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Research Paper

Development of Sensor-Based Air Quality Monitoring in Residential Areas

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Abstract: *Urban environments with a high degree of industrialization are infested with hazardous chemicals and airborne pollutants. These pollutants can have devastating effects on human health, causing both acute and chronic diseases such as respiratory infections, lung cancer, and heart disease. Air pollution monitoring is vital not only to citizens, warning them the risk of health due to air pollutants, but also to policy-makers, assisting them on drafting regulations and laws that aim at minimizing those health risks. Air pollution has undoubtedly affected the air quality, while continuous observations and monitoring initiatives by relevant government authorities and academic researchers are still ongoing. Recent data revealed that Malaysia was ranked 50th in an air pollution index ranking worldwide. The PM2.5 rating of 19.36 µg/m³, signifying the moderately polluted category, does not reflect a proud achievement as it indicates an increasing trend when compared to the previous annual pollution index. This study proposes a device that identifies and monitors air quality in a residential area. The focus of this study (i) to collect the monitoring data that captures individual exposure levels to air pollutants in residential areas located across heavy industrial areas. (ii) the proposed device was constructed with an open-source engine from Arduino combined with a custom-made sensor; both possess the ability to generate independent and reliable outcomes. (iii) if the recorded value exceeds the pre-set value, an alarm is released as a warning signal. Upon ensuring that the device satisfies the criteria of an eco-friendly design, the CATIA software was deployed as the final design for the proposed device. The results of this study (i) this device eases the process of measuring and identifying air quality in real-time, which is beneficial for the relevant authorities and the residences. (ii) The alarm incorporated into the device serves as a warning indicator. (iii) assist the citizens in monitoring with personalized insights about air pollutants in their daily commute and enhance healthier lifestyles ahead.*

Keywords: *Air quality monitoring; hazardous gasses; residential areas*

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I. Introduction

Throughout the world, in general, the pollution of the atmosphere has been increasing at an alarming rate with an increase in both industrial and human activities over a long period of time [1]. This has resulted in severe consequences, such as global warming and climate change, that have a devastating effect on the environment and our planet as a whole. Air is one of the most precious elements of natural resources because it is necessary for human survival, animal survival, plant survival, and ecosystem regulation. This gaseous combination, which functions as a spacesuit for the biosphere, is held in place by gravity. Some crucial roles of the air include absorption of ultraviolet sun radiation, air retention that warms the surface of the Earth, and reduction of day-night temperature fluctuation [2]. The determination of air quality is based on the number or size of particulate matter generated by anthropogenic/natural sources, as well as the number of gaseous pollutants contained in the air. When dangerous particles and gases are released into the atmosphere at a harmful concentration, the air becomes polluted [3].

There is a growing body of evidence demonstrating that poor indoor air quality (IAQ) is associated with a variety of health risks. A recent study concluded that indoor air pollution might be between 2 and 5 times higher than outdoor air pollution [3]. This underscores the importance of ensuring adequate IAQ to minimize health risks and protect the health of occupants. Air pollution has been the leading cause of death in many low-income countries. In 2017, 5 million deaths were reported due to air pollution. The whopping figure equates to 9% or one-in-ten death rate [4]. Air pollution has a detrimental impact on both the environment and the wellbeing of the community. For instance, exposure to particulate matter (PM) is linked to an increased risk of cardiovascular, respiratory, and neurological diseases, as well as adverse pregnancy outcomes, such as pre-term births, low birth weight and stillbirths. Air pollution occurs from a vast range of sources, while its complexity is heavily influenced by climatic conditions, terrain, and carbon emission [5].

Escalation of world population and massive industrialisation during the second half of the 20th century led to degradation of atmospheric air quality, which consequently affected the health of human beings. As a result, the need for more stringent regulations on air quality has become imperative to protect human health and the environment. Many inadvertent air pollutants discharged in acute exposure are a significant health concern. Air pollution is a hazard to both the public health and the environment with varying severity across countries [6]. Referring to the interactive map, the global death rates due to air pollution had been estimated based on 100,000 inhabitants in a country or region with Sub-Saharan Africa and South Asia recording the highest death rates [7][8]. For example, it is estimated that 3.2 million deaths occurred in 2019 due to exposure to household air pollution, with women living in low- and middle-income countries bearing the largest burden.

In 2017, about 3.4 million people suffered from premature death due to exposure to outdoor pollution. Thus, outdoor air pollution caused 6% of worldwide death and accounted for 10% or more fatalities in several countries. The map illustrates the annual death toll from outdoor air pollution as a percentage of all deaths worldwide [9]. Notably, outdoor air pollution had adversely affected less than 2% in countries across Sub-Saharan Africa, 2-3% in North America and Oceania, 4-6% in most of Europe and Latin America, and more than 6% in several Asian, North African, and Middle Eastern countries in 2017. A PM2.5 score of 12.1-35.4 g/m3 is crucial to classify a city or a country in the category of moderate pollution, which placed Malaysia at the low end of this moderate range [10]. Nonetheless, one should consider that in some months during the year, the pollution levels had hit dangerously high levels. In terms of annual average rate, underlying causes, and possible remedies; Malaysia had far lower pollution levels than many of its neighbouring Southeast Asian countries [11].

Based on the data published in 2019, Thailand was ranked 28th, followed by Vietnam (ranked 15th) and Indonesia (ranked 28th) [3]. Despite facing a host of pollution and haze-related challenges for many years, Malaysia has been improving when compared with other Asian countries. Malaysia has been making great progress in its green initiatives since the past few decades despite its flourishing industrial development; signifying that the road to clean air and a lower pollution rate may be achieved in the near future. Several sites were listed on the IQAir website, such as the seven most polluted cities in Malaysia recorded for year 2019; evidencing air pollution issue in these areas, as well as a decline in the national average annual rating. Among the seven cities, Petaling Jaya, Shah Alam, Kuala Lumpur, and Putrajaya had maintained relatively low pollution levels throughout the year, except for a notable sharp increase in August and followed by a hazardous surge in September that extended into October but later gradually declined [12]. Such cities displayed inferior air quality, particularly later in the year, which emerged as a significant concern for year-round residents that necessitated critical preventative measures.

With multiple sources of pollution, air pollution in Malaysia comprises of a diverse array of chemicals, compounds, and particles. The principal sources of pollution, in comparison to other Southeast Asian countries, are nitrogen dioxide (NO_2) and other greenhouse gases that are mostly emitted from automobiles, trucks, buses, and other forms of transportation. As NO2 is the principal pollutant emitted from automobiles and other engines, its concentrations alone in the air is frequently applied to determine the amount of pollution. As evidenced, regions with high traffic densities or high vehicle counts exhibit a staggering rate of NO_2 in the atmosphere [13]. The observation of massive, complicated datasets derived from air quality monitoring stations demands the integration of contemporary and rigorous statistical methodologies for simplification, primarily to avoid misinterpretation and to present spatial variation [14]. The air pollution levels in Malaysia have been excellent to moderate, although the trend displayed a slight shift between 2008 and 2011. According to Ahmad *et al.* (2015)[3], the number of persons who reported having satisfactory air quality decreased to 59.0% in 2008, 55.6% in 2009, 63.0% in 2010, and 55.0% in 2011 [15].

The API is applied to assess and characterise the ambient air quality in Malaysia in terms of potential public health threats. A non-dimensional number is calculated from the city's daily average pollution concentration. The API is calculated by using a sub-index based on five parameters that can affect air pollution (i.e., PM10, SO2, NO2, CO2, & O3) in Malaysia. The API value for a given period is calculated by dividing the sub-index values of various pollutants. In adherence to the Recommended Malaysian Ambient Air Quality Guideline (RMAQG) specified by the Department of Environment (DOE) since 1989, air quality is classified into the following five categories: excellent, moderate, unhealthy, severely unhealthy, and hazardous. These are also in line with the worldwide criteria outlined by the US Environmental Protection Agency [16].

This study proposes a device that identifies and monitors different types of hazardous gases in a residential area. The device works by detecting the concentration of hazardous gases in the air and then sending an alert to the user if it reaches a certain level. This allows people to take precautions against the potential health risks associated with exposure to these gases. For example, the device can detect the presence of carbon monoxide and alert the user if the concentration of the gas reaches a level that could be harmful to their health. If the recorded value exceeds the pre-set value, an alarm is released as a warning signal. The focus of this study does not rest in residential areas located across heavy industrial areas. The proposed device was constructed with an open-source engine from Arduino combined with a custom-made sensor; both possess the ability to generate independent and reliable outcomes. Upon ensuring that the device satisfies the criteria of an eco-friendly design, the CATIA software was deployed as the final design for the proposed device. This device eases the process of measuring and identifying air quality in real-time, which is beneficial for the relevant authorities and the residences. The alarm incorporated into the device serves as a warning indicator. The application of this device should significantly assist the affected citizens in monitoring and preventing air pollution to enhance healthier lifestyles ahead. For example, this device can be used to monitor the air quality in industrial zones and provide timely alerts to the local community when the pollution levels exceed a certain threshold.

II. Literature review

2.1 Carbon dioxide (CO_2)

High-density greenhouse gas CO2, which is easily stored in poorly ventilated areas, with an atmospheric concentration between 300 and 400 ppm. Every time a person breathes, they make CO2. While CO2 alone is not hazardous, if its concentration is higher than the average amount in the air, it can cause hypoxia, which is harmful to human health. The CO2 concentration will be beyond the recommended level and be uncomfortable if one spends a lot of time in an unduly congested setting or an area with poor ventilation. The State uses CO2 as a hygienic index to monitor indoor air pollution; in the case of a prolonged stay in a crowded place, the CO2 concentration shall not exceed 0.07-0.1%, and shall not exceed 0.15% if it's only a temporary stay. The immediate danger to life or health concentration (IDLH) for acute respiratory threats has also been established by the Ministry of Labor. A CO2 concentration of 4% puts humans in risk; a CO2 concentration of 7.5% causes palpitations, vertigo, and headaches; a CO2 concentration of 10% or higher causes hearing loss, nausea, and vomiting; a CO2 concentration of 30% or higher causes convulsions and loss of consciousness. The ideal range for indoor CO2 concentration is 350 to 450 ppm. Above 1000 ppm, people start to develop symptoms, such drowsiness, and this higher concentration causes severe symptoms. ASHRAE advises the indoor CO_2 concentration should not be higher than 1000 ppm. The detailed effects of CO_2 concentration on human health are shown in Table 1 [18].

Table 1: Effects of CO2 concentration on the human body. At higher concentration such as 1000 ppm, people begin to experience symptoms such as drowsiness. ASHRAE suggests that the indoor CO2 concentration should not be higher than 1000 ppm

CO_2 concentration (ppm)	Description
5000	Do not stay in this environment over 8 hours
2500	Bad for health
1000	Feel sleepy
700	Feel the air is filthy and uncomfortable
450	Acceptable range
350	Healthy and general indoor air

Table 2: Description of particle matters and particle sizes

Particle size (µm)	Name	Description
<2.5	Fine particulate matters (PM2.5)	Entering the bloodstream directly through alveoli
2.5-10	Coarse particulate matters (PM2.5-PM10)	Being inhaled by the human respiratory system
<10	10µm particle matters (PM10)	Through the nasal cavity to the throat
<100	Total suspended particulates (TSP)	Beach sand being suspended in the air

Table 3: Fine particulate matter indices

Index Level	Category	PM2.5 concentration (μg/m³)	Description
1	Low	0-11	May go out as usual
2	Low	12-23	
3	Low	24-35	
4	Medium	36-41	
5	Medium	42-47	
6	Medium	48-53	
7	High	54-58	Less go out if permit these
8	High	59-64	symptoms such as sore eyes
9	High	65-70	and throat.
10	Very high	>70	Not allow to go out

2.2 Carbon monoxide (CO)

As a chemical, CO is the most prevalent hazardous gas in daily life and is an odourless, tasteless, colorless, and non-irritating gas. Even while most organisms produce CO, the main sources of this gaseous compound are from engine exhaust, and incomplete gas combustion [5]. Since their capacity to bind heme is 200 times greater than that of oxygen (O2), it is difficult for them to carry O2 in the blood after binding. As a result, when someone inhales CO, they may experience a variety of symptoms, including headaches, nausea, dizziness, and chest pains. Consequently, the National Fire Protection Association (NFPA) also established the harmful symptoms for people inhaling different levels of CO, as shown in Table 4 inhaling different gases, and the United States Environmental Protection Agency (USEPA) mandated that the maximum CO content in the air shall not be greater than 10 mg/m3.

Table 4: Effects of CO concentration on the human body

CO content	Name
0.01 % (100 ppm)	Causing symptoms such as headache, lethargy, nausea, muscle weakness, and loss of judgment within 6-8 hour
0.02% (200 ppm)	Causing light headache within 2-3 hour
0.04% (400 ppm)	Causing worse headache within 2.5-3.5 hour
0.08% (800ppm)	Causing dizziness, nausea and cramping within 45 min
0.16% (1600 ppm)	Causing headaches and dizziness within 20min and leading to death within 2 hour
0.32% (3200 ppm)	Causing headache, dizziness and vomiting within 5-10min and leading to death within 30 min
0.64% (6400 ppm)	Causing headaches and dizziness within 1-2 min and leading to death within 10-15 min
1.28% (12,800 ppm)	May lead to death within 1-3 min

2.3 Indoor Air Quality (IAQ)

Although the outside air pollution has been worse over the previous 20 years, however, U.S. EPA analysis found that interior air pollution is five times worse than outdoor air pollution; as a result, people are starting to take the dangers of poor indoor air quality seriously. In spite of the fact that most people spend 85% of their waking hours in air-conditioned enclosed spaces like homes, businesses, and schools, people nevertheless frequently experience sick building syndrome, which was first identified by the World Health Organization in 1982. The sick building syndrome is brought on by poor indoor air quality brought on by the ongoing buildup of air pollutants inside, which results in abnormal problems like eye and nose irritation and, in some cases, asthma.

Table 5: Indoor air quality standards

Items	Critical concentration
Indoor Air Quality (IAQ)	
Carbon dioxide (CO_2)	1000 ppm
Carbon monoxide (CO)	9 ppm
Formaldehyde (HCHO)	0.08 ppm
Total volatile organic compound (TVOC)	0.56 ppm
Bacteria	1500 CFU/m3 (bacterial counts/cubic meter)
PM2.5	35 μg/m³

III. Methodology

The Arduino programme was used in this study to construct a device that effectively measures contaminated air. Arduino is an open-source platform that allows users to program and develop digital devices. It is widely used for prototyping, and it is relatively simple to use. In this case, it was used to create a device that can measure air quality with a high degree of accuracy. The CATIA programming was deployed to create an intuitive warning system when the air in a certain location becomes contaminated. Data gathered from multiple sources were used to formulate an algorithm. After processing both the data and the algorithm, the following steps were taken to design the device, while simultaneously considering all the surrounding factors. The CATIA was deployed to ensure that the device is user-friendly. After finalising and implementing the design, the software implementation phase was executed to ascertain that the device functions properly and meets the project aims. The user-friendliness of the device was ensured with the help of CATIA, and the software implementation phase was executed to test its functionality and check if it achieved the desired objectives. The next step was coding with Arduino Integrated Development Environment (IDE). All parameters were embedded to ensure smooth functionality of the device in real practice and all software programmes were tested. For example, the coding was tested for all of the device's sensors to ensure that they worked properly and that the data collected from them was accurate. Now the product is ready for data collection and further development.

3.1 Equipment

3.1.1 Arduino Uno

The Arduino Uno refers to a microcontroller board programmed that uses microcontroller data sheet. It consists of 14 digital input and output pins, 6 analogue inputs, a 16 MHz ceramic resonator, a USB connection, a power connector, an ICSP header, and a reset button. The microcontroller is connected to a computer via USB or powered with an AC-to-DC converter or battery. The term "uno" refers to "one" in Italian, which reflects the initial release of Arduino Software (IDE) 1.0. It functioned as reference versions, but superseded by subsequent releases. The Arduino Uno board is the initial series of USB Arduino boards, which functions as the standard model of a platform with a complete list of present, past, and defunct variants (see Arduino board index) [17].

Fig. 1. The Arduino board

3.1.2 Air monitoring sensor

Different sensors were used to monitor air quality. These sensors serve as the device input. Their rate of resistance varies based on the gas type. This change in resistance is then analysed and interpreted to determine the concentration of various gases present in the environment. The smoke sensor includes an integrated potentiometer that allows the sensitivity of the sensor to be adjusted to match the accuracy with gas detection. By accurately tuning the smoke sensor with the potentiometer, the accuracy and performance of the gas detector is increased, resulting in a more reliable air quality monitoring system. Next, the output voltage of the sensor varies based on the amount of smoke or gas present in the surrounding. The sensor yields a voltage value proportional to the amount of smoke or gas detected. For example, the output voltage of 4.5V is given when the smoke density is higher than the set threshold and the output voltage of 0.45V is given when the density is lower than the set threshold.

Fig. 2. Air monitoring sensor

3.1.3 LCD screen

A liquid crystal display (LCD) refers to a flat panel display or other electronically-modified optical device that uses fluid and polarising crystals to manage light (LCD) (see Figure 3). Liquid crystals do not produce light directly, but generate colour or monochromatic images by using a backlight or a reflector. The LCD informs the gas flow rate detected by the sensor. Notably, this is one of the outputs of the device.

Fig. 3. LCD screen

3.1.4 12V siren

This 12V siren is one of the device outputs that emits sound when the detected amount of gas exceeds the pre-set data fixed in the Arduino programme for gas rate. With a loud and piercing sound, this 12V siren serves as an alert for when the gas rate surpasses the pre-set limit programmed into the Arduino. This siren signals as a warning to the dwellers at the residential area if the air condition falls into the harmful category. As such, this 12V siren serves as a crucial device for informing dwellers of a hazardous air condition, making it an important part of any residential area's safety precautions.

Fig. 4. 12V siren

3.1.5 Arduino Programme

Arduino programmes are developed by employing Arduino IDE. Arduino IDE refers to a computer software programme that draws sketches for multiple Arduino boards (see Figure 5). This processing-based Arduino denotes a relatively simple hardware programming language, which can be compared with C language. The codes written in Arduino IDE are uploaded to Arduino board for implementation.

Fig. 5. Arduino programme

IV. Results

This research was conducted to develop sensor-based air monitoring in residential areas. The investigation was carried out by developing a device that can collect and monitor the inside and outside air and produce warning sounds to the resident. The development stage involved, data sampling and calibration, sensors installation, and field testing. The developed device is supplied with a 12V power supply. An important feature of this device is that it is equipped with three primary sensors, a logic board for the coding system, and a 12V siren. The device would be positioned at a height of approximately 120cm above the ground. Placement in this area will ensure that the device accurately collects samples from the air. Continuously, this device measures ambient temperature, humidity, and CO2 levels. It is embedded with pre-programmed data for each air particle. The warning siren emits a sound for four seconds when the particle counts increase and recalibrate for the next detection.

Fig. 6. The finished product

Using sensors, the proposed device will be able to identify the quality of the air by scanning the air and comparing the quality of the air to pre-set data used to calibrate the sensor based on the quality of the air. A four-second warning sound will be emitted by the system shortly after it detects abnormally high levels of air quality in the area before ceasing to be emitted. A calibration process is initiated by the device in order to prepare the sensor for detection. In the event that the air quality remains poor, the warning alarm will again emit the warning sound. The calibration process helps to ensure the accuracy of the sensor readings by calibrating the device to the specific air quality values of the environment. This allows the device to provide accurate and reliable readings, and the warning sound helps to alert people when air quality is not up to a safe level. Additionally, the warning sound serves as a reminder to take necessary measures to protect oneself from the health risks associated with poor air quality.

```
void setup()
{
  pinMode(siren, OUTPUT);
  digitalWrite(siren, LOW);
  pinMode(buzzer, OUTPUT);
  pinMode(A0, INPUT);
  Serial.begin(9600);
  lcd.begin(16, 2);
  lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print("Air Quality");
  lcd.setCursor(5, 1);
  lcd.print("System");
  tone(buzzer, 1000); // Send 3KHz sound signal...
  delay(1000);        // ...for 1 sec
  noTone(buzzer);     // Stop sound...
  delay(3000); //Wait before accessing Sensor
  lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print("Calibrating");
  delay(13000);
```

Fig. 7. Functionality coding

This design and the system development of the proposed device are critical for human health, especially for residential areas adjacent to industrial areas. The air quality in such areas must be monitored to ensure its suitability for human health. Therefore, the proposed device can significantly contribute to maintaining healthy air quality throughout the house. The device is designed to monitor air quality parameters such as temperature, humidity, and particulate matter levels. This data can then be used to identify any potential health risks, allowing people to take the necessary steps to improve the air quality in their homes.

Additionally, this device functions as a first responder that enables residents to take the necessary action in an effort to avert catastrophic consequences. This device continuously monitors the air particle concentration in that region until it detects an increment in air particle concentration that may be harmful gases. In order to effectively operate as a first responder, the device emits an alarm sound to alert the residents about the presence of low-quality air. The device also has the capability to identify certain types of gases by using sensors and a microcontroller. This allows it to detect the presence of any harmful gases in the air and alert people about it, giving them the chance to take the necessary safety precautions before the situation worsens.

Additional enhancements can be proposed to this project to make the device more user-friendly and manageable. For example, the device can be equipped with a voice activation system and an LCD display, which can be used to show an alert when a hazardous gas is detected and provide instructions for safety. Additionally, a mobile application can be developed, which can be used to monitor the device and receive real-time updates. Upon improvement, this device may serve as the ideal first responder in preventing undesired disasters among tourists enjoying nature. One setback of this proposed device is that this device runs only when it is connected to a power source. Therefore, an interruption in the power supply can affect the operation of this device.

To address this issue, a reliable power source should be identified and implemented to ensure uninterrupted functioning of the device. Besides, this device lacks connectivity with the user via seamless technology, as it heavily relies on intergrade warning alarms. This device can only identify air particles but is unable to conduct tests on hazardous gases. This device operates solely on pre-set data and is incapable of detecting the different types of gas. To ensure the effective functioning of the device, it is essential to include seamless technology for user connectivity and to ensure a reliable power source for uninterrupted operation. Furthermore, the device should not only be able to detect air particles, but also conduct tests on various hazardous gases in order to provide the user with comprehensive data. Moreover, as the alarm sound can only be heard within a specified radius, the residential community would need to install several of these devices to cover the entire residential area or neighborhood. For example, if the residential area were 500 feet in diameter, five such devices would need to be installed to ensure the entire community is alerted in case of a hazardous gas leak.

V. Conclusions

A number of improvements may further enhance the functionality of the proposed device. First, a portable version of this device is more user-friendly and can be used at any location. In addition, this device should be equipped with WI-FI connectivity to enable remote monitoring by those who are not within the target region. Furthermore, an app with a simple interface should be developed to make it easy for users to access the device's features. The device should gather data from a wider area to determine the type of gas detected and a larger siren should be implemented to cover a wider region. Moreover, the device should be equipped with robust security protocols to ensure that only authorized personnel can access its functions. Secondly, the users pushed the button on the voice emotion recognition device to speak into the Raspberry Pi 4- connected microphone. Their voice was subsequently interpreted by a Phyton-trained dataset. Meanwhile, AI recognized users; sentiment postinterpretation with the output transmitted to the cloud server. Furthermore, the AI-enabled device should be able to accurately detect and analyze user emotion, providing reliable and valuable feedback to the cloud server for further processing.

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