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Construction and Performance Test of Automated Air Purifier Using Arduino UNO

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ABSTRACT
Indoor air pollution is a serious concern that negatively impacts the health conditions of the occupants ranging from minor to severe extents. In order to mitigate these health risks and at the same time boost productivity, air filtration systems are necessary. However, traditional systems are not energy efficient as they operate continuously, even at marginal concentrations of airborne pollutants within the buildings. These need to be manually turned on or off to stop filtration at marginal concentrations. This study is unique from the traditional systems as it addresses this issue by constructing a smart air filtration system that operates only when the air pollution levels exceed a certain threshold, as opposed to traditional systems that run continuously comprising of two fundamental units- a filtration unit and a control unit. Two sets of sensors were used for monitoring and comparing the air condition before and after filtration. Its performance was evaluated under varying concentrations of pollutants. The results indicate that it is a highly responsive system operating only when the pollutant concentrations are over a threshold AQI value of 74. The rest of the time it remains inactive thus serving as an energy-efficient apparatus by saving power consumption. The system achieved a maximum AQI reduction of 12.941%, rendering it as an efficient and sophisticated system for filtering indoor air and thus preventing health risks.

Keywords: Smart air purifier, Dust filter, HEPA filter.

1. Introduction

In today's world of rapid urbanization and industrialization, air pollution has become a severe hazard, that affects the environment and the health of all living beings [1]. Moreover, with the advancement of the global population, air quality continues to deteriorate. Over the past few decades, ambient air pollution has been alarming worldwide [2]. On the other hand, indoor air pollution poses adverse effects on human health even at low concentrations, due to prolonged exposure [3]. Humans spend around 86.9% of their time indoors according to The National Human Activity Pattern Survey (NHAPS) [4]. From minor issues like sneezing, itchy eyes and headaches to life-threatening diseases like asthma [5], respiratory infections, lung cancer, heart disease and chronic obstructive pulmonary disease (COPD), air pollution has a broad impact on human health [6, 2]. Children and the elderly are particularly vulnerable to these health hazards [7]. Indoor air pollution causes 3.2 million deaths annually, including over 237,000 deaths of children under the age of 5 according to the World Health Organization (WHO) [8]. Indoor air pollutants are a mixture of indoor contaminants including emissions from building materials, electronic and other household apparatus, activities of the occupants and outdoor air pollutants entering through ventilation systems or infiltration [9, 10]. Six major air pollutants are identified by the United States Environmental Protection Agency (US EPA): particulate matter (PM), ground-level O_3, NO_2, SO_2 & lead [11, 12]. A dedicated air purification system is therefore crucial to combat these air quality issues & mitigate health risks.

Numerous researchers across the globe have developed such air filtration systems and progress has continued to date. An air quality monitoring system was created by Pu'ad et al. [13] using a Raspberry Pi. The system incorporates two Arduino Nano boards, a Raspberry Pi 3, a GPS module, and three gas sensors. It measures the concentrations of $PM_{2.5}$, PM_{10}, along with four hazardous gases: SO_2, CO, NO_2, and ground-level ozone. The system's performance was tested in areas with both high and low traffic.

Panicker et al. [14] developed a system to monitor air quality with two main parts: a filtering unit and an air quality monitor. Based on dust sensor readings, the system automatically turns the purifier on or off. The purifier uses an MQ135 sensor to detect gases like NH_3, NO_x, alcohol, benzene, smoke, and CO_2. The prototype was tested successfully but has a limitation—the small sensors aren't effective for large filtration areas.

Sharma et al. [5] designed an air quality monitoring and filtration system that includes components such as an MQ2 sensor (to detect LPG, CO, and smoke), as well as temperature and humidity sensors. The filtration section features multiple filters, including a Net mat, HEPA filter, Activated carbon filter, Silica gel, and a UV lamp. Once the filtration unit is activated, the air in the designated area is purified.

Janeera [15] et al. constructed an air quality and sound pollution monitoring system that allows to monitor and check live air quality as well as sound pollution in an area through IOT. It allows to monitor both sound and air quality which can be a threat to the public health if exceeds normal limits. Sound, dust, gas, humidity and temperature sensors were used and connected via IoT while utilizing WiFi.

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Abdullah et al. [16] constructed an Arduino-based air quality monitoring system which measured TVOC (Total Volatile Organic Compounds) and CO2 in ppm unit. For this purpose, the sensor used was CCS811 which can also measure temperature along with TVOC and CO_2.

Al-Areeqi et al. [17] created a Long-Range Outdoor Air Quality Monitoring system using a LoRaWAN-based IoT framework. It measures pollutants like NO_2, SO_2, CO_2, CO, and PM2.5, sending data to cloud platforms such as TTN and ThingSpeak for real-time analysis. The system operates autonomously with an Arduino microcontroller and solar power. Validation against high-precision devices like Aeroqual confirmed its accuracy and reliability for large-scale environmental monitoring.

Rachmawati et al. [10] developed a smart air purifier along with the test chamber as a test room to analyze its performance in reducing $PM_{2.5}$ concentration. Performance analysis is observed by conducting $PM_{2.5}$ reduction rate test, Clean Air Delivery Rate (CADR) measurements, and power consumption test of the smart air purifier. In addition, performance comparisons with a commercial air purifier were also carried out. The findings of the $PM_{2.5}$ reduction rate test when compared to a commercial air purifier reveal that the smart air purifier and commercial air purifier had reduction times of 160 and 130 seconds, respectively. According to the results of the CADR measurement, the smart air purifier's CADR is 0.0676 m^3/min for a 0.064 m^3 room volume. When comparing the smart air purifier's and a commercial air purifier's $PM_{2.5}$ reduction rate, power sensors are added to monitor power consumption. According to the measurement results, the smart air purifier's power consumption during the $PM_{2.5}$ reduction rate test may reduce the electricity consumption of commercial air purifiers tested using the same approach by 67.42%.

Unlike traditional air purifiers that operate continuously, this system only activates the filtration unit when the air pollution levels exceed a preset threshold, as determined by the Air Quality Index (AQI). The system uses sensors to continuously monitor the incoming air quality and only turns on the fans and filters when the AQI exceeds 74, thus reducing significant power consumption. Although 74 is set as the threshold value considering the system to be suitable even for sensitive people, this threshold value is customizable according to the user requirement. This provides flexibility to adjust the sensitivity of the system based on the specific air quality requirements of the indoor environment. Furthermore, the system employs a multistage filtration process using a dust filter and HEPA filter to effectively remove particulate matter and odors from indoor air. The system provides real-time feedback on air quality before and after filtration, displaying the inlet and outlet AQI values on an LCD screen. This allows users to monitor the system performance and air quality improvements.

2. Methodology

2.1 Description of the setup

The proposed smart air purification system consists of two key units as shown in Fig.1 namely the filtering unit and the control unit. The filtering unit consists of two DC fans, a dust filter and a HEPA FILTER. Among the two DC fans, one is set after the input air quality sensor to pull the air into the filtering unit and perform air filtration process and the other is set before the output air quality sensor to pull the air from within the filtering unit into the atmosphere. Also, two sets of air quality sensors are used to assess the state of the entering contaminated air and the filtered air respectively. A display unit is provided to update the users on the air quality conditions in real time.

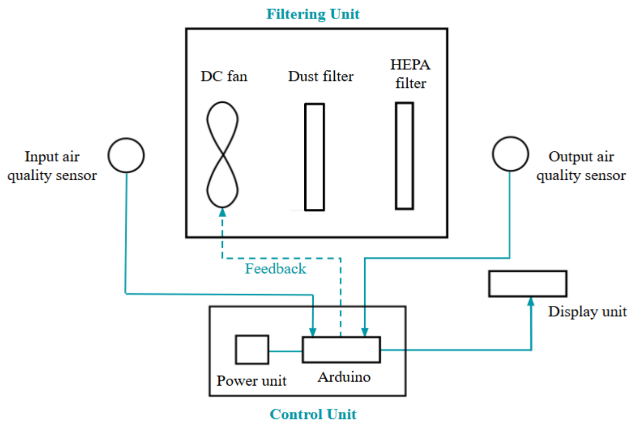


Fig.1 Block diagram of the smart air purification system.

The filtering unit has a DC fan to draw polluted air from the space into the system, followed by three distinct filters serving specific purposes. The impure air first passes through the dust filter which has the largest mesh and is capable of eliminating dust particles and particulate matter of the size 3 to 10 microns [18]. Next to the dust filter, there is a HEPA (High Efficiency Particulate Air) filter that can theoretically remove at least 99.97% of dust, pollen, mould, bacteria and any airborne particles with a size of 0.3 microns (µm) [5].

The control unit is responsible for rendering the apparatus as a smart system and thus distinguishing it from traditional devices. A microcontroller (Arduino) is used for data acquisition and interfacing of the sensors. The data collected by the first set of sensors monitoring the incoming air is used as a feedback signal to the DC fan. Whenever a preset threshold of air pollution is exceeded, the fan receives power and draws air into the system for filtration. The rest of the time the fan remains inactive, thus saving power consumption and enabling efficient operation. Environmental agencies use the Air Quality Index (AQI) to report air pollution levels. The AQI assigns a number between 0 and 500 [19]. The air quality decreases as the AQI rises. In the proposed system, the threshold value was set at 100.

After supplying power to the system, the MQ2 sensor at the inlet of the air purifier senses the gas concentration present in the air and displays it on the display board. If the gas concentration is more than 100, two 12 V DC fans turn on and thus the air purifier turns on. After the air is sucked into the air purifier through the fan at the inlet, the air passes through the dust filter and HEPA filter and again passes through a 12 V DC fan present at the outlet of the air purifier. The gas concentration of the purified air is also measured by another MQ 2 gas sensor at the outlet of the fan. This value is also shown in the display board.

Fig. 2 shows the developed system of the smart air purifier along with the Arduino connection and the lamp used to pollute the air in which the required data is to be taken.

2.2 Major Components

The major components used in the proposed air purification system and their specifications are listed in Table 1.

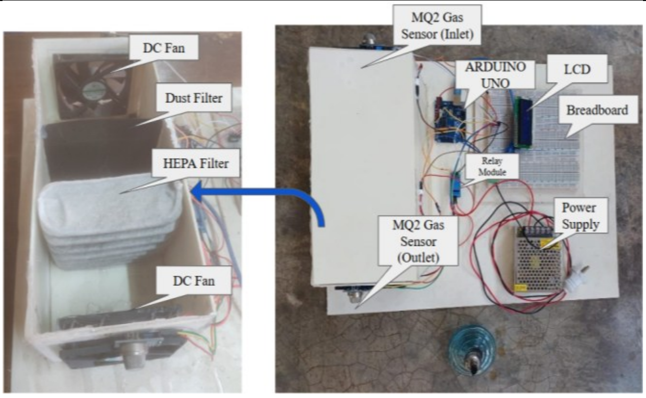
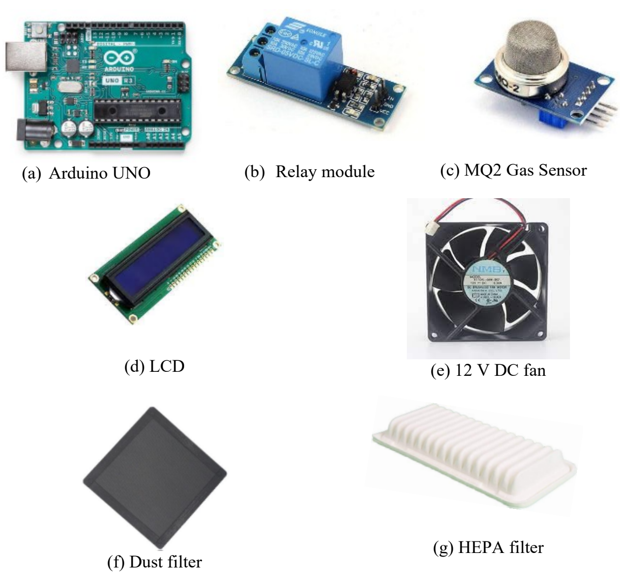


Fig. 2 The developed smart air purifier system

Table 1 List of components and their specifications used in the proposed system.

Component	Specification	Quantity
Arduino UNO	Operating Voltage: 5V	1 pcs
Relay Module	Input Voltage (recommended): 7-12V	1 pcs
MQ 2 Gas Sensor	5V	2 pcs
12 V Power Supply	5V	1 pcs
LCD	12V	1 pcs
DC Fan	5V	2 pcs
Dust Filter	5-inch x 5 inch, 12V	1 pcs
HEPA Filter	-	1 pcs
Breadboard	-	1 pcs
Connecting wires	-	As required
Arduino UNO	-	1 pcs



(a) Arduino UNO (b) Relay module (c) MQ2 Gas Sensor

(d) LCD (e) 12 V DC fan

(f) Dust filter (g) HEPA filter

Fig. 3 Major components used in the smart air purification system

ATmega328P microcontrollers are the foundation of the Arduino UNO. It has an ICSP (In-Circuit Serial Programming) header, a USB connector, 14 digital pins, six analog pin inputs, and a power jack. A relay is an automatic switch commonly used in automatic control circuits to control a high-current using a low-current signal. In the system in question, it was used to turn the air purifier fan on and off according to the given logic. The MQ2 gas sensor is an electronic sensor used for sensing the concentration of gases in the air such as LPG, propane, methane, hydrogen, alcohol, smoke and carbon monoxide. It can detect gases in the concentration range of 200 to 10000 ppm. An SMPS (Switched-Mode Power Supply) 12 V power supply is used to power the 12 V fans. The 16x2 LCD was used to display the inlet and outlet gas value and to show when the air purifier is turned on. A digital clock's seven-segment display, preset words, and numerals are examples of fixed graphics that can be shown or hidden on LCDs. The DC fan rotates its blades by converting electrical energy into electromagnetic energy via DC voltage and electromagnetic induction, mechanical energy, and ultimately kinetic energy. After initial purification by the dust filter, the activated carbon filter removes gaseous impurities and the HEPA filter performs the final stage of air purification by removing fine particles.

4. Results and discussion

Table 2 has been provided according to the data achieved from the proposed system. The air purification has been done by two different filters namely dust filter and HEPA filter.

Table 2 Data achieved by application of dust and HEPA filter.

Sl. No.	Inlet Gas concentration	Inlet Equivalent AQI	Outlet Gas concentration	Outlet Equivalent AQI	Fan condition
1.	130	63.5386	125	61.0948	OFF
2.	133	65.0048	129	63.0498	OFF
3.	130	63.5386	128	62.5610	OFF
4.	145	70.8699	142	69.4037	OFF
5.	144	70.3812	143	69.8924	OFF
6.	152	74.2913	149	72.8250	ON
7.	155	75.7575	150	73.3137	ON
8.	160	78.2013	155	75.7575	ON
9.	165	80.6451	152	74.2913	ON
10.	167	81.6226	153	74.7800	ON
11.	170	83.0889	148	72.3362	ON
12.	167	81.6226	147	71.8475	ON
13.	159	77.7126	144	70.3812	ON
14.	158	77.2238	145	70.8699	ON
15.	155	75.7575	144	70.3812	ON

From Figure 4 it can be seen that, when the AQI was below the threshold value (set at 74), the fan i.e., the purification system remained off. The inlet and outlet AQI levels were almost similar in this condition as no filtration process was carried out. As the AQI exceeded the threshold at the 6th observation, the filtration system turned on and a significant difference can be seen in the AQI levels of inlet and outlet which shows that the air purifier is functioning.

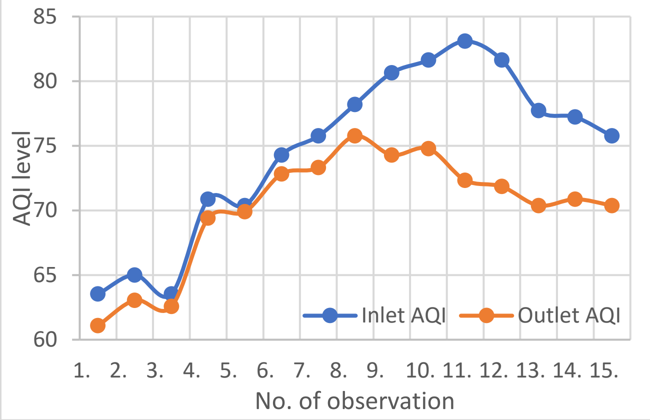


Fig. 4 Variation of outlet AQI with respect to inlet AQI

To be precise, the constructed smart air purifier achieves a maximum AQI reduction of 12.941%. According to the AQI chart, the range from 50-100 is considered to be the moderate AQI range. In this range, only sensitive people may have some health issues. Even in this range, the first half i.e. 50-74 can be considered relatively safer according to the AQI chart. For such reasonings, the threshold value was selected to be 74. Unlike traditional filtration systems, which operate continuously, this smart air filtration system stands out as it contributes to reducing power consumption as it works based on the feedback provided by the microcontroller, which receives data from the input air quality sensors and sends signals to the DC fan only when the AQI exceeds the preset threshold. This responsive mechanism makes this system much more reliable and convenient than traditional systems.

5. Conclusion

The construction and performance evaluation of a smart air purification system using Arduino UNO is presented in the paper. The key highlights of the system include:

- The system consists of a filtering unit with a dust filter and HEPA filter, and a control unit with an Arduino microcontroller.
- The system is provided a logic such that unless the AQI index reaches a value of 74, the system remains turned off i.e. the two DC fans remain turned off. This reduces the energy consumption if the system remained turned on even in lower AQI levels.
- The system achieved a maximum AQI reduction of 12.941%, which is promising but is relatively modest. The reduction of AQI could have been achieved even more if a few more filters could have been used namely activated carbon filter, an additional pre-filter, silica gel etc.

The authors conclude that it is undoubtedly a useful tool for maintaining healthy indoor conditions, as it operates only when required, saving power consumption and at the same time reducing health risks associated with indoor air pollution.

6. Recommendation

As it is an air-purifying mechanism, it is necessary for the filters to be replaced or cleaned on a regular basis. The dust filter can be cleaned on a monthly basis, and it is expected to function well. However, the HEPA filter should be replaced every 6-12 months.

If IoT is integrated into the system, real-time monitoring of indoor air quality in a certain room is possible, which allows for more advanced air quality control.

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