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Review article

Internet of things based visualisation of effect of air pollution on the lungs using HEPA filters air cleaner

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A B S T R A C T

The impact of air quality on human health and the environment is very significant, with poor air quality being responsible for numerous deaths and environmental damage worldwide. Whereas a number of studies have been done to monitor the quality of air with help of emerging technologies, little has been done to visualize its effect on health particularly on the lungs. The study explores an approach that combines Internet of Things (IoT) technology with High Efficiency Particulate Air (HEPA) filters air cleaner to monitor and visualize the effects of air pollution on lung health, highlighting the significant damage that poor air quality causes particularly on the lungs graphically. To achieve this, a 3D display of the lungs is modelled using HEPA filters, which changes colour based on the air pollutant concentrations detected by IoT-based sensors. The collected air quality data is then transmitted to Thingspeak, a visualization platform for further analysis. It is observed that the colour of the 3D lung display changed to black over time as air pollutant concentrations increased which in our study is an indicator of unhealthy lung. The study presents an innovative approach to visualize the effects of air pollution on lung health using IoT and HEPA filters air cleaner, which could have significant implications for public health policies aimed at mitigating the harmful effects of air pollution, particularly on lung health.

1. Introduction

Currently, air pollution is a global public health emergency. It consists of substances that are harmful to both humans and environment. Various studies indicate that air pollution remains a significant health risk factor globally. It is reported that air pollution continues to be a huge environmental risk factor across the entire globe.

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Fig. 1. Colour of a healthy lung Vs unhealthy lung [21].

In 2021, World Health Organisation (WHO) estimated that around 7 million deaths were mainly caused by the effects of both household and ambient air pollution and that nine out of ten people mostly in low developing countries live in places where air quality still exceeds WHO guideline limits [1].

According Global updates on air pollution 2021 [2], air pollution concentrations still exceed limit the levels and has greatly worsened mostly in the most parts of low- and middle-income countries due to increased urbanisation, industrialization, traffic and scaled up economic development that increase burning of fossil fuels [3].

Air pollution increases morbidity and mortality globally and also increases disease burden due to the illnesses that are caused by dirt air such as respiratory tract infections, lung cancer, Chronic obstructive pulmonary disease (COPD), preterm birth and other deaths especially in infants, children and the elderly groups [4].

Sources of air pollution in low- and middle-income countries include; big industries, power plants, factories that are popping up every year, second-hand vehicles and motorcycles that enter these countries in big numbers annually and also dust from unpaved and murram roads that are very common, burning of waste in open places by people as a way of managing it; in all these activities, large harmful amounts of air pollutants get into the air and bring great harm to both human health and environment [5]. This has caused millions to be hospitalized every year and crippled the economy [6].

1.1. Air pollution effect on the lungs

Lungs are amongst the body organs that are greatly affected by air pollution [7]. It is reported that air pollution harmfully affects the lungs and the airways. According to [8], it is estimated that about 223,000 lung cancer deaths that occur every year worldwide are attributed to air pollution. Ambient air pollution still remains a major risk to health in general and also a leading environmental cause of cancer deaths and in particular lung cancer.

Various studies indicate that air pollution damages lung development in infants and children which later leads to lung impairment in adults [9]. The International Agency for Research on Cancer (IARC) classified air pollution as carcinogenic, meaning that air pollution has great potential to cause cancer to humans as this is notably consistent in various epidemiology studies [10][11][12].

According to [13], in 2013, experts from various countries met at IARC in France. Their mission was to assess whether ambient air pollution is carcinogenic. Their findings indicate that air pollution from ambient air pollution is carcinogenic to humans based on their experimental results.

A study conducted by Xiaoxue Liu et al. in [14] attributed 36.4% of the global deaths to air pollution, out of which 12.3% deaths were due to lung cancer alone from the air pollution effect. Also in 2013, based on the wide range of epidemiological studies, WHO declared that air pollution was carcinogenic to humans [15].

In 2016, the Global Health Observatory (GHO) which is WHO's portal that provides access to data and analyses for monitoring the global health situation stated that approximately 29% lung cancer deaths were caused by air pollution [16]. GHO provides analysis for key health themes based on data from all WHO programs [17].

Air pollution affects various parts of the body differently, however to the lungs, when the air pollutant particles are too large to be filtered out of the human body, they penetrate the lung alveoli [18]

More so, air pollutants damage lungs by inflaming the linings of the lungs, this makes the lungs work harder which usually results into heart attacks. Inflammation of the lungs also causes coughing and serious breathing issues. Air pollutants concentrations that stay in the lungs longer get into the white blood cells and later the lungs change colour to grey if the person keeps breathing the dirt air and there is no way the body can get these particles out. This results into that person suffering from irritation, wheezing, coughing, and also puts dangerous stress on the cardiovascular system [19], every day, over 10,000 litres of air enter the lungs out of which 420 litres of oxygen have to be extracted for human survival, therefore quality of air that gets into the body greatly determines the health of the lungs [20].

In Fig. 1, it shows the colour of both healthy and unhealthy lung, specialists in the lungs indicate that a healthy lung has a pink colour where as that of unhealthy keeps changing until it turns black [22], [23].

Whereas there is sufficient research that certifies that air pollution causes great negative effect on the lungs, little has been done to bring out its effect on the lungs visually. Therefore, it is from this motivation, that this study has designed a visualisation of air

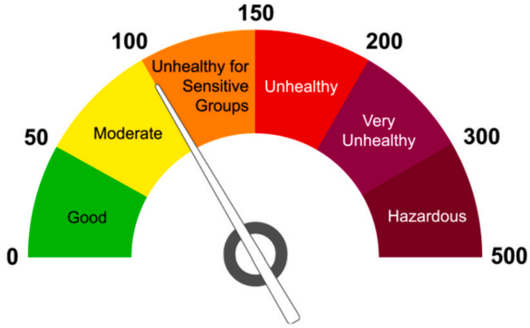


Fig. 2. Air Quality Index Guidelines [30].

pollution effect on the lungs through use of internet of things and High Efficiency Particulate air filters to show what toxins from dirt air do to the lungs.

Based on the results of the study, the concerned authorities, civil societies, individuals and governments worldwide can pay attention to the great effects of dirt air on the lungs and seek to improve air quality and as a result this can reduce the public health and economic burdens that are associated with breathing dirt air effect on the lungs especially in the low- and middle-income countries where air pollution has remained such a great silent killer [24].

1.2. IoT application in air quality monitoring

Influence of technology in every area of our lives is greatly increasing, this has created easier and efficient management in most areas. Internet of Things (IoT) has emerged recently as important technology that has brought connectivity and monitoring close from anywhere at any time in most applications applicable in various fields [25].

In IoT, real world objects are transformed into smart virtual objects. IoT aims to keep us informed of the state of the things at anytime, anywhere by anyone without constant human intervention, information is exchanged between things-to-things, human-to-things and human-to-human.

In recent years, IoT has been greatly applied in tackling environmental challenges; air quality monitoring and visualisation included, in the study [26], they developed an air quality monitoring system capable of providing real time data. The areas of air quality monitoring included metropolitan areas. In this study, vehicular based approach was used where the IoT devices mounted in mobile vehicles was used for measuring fine-grained air quality in real-time.

The first one was deployed in public transportation and the second one was implemented as a personal sensing model thereby allowing people walking around to collect data via the devices they possess.

Also in [27], study investigated whether a low-cost monitoring system can provide reliable indications about air quality in a place and, hence, be used in practice. From study, it emerged that, measurements provided by low-cost sensors can provide useful information about air quality in a specific location.

In the study carried out by [28] in the design and deployment of vehicular Internet of Things for smart city applications indicates that IoT can be used as a great tool to monitor the air quality. In their study, they deployed Lora-enabled sensors to monitor CO_2 and $PM_{2.5}$ from intra-vehicular environments on real-time. It was observed that the quality of air can act as sign of either low or heavy traffic depending on the air pollutant concentrations.

1.3. Air quality index in air quality monitoring

Air Quality Index (AQI) is a system based on numbers and colours to communicate the quality of air in an area. AQI is a standard designed by the Environmental Protection Agency (EPA) to present air quality concentrations in more understandable form to the public [29] and also help regions to evaluate and develop policies that can mitigate air pollution levels. AQI was developed based on the combined effect of all the air pollutants present in the environment. Humans over few days or even hours might experience negative impact on their health if they keep on breathing in dirt air, therefore it's the focus of AQI to report the level of severity of air pollution in an comprehensible manner to the public so that it can act accordingly and protect their health.

As shown in Fig. 2, The AQI numbers go from healthiest that is (0-50) and to the unhealthiest (150+). It also describes the AQI range values from 0-500 which are divided into five levels. That is; Good: 0-50, Moderate: 51-100, Unhealthy for sensitive groups: 101-150, Unhealthy: 151-200, Very unhealthy: 201-300, Hazardous: 300-500. Therefore, the higher the AQI value the poor the quality of air, and lower the AQI value the good the quality of air.

AQI also has a colour scheme that starts with green for healthy air and ends with maroon for the unhealthiest air pollutant level as indicated in the Fig. 2.

The equation of AQI follows linear interpolation formula; so, in order to calculate the AQI value corresponding to any of the air pollutants, the formula in equation (1) was followed

$$\mathrm{lp} = \frac{Ihigh - ILow}{BPhigh - BPlow}(Cp - BPlow) + ILow \tag{1}$$

Table 1
AQI levels and its associated health complications.

AQI Levels	Health Impact
0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
201 to 300	Health alert: The risk of health effects is increased for everyone.
301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Where,
Ip = the index for pollutant p
Cp = is the monitored concentration of pollutant p
BPHigh = the breakpoint that is greater than or equal to Cp
BPLow = the breakpoint that is less than or equal to Cp
IHigh = the AQI value corresponding to BPHigh
ILow = the AQI value corresponding to BPLow

According to WHO, the greater the value of AQI, the greater the health concern that air pollution brings as indicated in Table 1. Therefore, in this work, the AQI values used follow EPA standards and guidelines in relation to air pollution.

1.4. High efficiency particulate air (HEPA) filters

According to United States Environmental Protection Agency in [31], HEPA filter is a mechanical air filter that filters the air and removes at least 99.97% of mold, pollen, dust, bacteria, and any airborne particles. HEPA filters are capable of trapping large amount of dirty particles in the air.

In the study conducted by Allen et al. in [32] shows substantial evidence that HEPA filters can filter and purify air concentrations and improve sub clinical health indicators better than other interventions whose their effect is limited according to the study.

In the study, they reviewed three categories of interventions against air pollution: air purifiers, face masks, and behaviour change and in the findings, it is stated that HEPA filter use can purify the air over days to weeks which substantially reduces air pollutant concentrations and improve health. As a result, use of HEPA filters is being recommended by a big number government agencies and public health organizations [33], [34].

Also in [35], a study was conducted to assess whether operating HEPA filter unit in a child's bedroom can improve his/her respiratory health, the study showed that volatile organic compounds and particulate matter concentrations decreased by 72% over a period of twelve weeks.

The study in [36] performed an evaluation on HEPA fitted air purifier's effectiveness in reducing particulate matter of different sizes concentrations and other air pollutant concentrations in the real-world environment. The result of the study showed that HEPA equipped air filters reduced air pollution levels therefore the study recommends the use of air purifiers with HEPA filters for effective air pollution mitigation measures.

More to that, a study titled "HEPA filters reduce cardiovascular health risks associated with air pollution" conducted in [37] shows that HEPA filters are efficient in reducing the amount of airborne particulate matter, resulting in a reduction in blood indicators linked to an elevated risk of cardiovascular disease and an improvement in blood vessel health.

Therefore, in this study HEPA filter material is fitted into the lung model to filter the air pollutants.

1.5. Visualisation of the effect of air pollution on health

In this subsection, we look at other studies that have similar work and make a comparison.

In the study titled "inAir: Measuring and Visualizing Indoor Air Quality" in [38], the study focused on the development of a system called inAir, which aims to measure and visualize indoor air quality (IAQ). The authors address the importance of IAQ, considering its impact on human health and well-being. The study incorporates various sensors and data collection mechanisms to monitor different parameters related to IAQ. Furthermore, the visualization technique used in this inAir system to present the IAQ data in an understandable and user-friendly manner is through inAir system screen which presents general IAQ values to user.

Also in the paper titled "Web-Based 3D Visualization of Time-Varying Air Quality Information," by [39] focused on the development and implementation of a web-based system that visualizes air quality information in a 3D format. The goal of the study was to present time-varying air quality data in a more interactive, enabling users to visualize air pollution values in 3D format via the we-based system developed. In other related studies such as [40], [41] and [42], researchers investigated different approaches to monitor air pollutant concentrations in the environment and their effect on health using emerging technologies to measure air quality index in real time. However, in the studies done so far, the focus is mainly on real time air quality monitoring however there is no study that has been done yet to focus on the visualisation of effect air pollution on the lungs.

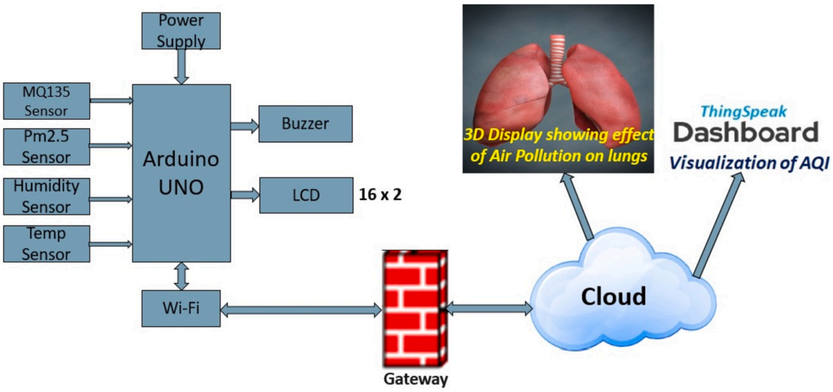


Fig. 3. System Architecture.

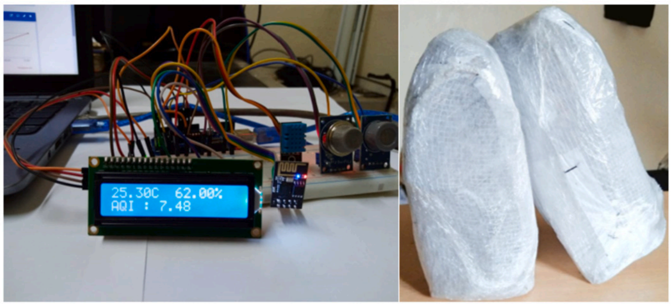


Fig. 4. System set up.

Therefore, this paper clearly shows how IoT-based technologies can be integrated with HEPA filters to show visually the impact of air pollution on the lungs which is research contribution of this work. The methods and results discussions are discussed in the following sections of the paper.

2. Materials and methods

This section introduces an architectural design for our study as shown in the Fig. 3.

Sensing nodes are deployed in the case-study area to collect numerous data that is useful for air quality monitoring and effect visualisation on the lungs. These include weather parameters; humidity and temperature and also air pollutant gases. Also a replica of lungs in shape human lungs is designed using HEPA filters to mimic the human lungs.

Data collected by the sensor nodes from the targeted case study area is averaged and sent to the cloud via a gateway that links all the sensing nodes to the internet. Arduino Uno a programmable interface is configured to manage data processing, retrieval and display. Also an IoT cloud server analytic service of ThingSpeak is configured to aggregate, analyze and visualize live data from the sensor nodes. Therefore, the results after data processing are visualised through an intuitive web-based ThingSpeak dashboard and also the colour change effect is noted in the lung display. In this case the AQI values are captured and also graphically visualised on ThingSpeak dashboard.

2.1. System overview

An IoT based visualisation of effect of air pollution on the lungs has been designed and deployed to collect data using air pollutant sensors. Fig. 4 shows IoT based prototype for air quality monitoring and 3D lung display model. To construct the prototype, an Arduino Uno micro-controller board based on the ATmega328P integrated with Arduino Integrated Development Environment (IDE) is used. This board can be powered by connecting to a computer with USB cable or directly to power with a AC to DC adapter.

Arduino IDE is cross-platform software application that is used in various IoT projects. It is used to write and upload instructions that are compatible with the Arduino to the MCU boards. Therefore, in this work, Arduino IDE is utilised to import all the important libraries for the board, at the same time transfer the code to Node MCU and update data to ThingSpeak. All the instructions and functions were written in embedded C which an extension of the C high level programming language.

Data is transmitted to the Thingspeak cloud server for analysis and visualisation through a system-on-chip WiFi module. The system monitors well air pollutant concentrations in the environment.

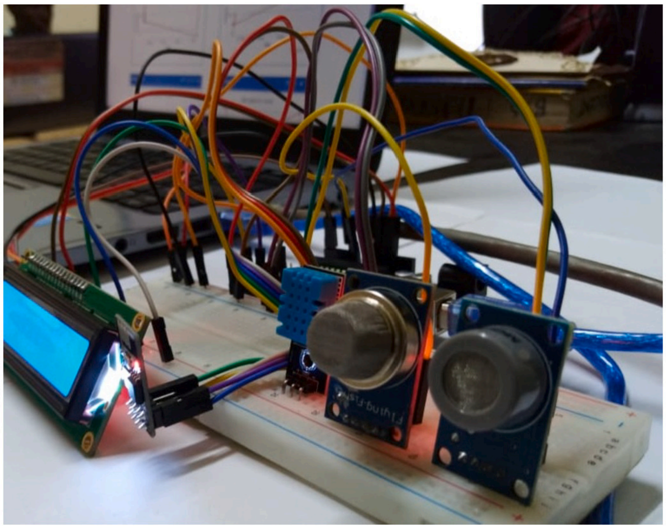


Fig. 5. Air Quality Monitoring Setup.

2.1.1. Sensor-based air quality monitoring unit

In this study, a range of pollution gases monitored include CO_2, CO and $PM_{2.5}$. The sensors used to implement air quality monitoring unit include; MQ135 for CO_2, MQ7 for CO, $PM_{2.5}$ sensor for $PM_{2.5}$ and DHT11 composite sensor for both temperature and humidity.

Basing on air pollutant concentrations, AQI value is calculated based on the formula in (1) and displayed on the ThingSpeak dashboard in real-time basis. Using such information, people having respiratory issues and other lung related health challenges can make decision and avoid places that are highly polluted and also the policy makers can advise accordingly on how to keep air pollution under control.

DHT11 sensor used in this study, is an ultra low cost digital temperature and humidity sensor, it has in an in-built chip that converts analog signals to digital. Therefore, it gives out temperature and humidity values that are in digital format which are compatible with the micro controller used in this study. This is demonstrated in Fig. 5 of our prototype. Also in the prototype we have included the buzzer for the sound alarms, so that when the measured AQI value becomes higher and exceeds the set threshold. For instance, if the levels of AQI exceed the EPA given limits allowed for human lives, then goes on the alarms to alert the end-users so in this case the public can take the appropriate decisions from the informed point. Furthermore, a replica of lungs was designed using HEPA filters.

2.1.2. Processing

A microcontroller unit (MCU) based on ATmega328P and AVR RISC processing power that can execute heavy instructions in single clock cycle is used. With this functionality, processing speed is highly offered.

Table 2. Shows the key properties of the MCU used in this work. It consists of 6 analog input pins from A0 to A5 and 14 digital input/output pins out of which 6 provides PWM output. The micro-controller is connected to the PC through the USB port and when connected it appears on the PC as virtual com port, in this prototype, all the data from the sensors is sent to and from Arduino board using the serial monitor. Therefore, in this study, MCU is the heart of processing in our prototype.

2.1.3. ThingSpeak IoT platform

ThingSpeak is web-based IoT platform. It is an open-source IoT application interface that is used to store and retrieve information from IoT-based devices. It uses the HTTP protocol over the cloud or via a Local Area Network to retrieve and store. ThingSpeak has the capability to provide API keys for different channels created so that the data exchanged through the cloud is secure. A channel in ThingSpeak updates every minute and is set as a continuous line graph. The graph is constructed as concentration against time (days).

Therefore, in this work, air pollutant data values from sensors is calibrated to create a conversion for the voltage readings obtained to standard AQI values. AQI values are captured in real-time with the help of ThingSpeak dashboard.

2.1.4. 3D lung display description

Furthermore, a 3D lung display in shape of human lungs is modelled using HEPA filters fabric to mimic the human lungs as shown in Fig. 6b. A fan is inserted at back of the lung to mimic the process of breathing. The fan increases the rate at which air enters and leaves the lungs. HEPA filters are equipped with high efficiency fabric air filters to capture the inflow of air pollutants from the atmosphere; when used, they operate as conventional air purifiers. They have been greatly used in designing and developing of air purifiers to perform the filtration. They are formed out of pleated papers in form of dense network of glass fibbers as shown in Fig. 6a.

Table 2
Arduino UNO microcontroller Properties.

Model	ATmega328P_ AVR family microcontroller
Input Voltage	6-20 V
Operating Voltage	5 V
Digital I/O Pins	14 (6 out of which Provide PWM output)
Analog Input Pins	6(A0-A5)
DC Current on 3.3 V Pins	50 mA
DC Current on I/O Pins	40 mA
Operating Voltage	5 V
SRAM	2 KB
Flash memory	32 KB
EEPROM	1KB
Frequency (Clock Speed)	16 MHz

(a) HEPA Filter Fabric

(b) 3D Lung Model fitted with HEPA fitted with HEPA Filter Material

Fig. 6. HEPA Filter Fabric and 3D Lung Model fitted with the HEPA Material.

As air is being filtered in the lungs, the colour change of the lungs of is observed over the period of time as the air concentration levels are noticed.

To test the HEPA filters across the pollution ranges, the air pollutant concentrations were intentionally increased systematically by burning of hydro carbons components such as polythene bags, plastic bottles and coal in order to emit soot, dust and gaseous emissions in a controlled environment where the 3D lung display model was also placed.

The 3D lung display is deployed away from the air quality monitoring unit based on the transmission range. For instance if D is the transmission range (distance) of the air from the air quality monitoring unit (x_i,y_i) location to the 3D lung display unit at location (x_j, y_j), then D in meters is determined in formula below

$$D = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

2.1.5. Algorithms for sensor data retrieval and 3D lung display colour changes

In Algorithm 1, the average data retrieval is implemented and displayed through a user-friendly ThingSpeak a web-based dashboard. The average measurement for each parameter, including the average air pollutants concentration, temperature, and humidity, is computed in lines (5)–(6). To capture the real time reading, the algorithm compares each measurement to the preceding reading and updates the dashboard accordingly in lines (8)–(11)

2.1.6. Algorithms observing the colour intensity change in the 3D lung display model designed

The algorithm described in Algorithm 2 is used for observing the change in colour intensity of the 3D lung display model over a specified observation time period.

Algorithm 1 Retrieval and Display of average Sensor Data.

Parameters Monitored: PM_1, PM_2, PM_3, PM_4,…, PM_N
Output: AvgPM_1, AvgPM_2, AvgPM_3, AvgPM_4, …, AvgPM_N
Initialization:
for j = 1 to N **do**
  Compute: AvgPM_1, AvgPM_2, AvgPM_3, AvgPM_4,…, AvgPM_N

$$AvgPM_1 = \frac{\sum_{j=1}^{N} PM_{1j}}{N}, \qquad AvgPM_2 = \frac{\sum_{j=1}^{N} PM_{2j}}{N},$$
$$AvgPM_3 = \frac{\sum_{j=1}^{N} PM_{3j}}{N}, \qquad AvgPM_4 = \frac{\sum_{j=1}^{N} PM_{4j}}{N},$$
$$\dots,$$
$$AvgPM_N = \frac{\sum_{j=1}^{N} PM_{Nj}}{N}.$$

  Sensor Data Display:
  if $\left(AvgPM_j = AvgPM_{j-1}\right)$ **then**
    Display $AvgPM_{j-1}$
  else if $\left(AvgPM_j \neq AvgPM_{j-1}\right)$ **then**
    Display $AvgPM_j$
  else
    Exit
  end if
  end if
  end for
  END
end for

The algorithm takes in four monitored parameters: the initial colour intensity of the 3D lung display represented by variable I_s, the current colour intensity I, the intensity colour change T_{ch}, and the observation time denoted by T. The algorithm outputs the extent of the colour intensity change, represented by variable ΔI.

The algorithm begins by setting a timer for the specified observation time period and initializing a time counter t to 0 and an intensity change flag Colour Intensity Changed to false from line (4) to (6). In line (7), the algorithm then enters a while loop that runs as long as the timer is running and the time counter is less than or equal to the observation time.

During each iteration of the loop, the algorithm takes regular readings of the 3D lung display colour intensity and stores it in I. It then calculates the absolute difference in colour intensity between the current reading and the initial reading, represented by $\Delta I = |I - I_s|$.

If the calculated ΔI is greater than or equal to the specified colour intensity of colour change T_{ch}, the algorithm sets the intensity change flag to true and records the extent of the colour intensity change by setting ΔI to $|I - I_s|$. The algorithm then increments the time counter by the time interval Δt and exits the loop early since the intensity has already changed. At the end, the algorithm sets the extent of the colour intensity change to zero if no intensity change is detected and returns the ΔI value as the output in different remaining lines of the algorithm.

Algorithm 2 Algorithm for Observing Colour Change Intensity of the 3D Lung display.

1: **Monitored parameters:** I_s, I, T_{ch}, T
2: **Output:** ΔI
3: *Initialization:*
4: Set a timer for the specified observation time period
5: $t \leftarrow 0$ ▷ Initialize time counter
6: $ColourIntensityChanged \leftarrow$ **false** ▷ Initialize intensity change flag
7: **while** (timer is running and $t \leq T$) **do**
8:   Take regular readings of the 3D lung display colour intensity and store it in I
9:   $\Delta I \leftarrow |I - I_s|$ ▷ Calculate absolute difference in the colour intensity
10:   **if** $\Delta I \geq T_{ch}$ **then**
11:     $ColourIntensityChanged \leftarrow$ **true** ▷ colour intensity has changed
12:     $\Delta I \leftarrow |I - I_s|$ ▷ Record the extent of the intensity colour change
13:     $t \leftarrow t + \Delta t$ ▷ Increment time counter
14:     $\Delta I \leftarrow 0$ if $ColourIntensityChanged$ is **false** ▷ If no colour intensity change is detected, set the extent to zero
15:   **end if**
16: **end while**

3. Results and discussion

In this study, the colour change of the modelled 3D lung display is monitored with the respective AQI values over period of six months.

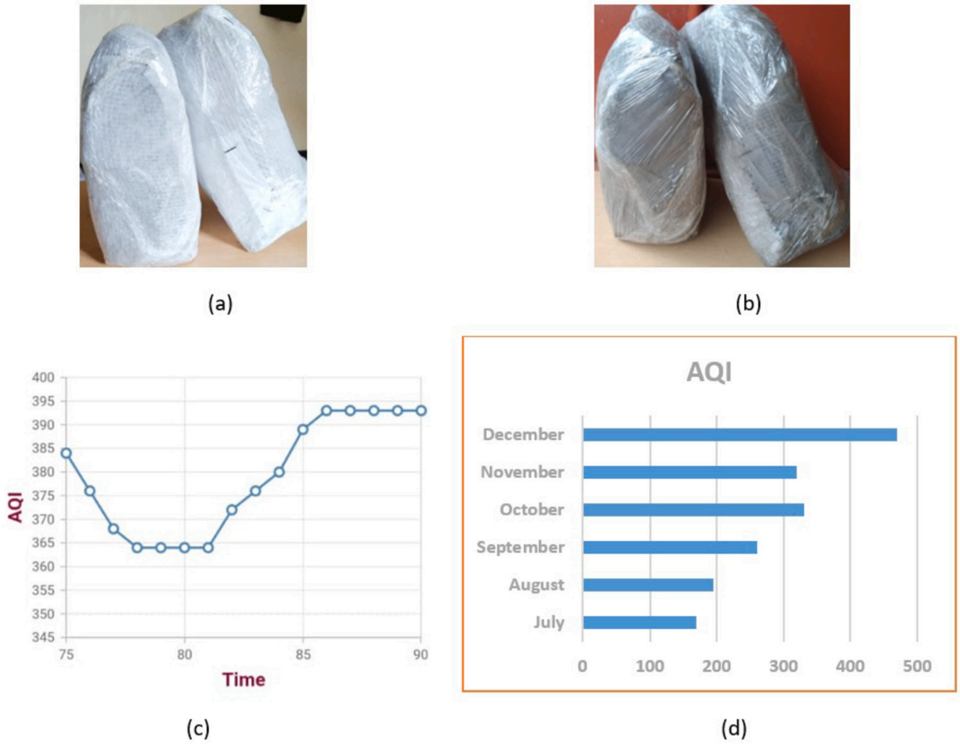


Fig. 7. Colour Intensity Change.

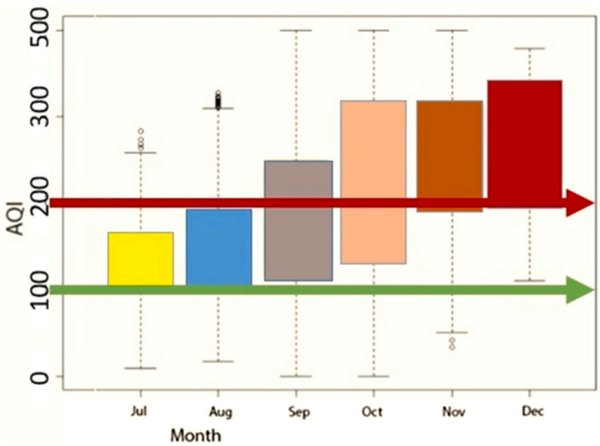


Fig. 8. AQI Monitored.

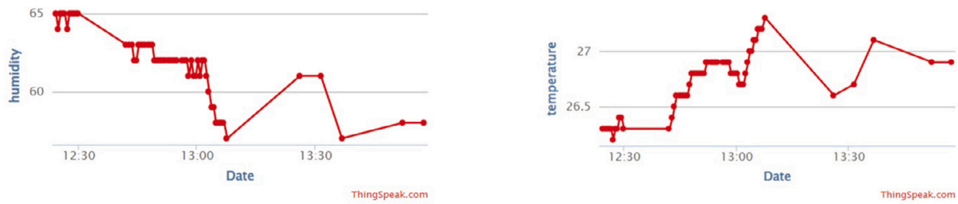
It was observed that the colour of the 3D lung display turned to dark over a period of time as the values air pollutant values were increased as indicated in Fig. 7

In Fig. 7 from (a) to (b) shows the colour of the modelled 3D lung display has turned to dark over period of time. It is well known that the colour of unhealthy lung keeps changing until its dark. In this work it observed that using HEPA air filters, it's possible to visualise the effect of dirt air on the lungs, as the HEPA air filter material filter the air as it enters the 3D lung display.

Also in Fig. 7 from (c) to (d) shows the data graphic visualisation data captured from the cloud-based server Thingspeak. Using ThingSpeak cloud services, the average AQI values are captured and graphs based on the values of each parameter evaluated.

In the Fig. 8, AQI values for different months are captured as indicators of air pollution status. The values that are below the green line show from 0-100 show that the AQI moderate therefore the quality of air healthy, however numbers between 100-200 indicate that the AQI numbers are unhealthy for the sensitive groups whereas those numbers above 200 indicate very poor quality of air.

It is also very crucial to monitor the saturation of humidity and temperature. Fig. 9a and 9b demonstrates the average humidity and temperature in saturation along with air pollutant concentrations visualised through an intuitive web-based dashboard



(a) Average Humidity (b) Average Temperature

Fig. 9. Average Humidity and Average Temperature.

Thingspeak and also its impact is visualised through the modelled 3D lung display by observing the colour change after a period of time.

4. Conclusion

The use of HEPA filters to filter the air has been proven to be an effective way to reduce the harmful effects of air pollution on human health, particularly on the lungs. By integrating IoT-based technologies with HEPA filters, it is possible to monitor the air quality in real-time, and visualize the impact of air pollution on the lungs using different visualizations and data analytics tools.

With the rise of air pollution, the development of IoT-based air quality monitoring systems has become crucial for providing real-time data. Therefore, this work clearly shows how IoT-based technologies fused with HEPA filters can visually illustrate the effect of air pollution on the lungs and in turn this can help the concerned parties take appropriate actions to protect their health.

The future recommendations of this work include performing a comparative analysis of air cleaning technologies, that is to compare the effectiveness of HEPA filters with other air cleaning technologies, such as electrostatic precipitators, activated carbon filters and photo-catalytic filters, in terms of their ability to remove air pollutant concentrations and their ability to improve the quality of air. This can later help in identifying the most efficient and cost-effective solutions for air purification.

CRediT authorship contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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