delay(100);
 lcd.setCursor(2,0);
 lcd.print("AIR QUALITY : ");
 lcd.setCursor(2,1);
 lcd.print("");
 lcd.print(Gas);
 int analogSensor = analogRead(smokeA0);
 Serial.print("Gas Quality: ");
 Serial.println(analogSensor);
 // Checks if it has reached the threshold value
 if (analogSensor > sensorThres)
 {
 lcd.print(" Bad ");
 digitalWrite(redLed, HIGH);
 digitalWrite(greenLed, LOW);
 tone(buzzer, 3000, 300);
 }
 else
 {
 lcd.print(" Good ");
 digitalWrite(redLed, LOW);
 digitalWrite(greenLed, HIGH);
 noTone(buzzer);
 }
 delay(100);
}
```

3) Code for the filtration unit (Automatic)

This code is a standard code for servo motors to be executed when the if statement is satisfied. The code is set without any values which is to be inputted with the user's values of choice. The basic functionality of this code is that when the value of the surrounding air exceeds the desired threshold, the servo is to be rotated 180 degrees or 0 degrees according to the inputted values.

```
#include <Servo.h>

Servo myservo;
int pos = 0;
const int analogPin = A3;
const int servoPin = 9;
const int threshold = 3;

void setup() {
 pinMode(servoPin, OUTPUT);
 Serial.begin(9600);
 myservo.attach(9);

}
void loop() {

 Serial.print("A3 = ");
 Serial.print(volts(A3));
 Serial.println(" volts");
 delay(1000);

int analogValue = analogRead(analogPin);

 if (analogValue > threshold) {
  digitalWrite(servoPin, HIGH);
 }
 else {
  digitalWrite(servoPin,LOW);
 }
 Serial.println(analogValue);
 delay(1);

 for(pos = 0; pos < 180; pos += 1)
 {
  myservo.write(pos);
  delay(15);
 }
 for(pos = 180; pos>=1; pos-=1)
 {
  myservo.write(pos);
  delay(15);
  }
  }
 float volts(int adPin)
{
 return float(analogRead(adPin)) * 5.0 / 1024.0;

}
```

The manual control is a nonstop filtration function that works the filtration unit continuously, therefore no code is required for this process of implementation, although a separate switch for this specific unit can also be implemented to avoid unnecessary consumption of power and to make sure it works when needed.

Design and Model

Body Design: Designed in a cuboid format, the device is built with core material and structure made out of sun board, which makes it light and sturdy, and another chamber made out of polycarbonate or any UV absorbent for housing the UV-C lamp and Titanium Dioxide system units for maximum efficiency. The device has slots, wherein the first slot is used for the primary filtration system, consisting mainly of metal mesh, the second slot is used for the secondary filtration system, consisting of HEPA filters of 0.3 microns, the third slot is used for the UV-C chamber, and the fourth another UV-C chamber which is made up of polycarbonate with TiO_2 coated metal for the double filtration.

Additionally, the device's electronics are configured underneath the LCD display, and the box is designed to allow the whole unit to be compressed into a single unit to take full advantage of the device's size and shape. Because the interior is made up of sun board, repairs and upgrades are easy. This device is designed in a way that allows for future upgrades, attachments, and repairs.

Fig. 6. Prototype of the detection unit

1) Microcontrollers

a) Arduino Uno – Arduino UNO (Fig.7) is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable.

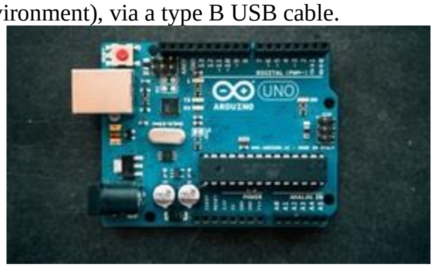


Fig. 7. Arduino UNO

2) Sensors

a) MQ-135- The MQ-135 sensor (Fig.8) is a sensor with a wide range of detection, it can detect harmful gases like Ammonia , Sulphur, Benzene, smoke carbon dioxide , making it the best sensor for this device .

Fig. 8. MQ-135

3) Filtrates

a) Primary Filter- The primary filtration consists of a metal mesh, that is mainly for the purpose of filtering out larger particles

b) HEPA Filter- HEPA, which stands for High Efficiency Particulate Air, is a designation used to describe filters that are able to trap 99.97 percent of particles that are 0.3 microns.

c) Ultraviolet C- Germicidal Ultraviolet light or commonly known as UVC lamp is an electromagnetic wave in the spectrum of light with a wavelength of 254 nanometres (nm). UVC light is a known disinfectant for air, water, and nonporous surfaces.

d) TiO_2 - Titanium dioxide is one of the best photocatalytic elements that helps get rid of many types of pollutants, the element is used because of the ease of use and for being not at all harmful to the environment. This compound is called photocatalytic due to its property to catalyst in the presence of mainly the UV spectrum of light to turn water to hydrogen by the process of photocatalysis. (Fig.9)

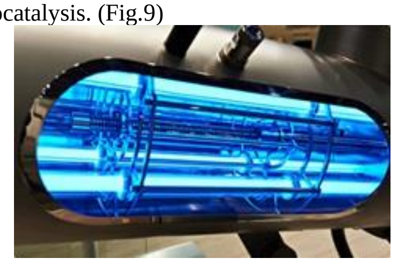


Fig. 9. TiO2 coated material with UV

4) Electronic components

a) Connecting wires – Mainly for electronic circuit connections jumper wires are used, due to its ease of use for connections and for the lack of solder requirement. Three types of wires are used simple wires, female jumper and male jumper wires

b) Motors- This motor is the main suction unit of air for this device, connected to a propellor the motor can be of any type but most preferably a brushless motor if the device is to be kept in a large environment, but for closed environment any brushed motors can be used.

c) I2C Liquid Crystal Display 16x2 – This is an LCD display (Fig.10) that can show up to 32 characters. This LCD has a built in I2C module that makes it easy to use as no extra wiring or soldering is to be done

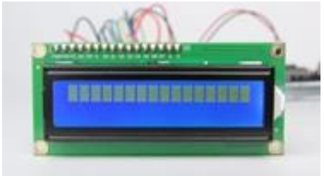


Fig. 10. I2C Liquid crystal module

d) Servo Motor- Servos have integrated gears and a shaft that can be precisely controlled to have optimum precision in various scenarios. Standard servos allow the shaft to be positioned at various angles, usually between 0 and 180 degrees.

e) HC-05 Bluetooth module- HC-05 (Fig.11) is a Bluetooth module which is designed for wireless communication. Bluetooth serial modules allow all serial enabled devices to communicate with each other using Bluetooth.

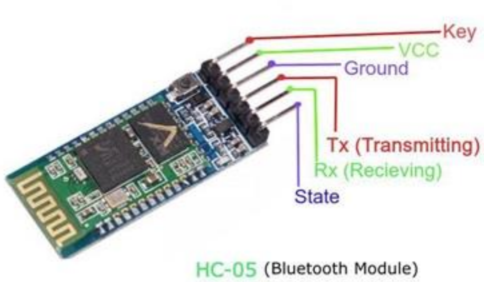


Fig. 11. HC-05 Bluetooth module

RESULTS

After calibration, the pollution threshold for the device was set to the value of 100, and the resting or environmental quality value occurred in the range of 150-200 ppm, depending on the sensor's start-up state. As a result of its testing, the device was highly successful in detecting different gases and compounds from different sources.

1) Test for Carbon dioxide

The test for detecting carbon dioxide was done by burning a piece of paper or just by exhaling in front of the sensor, the sensor showed successful detection of Carbon dioxide with the value exceeding 100 up to 200 ppm, these values exceeded the threshold value thus triggering all the indication system.

2) Test for Propane

Methane and propane are both linear, singly-bonded hydrocarbons called alkanes and are also natural gases, so their detection range is similar. This propane was obtained from a lighter which detected its presence again upon pre-ignition, and the value threshold of 100 ppm was again exceeded up to 165 ppm indicating the presence of an unwanted gas.

3) Test for alcohol Derivatives

This test was devised in order to detect the presence of alcohol and its derivatives. Although this test does not hold any significance, it does illustrate the vast array of possibilities for this device. The source was a hand sanitizer for the detection of alcohol. Upon the detection of ethanol, the sensor exceeded the threshold value of 100 ppm up to 195 ppm, showing the presence of an unwanted compound in the atmosphere.

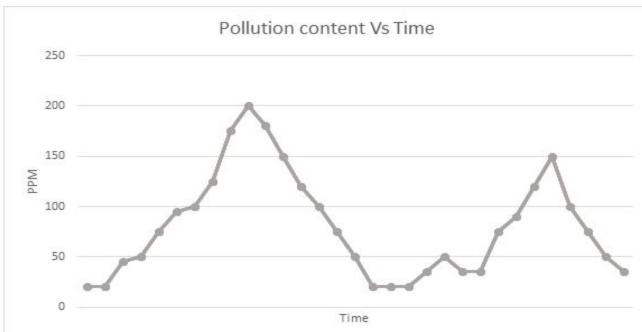


Fig. 12. The rate at which polluted air is purified

The above graph (Fig. 12) shows an upward trend which indicates the presence of a pollutant in the atmosphere detected by the sensor, the upward spike stops at a point which indicates that the unit has started to work on purifying the air, the lower trend or the declining slope shows that the atmospheric air contamination content has come back to the normal and healthy rate.

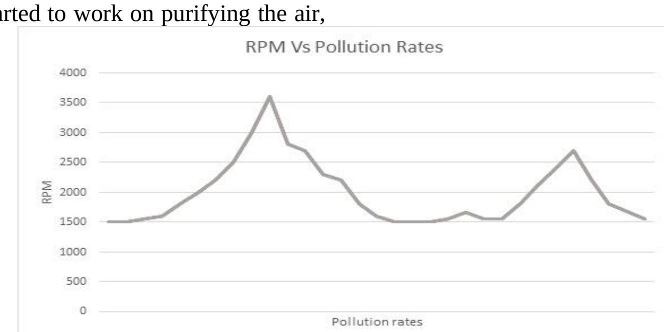


Fig. 13. The change in RPM with respect to pollution rate

The graph (Fig. 13) also shows the Fan RPM that is increasing over time with respect to the amount or quantity of pollutants present in the atmosphere showing an upward trend whenever the PPM exceeds the standard threshold and shows a constant lower trend whenever it is in a standard rate of PPM.

The filtration unit would be initiated at the moment it exceeds the standard threshold rendering the system cycle complete. Here when the value of the air exceeds the value 100 ppm the unit will be turned on automatically, with the help of a simple servo circuit switch. The emission sources were chosen so as to show that the gases of similar characteristics and properties will also be detected, with the available sources the device showed promising results with high accuracy.

CONCLUSION

It can be concluded that the device has proved to be an optimal device to be used in open or closed spaces, however, although the optimum operation area is in a closed environment, a larger model can be derived from this unit to cover a wide area so that it can be used in densely polluted areas. As for connectivity and UI, the device has room for improvement, with more advanced operators and functions being a possibility. People can use the device to become aware and to take action towards the environmental crisis in the most effective manner. Based on the results and the working methodology, we can conclude that the device is safe, cost-effective, and portable, without any degradation in functionality.

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