

SMART AIR QUALITY MONITORING AND PURIFICATION SYSTEM

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Abstract

The quality of the air indoors (IAQ) can have a profound impact on the health of human occupants, their comfort, and their overall wellbeing, especially when people are inside for most of their daily activities, like in a hospital, office, school, or a residential building. Low air quality has been associated with many health effects including Respiratory issues, Allergies, Fatigue and Chronic health effects. However, the traditional technology of air quality control is passive, and can't offer real-time monitoring and intelligent control. This is a study focused on the design and development of a smart IAQ monitoring and purification system which can be used for real-time assessment and response. Particulate matter sensor can detect particulate matter PM1.0, PM2.5 and PM10, which are harmful substances to health as they can enter into the respiratory system. The information obtained from the sensors is sent to a preprogrammed unit with a microcontroller in it, which also performs the analysis and evaluation of the air quality when compared to preprogrammed safety levels. To make optimal use of the air purification function, the system automatically activates various components such as the HEPA filters, ventilation blowers and the UV sterilization units when the pollutant level exceeds the safe range, then integrates the system with a mobile robot, allowing the system to respond quickly, reduce manpower, and enhance the effectiveness of maintaining the indoor air environment. Through the proposed system, a reliable and intelligent solution is proposed to improve the indoor air quality in sensitive and daily places.

1. INTRODUCTION AND BACKGROUND

Indoor air quality (IAQ) is a critical aspect of patient safety, infection prevention and healthcare effectiveness. When you think about hospitals airborne contaminants, such as particulate matter (PM), microbes and chemical vapors might not be the first thing that comes to mind but they are not

left out. These pollutants can cause a significant effect to hospital acquired infections (HAIs) in high-risk environments such as intensive care units (ICUs), operating theatres (OTs), surgical and neonatal wards where patients are exposed to a vulnerable situation. It can be a medical and engineering problem and it's a poor IAQ [1]. The small particles can penetrate deeply into the lungs

and into the bloodstream and lead to inflammation, oxidative stress and long-term health problems [2]. Higher concentrations of pollutants are correlated with increase in infection rate and hospital stay. Poor ventilation, poor infrastructure, overcrowding and lack of correct maintenance of the AC system can also cause dust, fungal spawns and VOCs to build up which makes it even more complicated in developing countries. To tackle these issues, smart and automated air quality management systems have been introduced little by little. Using a monitoring system based on the Internet of Things (IoT) along with sensors and microcontrollers, air pollutants and environment status can be monitored continuously in real-time [3]. These systems can be automatically activated purification systems, such as High-Efficiency Particulate Air (HEPA) filters,

Ultraviolet (UV-C) sterilization, and controlled airflow systems. The HEPA filters will have as high as 99.97% efficiency in removing airborne particles and the UV-C radiation will disrupt the gene of microorganisms [4]. Moreover, outside the hospital in polluted region like Pakistan the air is contaminated and would also enter into the hospital building, therefore, if the air purification system is to be used then it is essential to have polluted air outside the hospital, which would also be brought into the hospital premises. Monitoring and purification solutions go hand-in-hand to provide smart and cost-effective solutions that enhance patient recovery success and the working environment for health care staff. Thus, best IAQ is not a choice, it's a must in this health care system.

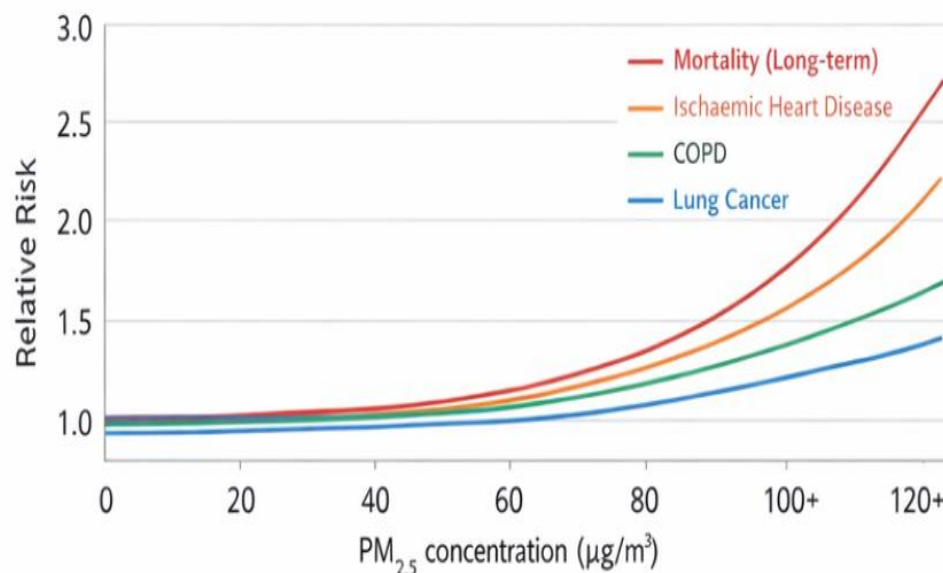


Figure 1: PM_{2.5} Concentration with the Relative Risk [5]

Moreover, in polluted areas like Pakistan air outside the hospital is polluted and would also be introduced inside the hospital premises, therefore, for using the purification system it is essential that area of the hospital is also polluted. Monitoring and purification solutions go hand-in-hand to provide smart and cost-effective solutions that enhance patient recovery success and the working environment for health care staff. Thus, the best

possible IAQ is not a luxury, but a requirement, in today's health care system.

2. LITERATURE REVIEW

Patient safety and infection prevention is of paramount importance in the health care setting and the issue of IAQ has become a major concern. The World Health Organization (WHO) highlighted the role of particulate matter (PM_{2.5} and PM₁₀) in respiratory and cardiovascular

diseases was the first one. Similarly, the Environmental Protection Agency (EPA) has set a national Air Quality Index (AQI) criteria that describes when air quality is bad because of its constituents and for individuals who may be vulnerable to them [6]. The principles stressed the importance of continuous monitoring and proper air purification in strategic areas, such as hospitals. The study of the link between air pollution and hospital-acquired infections (HAIs) says that higher levels of PM in hospital wards leads to poorer recovery time and a high risk of infection as found in research [7]. At this time, due to new sensing technologies, low cost optical sensors like PMS sensors could be used for real time AQ monitoring. The developments at that time were the starting point of the use of embedded systems in environmental health monitoring. Internet of Things (IoT) solutions revolutionized the way in which indoor air quality management is performed [8]. The researchers proposed to use the smart monitoring systems to collect real-time data about the environment and pass this information on to the cloud, where it can be analysed. Such systems enhanced the responsiveness and enabled healthcare professionals to take proactive steps. The incorporation of the wireless communication module and the mobile application increased its ease of access and also the distance monitoring function. In [9], a new emphasis was on combining the system and investigations were proposed for integrating HEPA filtration with ultraviolet (UV-C) sterilization to form an automatic air purification system. The accuracy of the pollution measurements was checked by comparing the measurements recorded by the sensors [10]. When the pollutant concentration measured was equal to a certain pollutant threshold, the purification processes were turned on by the feedback control. The results of using these methods revealed highly significant reductions in the airborne particulate and microbial contamination, especially in closed hospital environments. Special attention was given to Adaptive control systems and Energy efficiency [11]. The advanced designs were given closed loop control systems to help optimize the efficiency of the purification systems, and to minimize power

consumption. Other factors were also noticed to play a significant role in the survival of pathogens in the air, such as temperature and humidity, and were investigated in detail, and more comprehensive systems developed for their monitoring. Intelligent and scalable solutions started to focus the research [12]. The potential of IoT, real-time analytics, mobile dashboard for continual monitoring and decision making were discussed. There was there also a need for a system to be low cost, and portable, to address the needs of low- and middle-income countries, where health resources may be limited. These systems were designed to achieve the optimal balance in performance, cost and deploy ability [13]. While there has been a tremendous amount of progress, it is important to ensure that the cost, efficiency and scalability are optimized [14]. Some of the better-quality air purification systems have more advanced features, but in some cases, it may not be practical to use those systems, or have the funds to afford those systems. However, the low-cost solutions may not provide a true-time monitoring and intelligent control. Current research is therefore to do with hybrid systems and modular systems, which are not only cost-effective, but also smart [15]. On a broader scale it is a public health issue, IAQ is also an engineering issue. To minimize airborne infections and ensure patient safety, continuous monitoring, auto-purification and intelligent control systems is a promising solution. Sustainable and energy efficient solutions will have to be available in various settings in the future to address health equity.

3. RESEARCH METHODOLOGY

The proposed Smart air quality monitoring and purification system is based on a microcontroller (Arduino) as the central control unit and a sensor (PMS5003) which measures particulate matter (PM1.0, PM2.5 & PM10). The real-time is shown on an LCD and sent wirelessly by an HC-05 Bluetooth module to monitor it remotely in a mobile application. The system also includes a purification system comprising of a HEPA filter, UV-C sterilization unit and a fan-based airflow system to keep the indoor air clean. Figure 2

created and prepared by our team, shows the working methodology of the system. It is a closed loop control system, where the air quality sensor reading is continuously compared to the pre-determined air quality level throughout the process. At a higher level where the level of pollutants reaches the threshold value then a purification system is triggered. When the air

quality has gone back to the acceptable levels, the purification system is automatically switched off by the system. Furthermore, the ultrasonic sensors will enable the obstacles to be detected and the system can be operated as a travelling sensor unit, which will constantly monitor the environment, activate the purification system if need be and provide efficient self-governing air quality control.

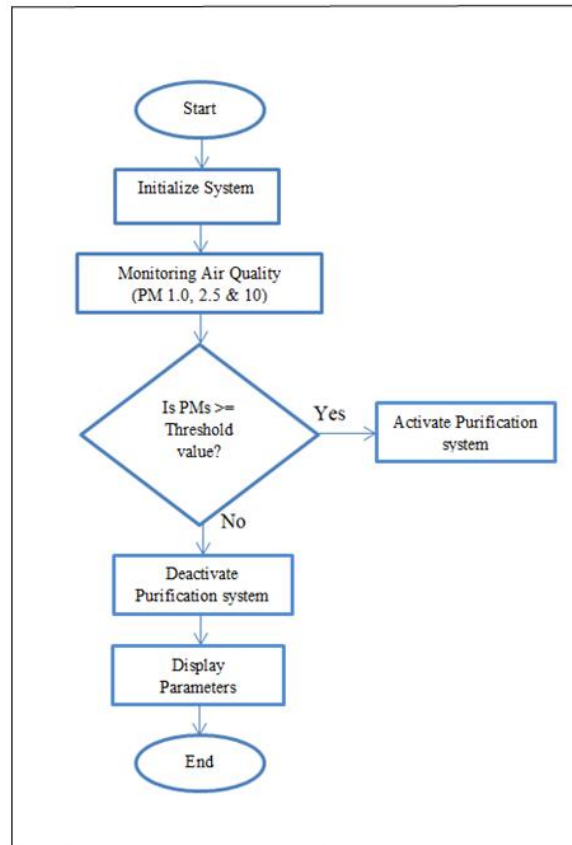


Figure 2: Flow Diagram of Smart Air Quality Monitoring and Purification System

4. RESULTS AND DISCUSSION

This section provides the evaluation of the proposed smart air quality monitoring and purification system based on the results of the experiment and analysis. The 3D design and

functional prototype of the developed system is provided in Figure 3 and demonstrates the structure of the system, such as the sensing unit, purification module, and mobility mechanism.

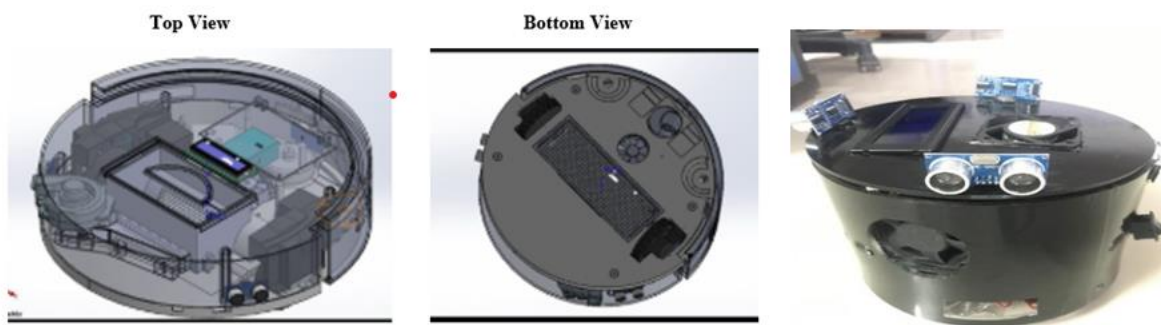


Figure 3: Smart air quality monitoring and purification: 3D Design and Functional Prototype

4.1. PM Concentration Analysis

The air quality was measured during the indoor condition to determine the baseline air quality unfiltered condition to evaluate the performance

of the system. A PMS sensor was used to measure the levels of particulate matter (PM1.0, PM2.5 and PM10).

Table 1: Baseline PM Concentration (Without Purification System)

Parameter	Concentration ($\mu\text{g}/\text{m}^3$)	Purification Status
PM 1.0	65	OFF
PM 2.5	105	OFF
PM 10	111	OFF

These values which shown in Table 1 signify poor air quality or conditions that are usually enclosed or poorly ventilated and they can be dangerous.

When the purification system is activated, the particle reduction results were obtained in a very short time.

Table 2: PM Concentration (With Purification System)

Parameter	Concentration ($\mu\text{g}/\text{m}^3$)	Purification Status
PM 1.0	13	ON
PM 2.5	21	ON
PM 10	27	ON

The recorded decrease is a proof of efficiency of filtration and sterilization used in the system as shown in Table 2.

4.2. Graphical Analysis

The changes over time of particulate matter after the purification unit is turned on are displayed in Figure 4. The three curves are for the different types of particles:

Blue curve (PM1.0): Particles of fine grade. Great efficiency in removal is seen from the sharp decrease in the range from $65\mu\text{g}/\text{m}^3$ to approximately $13\mu\text{g}/\text{m}^3$.

Orange curve (PM2.5): Particles in the air that can be inhaled. The values are considerably lowered (about $105\mu\text{g}/\text{m}^3$ to about $21\mu\text{g}/\text{m}^3$) which reflects good performance of the filtration process. Green curve (PM10): Fine particles (coarse). The ability to monitor larger particulates is confirmed by a gradual decrease of the levels of almost $111\mu\text{g}/\text{m}^3$ to a range of about $27\mu\text{g}/\text{m}^3$.

All curves are steeply descending in the first few minutes, and then a plateau. This is an action that is rapid, clean and in the future provides oxygenation.

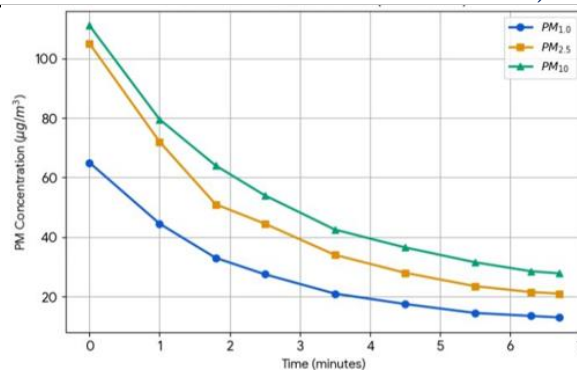


Figure 4: PM Concentration Vs Time (Purifier ON)

A comparison is made in Figure 5 to compare the amount of particulate matter before and after the system is operated. Both types of lines are used to depict each category:

PM_{1.0} (Blue): The line is dashed (initial conditions) and the solid one (after operation) indicating a clear decrease.

PM_{2.5} (Orange): There are higher initial values in the dashed curve, but much lower values in the solid curve after activation.

PM₁₀ (Green): The dotted line is the pre-operation levels and the solid line is lower concentrations after the operation.

The dotted lines are pre-treatment conditions and the solid lines are post-treatment results in Figure 5. The evident difference between these curves proves the good performance of the offered system in reducing the levels of particulate matter.

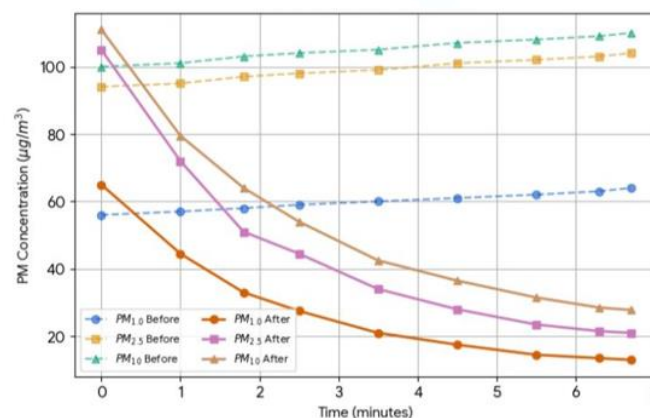


Figure 5: Before Vs after Purification

4.3. Display of PM's Concentration on Mobile Application

The designed mobile application created with the help of MIT App Inventor offers a convenient interface to monitor the parameters of the quality of the air inside successfully. The application interface, shown in Figure 5, shows the air quality conditions before filtration. The particulate matter contents of the readings indicate high levels of particulate matter with the recorded amounts of PM_{1.0}, PM_{2.5}, and PM₁₀ being much higher

than the acceptable level. I have the purifier position as OFF which means that there is no purifying process in this position. These values suggest the state of unhealthiness of the environment and the need to take corrective action, which is demonstrated in Fig. 6, when the purification mechanism is activated. A large reduction can be seen in the amounts of particulates in all categories. The purifier status is set to ON and this ensures that the system is operational. The improved readings reveal that the

purification process can be effective in improving IAQ.



Figure 6: Display of Air Quality Before and After Filtration on Mobile App

Connection status is also shown on the application that guarantees the mobile device and embedded system to communicate well. This is a useful function that allows users to check on the environmental conditions and system performance from afar without having to deal with the hardware itself. The mobile platform will generally improve the accessibility of the system, enable real-time decision making, and practicality of the proposed system in real-life scenarios.

5. CONCLUSION

This work provides an intelligent indoor air quality monitoring and purification system, which combines air quality monitoring, automatic air quality control and mobile application functions into a single. This is a proposed system for continuous monitoring of the concentration of particulate matter like PM1.0, PM2.5 and PM10, which enables the determination of the air quality at the time of its need. Data collected is used to automatically activate purification processes, and purifies the environment inside the system without continuous monitoring and intervention by people. It uses several technologies, such as HEPA filtering particles, UV-C sterilizing the microbes and regulating airflow as to improve the circulation and purification efficiency. The experimental evaluation confirmed effectiveness of the purification system, with a significant reduction in the level of PM after the system was

turned on. Furthermore, closed loop automation and real-time monitoring of the mobile applications allows for remote monitoring of both air quality and system performance. By significantly decreasing the need for manual operation, the proposed system increases the system's usability and operational efficiency, and is particularly suitable for use in healthcare areas such as hospitals, healthcare facilities, laboratories, offices and other indoor spaces, where clean air is essential for health and safety reasons.

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