The Development of Smart Indoor Air Purifier with Real-time Monitoring System and Interchangeable Activated Carbon Filter

Aaron Ruy G. Musa[1], Mark Laurence R. Seplo[1], Josephine Q. Salillas[1], and Brian Jay R. Lumauag[1]

[1] College of Engineering, University of Negros Occidental-Recoletos, Incorporated, Bacolod City, Philippines

ABSTRACT

For many decades, Earth's environment has had a significant problem with air pollution, which offers a dangerous toxicological effect on human health. Globally, each year, air pollution is related to millions of deaths. Cardiovascular dysfunctions, respiratory infections, and cancer are the widely expected illnesses that will occur on air pollution's long-term effects. Millions of people die from household air pollution and ambient air pollution, and most of them live in Asia. This research's main objective is to design and fabricate a smart air purifier with a monitoring system to detect air pollutants such as Smoke and Particulate Matter found indoors using dust and gas sensors. The researchers will use an interchangeable Activated Carbon (AC) filter to reduce contaminants and impurities in the air. The study used a constructive research method that comprehends theory and a process for producing innovative constructions. It includes an Intake and Purified Sensor System; the Intake Sensor System detects unfiltered air pollutants. The Purified Sensor System detects the air passed through and adsorbed by the interchangeable Activated Carbon filter. Hence, indoor air purifiers' impact has eliminated the pollutants, namely smoke, Carbon Monoxide (CO), and Particulate Matters (PM2.5 & PM10), to produce 93.14% up to 99.98% cleanliness of the enclosed environment. This device's beneficiaries are children with asthma, hospital patients, house families, PWDs, and senior citizens sensitive to airborne diseases.

Keywords
air purifier, Monitoring system, Dust sensor, Gas sensor, Activated Carbon

INTRODUCTION

Most people think that air pollution only occurs outdoors, but the air inside our houses or buildings is also prone to air pollutants. Indoor air pollution indoors can be obtained through cigarette smoke, carbon monoxide, radon, asbestos, dust, and household products. At times, enclosed air is even more hazardous than the outside. The Environmental Protection Agency (EPA) studies show indoor air pollutants may be two to five times higher than outdoor air pollutants. They indicate a certain level because most people spend around 90% of their time inside their houses, offices, schools, and other buildings. Preventing indoor air pollution can have plenty of health benefits for us. Proper ventilation and air purifiers are the number one resolution to reduce and prevent air pollution inside our homes. Millions of people die from household air pollution and ambient air pollution, most of whom live in Asia.

This research's main objective is to design and fabricate a smart air purifier with a monitoring system to detect air pollutants such as Smoke and Particulate Matter found indoors using dust and gas sensors. The researchers will use an interchangeable activated carbon filter to help reduce contaminants and impurities in the air.

Specifically, the study will address the following:

Design and fabricate a device that can accurately detect different pollutants found in the air, such as Particulate Matter (PM_{10} & $PM_{2.5}$) using a PPD42NJ Dust Sensor and smoke, especially Carbon Monoxide (CO), using an MQ-2 Gas Sensor.

Design a device that can suck in the air using a built-in fan and an interchangeable filter system that adsorbs the pollutants using Activated Carbon.

Develop a Monitoring System that displays real-time air quality readings, including the time, date, and filter condition, in a TFT Liquid-Crystal Display (LCD) and real-time RGB LED indicators. The indicators signify air quality colors following the Air Quality Index (AQI): Green as Good, Yellow as Moderate, Orange as Unhealthy for Sensitive Groups, Red for Unhealthy, Purple for Very Unhealthy, and Maroon for Hazardous.

Test and evaluate the system's purification efficiency and ensure the database's information to be stored is accurate.

As air pollution increases every year and causes a life-threatening toxicological impact on an enclosed environment and human health, this research will be of great benefit to the following:

Environmental organizations and health departments. The device will provide them with the technical capability to help reduce air pollutants that contribute to indoor air pollution. The device features a real-time monitoring system showing how much pollutants are in the air. This will improve their service in the community, offering awareness ahead of time without being exposed through the database.

Hospitals and clinics. The device will help medical employees maintain aerial cleanliness inwards, emergency, operating, delivery rooms, ICU, pharmacies, etc. Not only will it provide clean air, but also help the patients heal quickly.

Residential families. Providing breathable air to our homes can reduce the risks of having lung diseases and respiratory problems. For family members with conditions such as chronic instructive pulmonary disease (COPD) and asthma who receive medical treatment that is more likely caused or triggered by exposure to intense indoor air pollution, having the device beside them will reduce the risks of more infections.

For students, faculty staff, and office employees, attending classes and working in offices with unsustained facilities can increase tardiness and affect their performances. Having to go to school or work with a breathable ambiance will result in excellent potential performance. Making sure the facility can provide such a device will ensure its surroundings.

The study can be developed for future innovators by extending the device's coverage. It detects more air pollutants and wider indoor cleaning circulation because the more effective the device will be, the more chances of reducing contribution to air pollution.

An article about the impact of air pollution on human health and the environment, such as global warming, the greenhouse gas effect, and ozone depletion, are the threatening global effects of air pollution (Lu, 2016). To human health, it poses a threat that provides concern to the community. Equally, it affects the ecosystem and the environment exceedingly. Given its impact on the ecosystem and the environment, it involves plants, leading to decreased crop yields. Pollutants such as Nitrogen

Dioxide (NO_2), Carbon Monoxide (CO), and Particulate Matters (PM_{10} & $PM_{2.5}$) can be found in houses indoors and, most importantly, in urban areas that will cause climate change. Appropriate ventilation should be considered when buying or constructing a house. Based on the Department of Labor and Employment standards, big industries must own a workplace environment monitoring (WEM).

A Brazilian researcher, Marilia Coutinho explained in her article that there is not much we can do about outdoor air pollution since the absolute amount of people exposed to air pollution increased as urbanization in the last 50 years rise (Coutinho, 2019). The author said an air purifier is a great name product as it directly speaks for itself, a major universal concern. Even children know that the air is not clean anymore, that there is pollution, and that it is unhealthy. The term «air purifier» is «a device that will clean the air and get rid of bad things in it,» which is what a person will think of in the first place. This explanation by the researcher verifies why air purifiers are needed. In simple terms, it is a device that eliminates pollutants from the air in an enclosed environment. According to Coutinho, one of the most important technological inventions in the 1950s was the HEPA filters' development (High-Efficiency Particulate Adsorbing). Since HEPA filters are costly, their main feature for adsorbing pollutants is the Activated Carbon, which can be used separately by fabricating a more affordable filter holder. Coutinho mentioned that these filters remove at least 99.97% of particles down to 0.3 micrometers.

According to the author Perry Santanachote, outside air can be two to five times more dirty than indoor air (Santanachote, 2019). If removing pollutant sources and ventilating with clean outdoor air methods is not enough, placing it indoors, like portable air purifiers, can reduce pollutants.

Air filters or purifiers throughout the days, weeks, or months of usage may also contribute to air pollution, such as waste management. Some researchers described that previous research about air filters being replaced prematurely before reaching full capacity of utilization weighs down to an increase in maintenance costs and causes more damage to the system than protection (Gandhe, 2017).

Household air cleaners are tools designed for people who do not desire to live in polluted indoor air but are rather exposed to breathable and healthy air. Standard air purifiers consist of a fan, sets of filters, and detection of pollutants such as Carbon Monoxide (CO) and Particulate Matter ($PM_{2.5}$ & PM_{10}) combined with a single piece of equipment (Ekaterina, 2011).

Based on the study of researcher Lowella Pineda Liong, a monitoring system was a method of testing the quality by recording the inputs, outputs, and results that aimed to enhance the resolution and analysis of strengths and weaknesses of educational and training programs (Liong, 2005). In the study th,e researcher Shirin Mazaheri explained that the Network Monitoring System played an important part in network security and control. Providing a secure network was the purpose of network monitoring via observation of the events through the network. The data acquired from the system was stored with the monitoring weather station system simultaneously with the air (Mazaheri, 2015).

Fine Particulate Matter or dust could be a safety risk to human health, critically to respiratory diseases. The research investigated the practicability of dust measurement using a valuable and useful dust sensor that would suit small and mobile devices (Budde et al., 2012).

Impaction was used for the sample air; the water droplets and dust images were captured using a USB microscope. The researcher developed a software algorithm to differentiate dust from the image background to find the dust particle diameter and mass. They did not use filters to keep the samples clean from coarse dust, and the results were accurate.

The goal was to detect and calculate the margin of errors linking the sensors and adjustable device and evaluate which type of application, COTS or commercial off-the-shelf dust sensor, can be used (Klar, 2016). These devices were designed to be ultra-tiny and light in weight, just like an ordinary particle that can remain suspended in the environment. A 5 mm cube was achievable. (Nerkar, 2016). When the temperature rises, the $PM_{2.5}$ also rises, while relative moisture and wind speed increase, $PM_{2.5}$ decreases. It statistically showed a positive connection with temperature and a negative connection with moisture and wind rate.

Chen's study concerned the safety and consistency of a power system directly disturbed through the operation conditions. To maintain the safety of the power transmission and avoid serious losses to the national economy, the power transformer must be monitored to make accurate response properties of the gas nano-SnO_2 towards H_2 and CO (Chen et al., 2012).

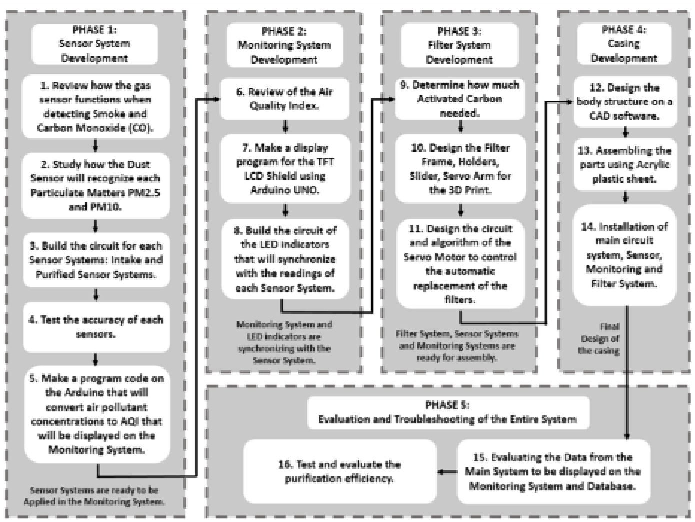
The gas sensor uses a small heater inside by way of an electrochemical sensor to vary sensitivity for a range of 20 to 2000pp. The sensor works when a Carbon Monoxide (CO) gas concentration is present in clean air. The sensor's conductivity becomes pooper, increasing through the rise and fall of the concentration of the gas (Śpiewak & Sałabun, 2015). As a result, it becomes essential to detect these pollutants' presence since our surroundings involve humans and living organisms as the main inhabitants. Hence, the uppermost priority is the safety of their lives (Yunusa et al., 2014). Gas sensors, especially the MQ-2 module, are some of the most useful sensors for applications such as domestic gas leakage and industrial combustible gas detectors, and they can also be used as portable gas detectors. MQ-2 can detect the presence of Carbon Monoxide (CO). As it detects these targeted gases, the sensor's conductivity becomes greater when there is an increase in gas concentration. If it detects clean air, its conductivity is lower. (Li, 2015).

In the fight against climate change, the elimination of Carbon Dioxide (CO_2) has become crucial for industrial production and the environment. Singh has selected adsorption on activated carbon as the practical solution for CO_2 separation since it is easy to use and inexpensive compared to other existing CO_2 separation methods (Singh & Kumar, 2014). Air cleaners with activated carbons can eliminate gaseous and dangerous pollutants (Fox, 1994). However, these activated carbons are of great expense because, as Professor Cimbala said, they should be replaced once used for a long period (Cimbala, 2019). Activated carbon is a matter created from coal, wood, and other materials containing high-carbon substances through heat without air. (Lizardo, 2007).

They concluded that using Activated Carbon in adsorption was likely a feasible technique for removing impurities from aquatic solutions (Tadda et al., 2016). As a result of contaminated water worldwide, millions of people die every 21 seconds, and 6000 Filipinos die early from water-borne diseases, as stated by the Department of Health. As one of the most effective purifying agents for domestic water treatment, Activated Carbon was used for adsorbing impurities that were found, such as drinking water, to avoid risks (Aranzo et al., 2017). Charcoal filters were most commonly used to eliminate pollutants that can be found in the air and water areas. They were also used in air conditioning and exhaust fans to remove impurities like smoke and gas. Charcoal filters comprised solid carbon, filling foam materials, powder, and fabric. Activated carbon is a charcoal that oxygen has preserved to expose millions of microscopic holes between carbon molecules. (Cimbala, 2019).

The purpose of this study is to maintain air quality control indoors. Life-threatening gases and particles such as Smoke, Carbon Monoxide (CO), and Particulate matter (PM_{10} & $PM_{2.5}$) are significant contributors to air pollution. Our main objective is to prevent these air pollutants from spreading around the area through adsorption using an Activated Carbon (AC) filter. This study includes a monitoring system, and RGB LED indicators. There have been a few research studies similar to this, such as the project of Daan Roosegaarde, the Smog Free Tower, which focuses only on filtering ultra-fine smog particles (Roosegaarde, 2018). In contrast, this research focused on filtering and monitoring several air impurities in real time. Compared to Roosegaarde's project, which can only be stationed statically, our research weighs enough to be carried by one person and is portable. contribution. This device's monitoring system can write, record, modify data, and collect and keep information to give accurate history readings to users. Based on the different Dust Sensor studies and the gas sensor detecting the other air components, the proponents focus on detecting smoke and carbon monoxide because the device would be used indoors. Based on the activated carbon filter research, solid carbon was made up, filling foam materials, powder, and fabric. Activated carbon is a charcoal that oxygen has preserved to expose millions of microscopic holes between carbon molecules. Proponents use This method to activate carbon to filter out the pollutants. By this additional research,

Figure 1
Conceptual Framework



Based on the different research from air purifiers, the Intellipure ultrafine 468 is a professional multistage air purification system that features proprietary DFS technology, which traps and eliminates potentially harmful ultrafine particles in your indoor air at 40x the efficiency of a HEPA filter. The proponents use this kind of method to improve the indoor air quality the proponents fabricate a device to purify the air and return it to the environment. The data from the air quality can be gathered through the readings from the Intake Sensor System and Purified Sensor System. As these data reach different levels where it can affect dangerous diseases to the people, the fans installed vacuums in the polluted air and blow out to breathable air.

As one of the most reliable devices that eliminate air pollutants, an air purifier is found indoors. Since the device is beneficial to those who suffer from allergies, asthma, and smoke, the researchers conducted many studies to monitor the air quality and minimize air pollutants. Being aware of the surroundings, such as information displayed in an understandable method. That is where the Air Quality Index (AQI) comes in. Most air purifiers only display standard concentration, but most users cannot interpret the readings. AQI provides levels for each air pollutant, showing when and what to act at current air quality. Like other air pollution elements, particulate matter, or what we call dust, can also be one of the dangerous health risks, particularly to respiratory and circulatory system illnesses.

In the study's Conceptual Framework, the researchers constructed a phase of step-by-step method that will assist in building the study. Phase 1 indicates the development of the sensor systems, specifications, and investigations will be listed in detail. Phase 2 will start developing a monitoring system and reviewing the Air Quality Index (AQI). Phase 3 will be for the filter system, including its automation. Phase 4 is the fabrication of the casing for the entire device. While Phase 5 is for evaluation and troubleshooting.

METHODOLOGY

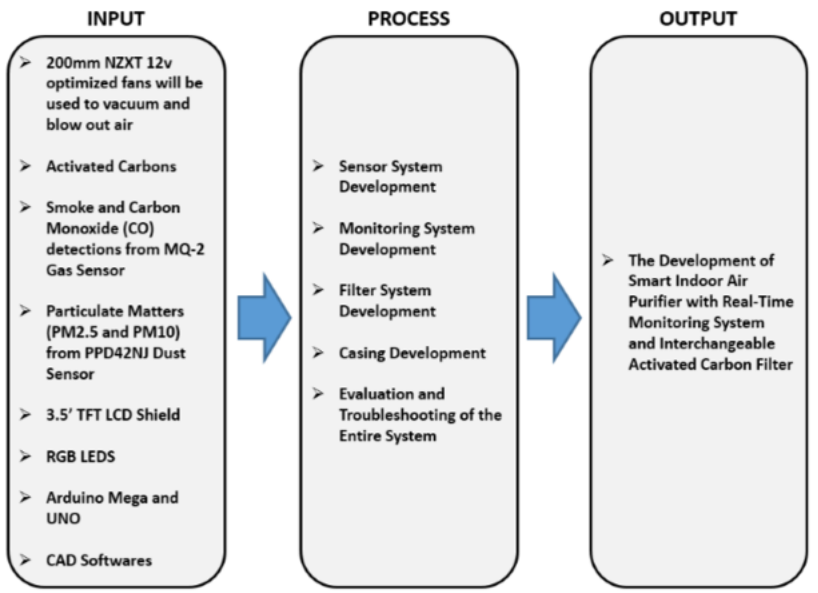
The researchers used constructive research, which comprehends the field of theory and a process for producing innovative constructions, aimed to find solutions for problems facing the real world and, by that means, to create a provision to the theory of the discipline in which it is applied. The primary notion of this method, the construction, is a synopsis concept involving a major, literally countless, number of potential realizations. Designs such as different models, diagrams, defining steps and structures, information system and circuit designs, and algorithm and data gathering tools are what develop constructions at their purest. The feature of constructive research is that these designs are invented and developed, not discovered. By developing a construction that contrasts profoundly from anything that existed before is created by meaning, constructions bring forth a new reality.

Algorithms and new arithmetical entities deliver theoretical samples of construction. In philosophy, constructive research can be applied in situations where the world is constructed, phase by phase, starting from given essential elements like objects, time-space segments, observations, logical dealings, and thoughts. In medication, constructive research is found in creating a new treatment (Kasanen et al, 1993).

Constructive research focuses on addressing real-world problems that are believed to have practical solutions. It involves creating innovative constructions designed to resolve these primary issues effectively. The research process includes implementing the developed construction to test its practical functionality. A key feature of this approach is the collaborative interaction between researchers and respondents, fostering empirical learning. Furthermore, constructive research is deeply rooted in existing theoretical knowledge and emphasizes integrating new findings into the original theoretical framework, ensuring a continuous cycle of reflection and improvement (Lukka, 2000).

The IPO Model shown in Figure 2 indicates the Smart Indoor Air Purifier process. Air is sucked in by the fan, which contains gases and dust, while being detected by the sensors will be the input. The Arduino converts the reading from the sensors while the filter with activated carbon adsorbs the impurities while these readings reflect the LED indicators. The output is displayed as the new LCD

Figure 2
IPO Model



readings that serve as the real-time monitoring system. The researchers estimated the purification percentage of the air by 93.14% to 99.98%.

The researchers reviewed, designed, and evaluated the prototype's entire structure and system for this section. After fabricating the prototype, they determined the percentage purification of the impurity readings. The researchers indicated collecting data and developing the different systems, each with a list of materials for the study.

In the first phase, the researchers developed the sensor system. The initial steps were to study the gas and dust sensors' function and how they can recognize Smoke, Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$ and PM_{10}), respectively. The researchers next designed two circuits in software and built them using universal PCBs for the intake and purified sensor system.

Lastly, they tested the sensors' accuracy and made a program code on the Arduino Mega to convert the readings to AQI values to be displayed on the Monitoring System.

The Intake Sensor System's schematic shows two power supply pins and three Arduino Mega pins. The MQ2 Gas Sensor used the Analog Pin, and the PPD42NJ Dust Sensor used the TX and RX pins for the Purified Sensor System, similar to the Intake Sensor System. Both systems are soldered on a universal PCB, each with different wiring.

Air Quality Index (AQI) is a guide for informing everyday air quality to help the public understand how polluted or clean the air is. It is used to convert standard units such as Parts Per Million (PPM) for Carbon Monoxide (CO) and Smoke while Microgram per Cubic Meter (μg/m^3) for Particulate Matters $PM_{2.5}$ and PM_{10}. AQI is categorized into value levels, health concern statements, conditions, and colors. Air Quality Index (AQI) is a guide for informing everyday air quality to help the public understand how polluted or clean the air is. It is used to convert standard units such as Parts Per Million (PPM) for Carbon Monoxide (CO) and Smoke while Microgram per Cubic Meter (μg/m^3) for Particulate Matters $PM_{2.5}$ and PM_{10}. AQI is categorized into value levels, health

Figure 3
Air Quality Index Indicators

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

concern statements, conditions, and colors.

Specific colors represent the Air Quality Index (AQI). Each color category includes numerical values that the public can easily understand the condition for each.

In the second phase, the researchers studied the Air Quality Index (AQI) and its public health risks. The TFT LCD shield and the Arduino UNO were used to display the results of the readings coming from the sensors. Lastly, in this phase, the researchers built a circuit for the RGB LEDs to show the color indicating the results.

The AQI scale for Carbon Monoxide (CO) is the same as Smoke, though their readings will be different since CO is 3% higher than Smoke. Their reading unit is Parts per million (PPM). As shown in Figure, the equivalent of PPM in AQI values; 0-4.5ppm between 0-50 AQI, 4.6-9.5ppm between 51-100 AQI, 9.6-12.5ppm between 101-150 AQI, 12.6-15.5ppm between 151-200 AQI, 15.6-30.5ppm between 201-300 AQI, 30.6-40.5ppm between 301-400 AQI and lastly 40.6-50.5ppm between 401-500 AQI.

As mentioned in the previous phase, Particulate

Figure 4
Display Layout

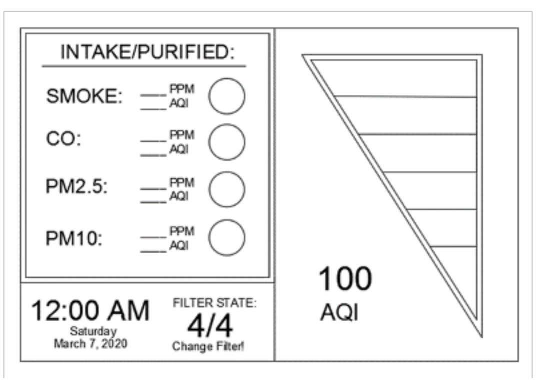
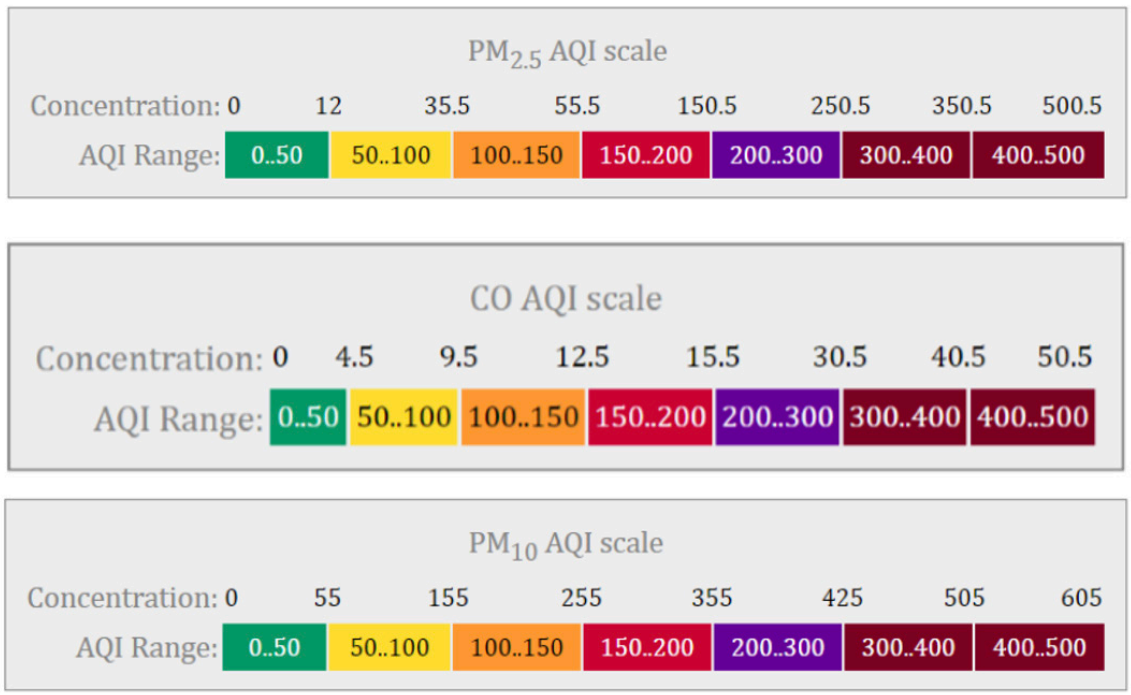


Figure 5
Air Quality Index Scale for $PM_{2.5}$, CO, and PM_{10}



Matter concentration is Microgram per Cubic Meter (µg/m3). Since PM_{10} are more extensive than $PM_{2.5}$, their scale of concentration exceeds more than 500 AQI.

The Monitoring System's display layout using a 3.5" TFT LCD Shield includes a real-time reading specifically; Smoke, CO, PM2.5, and PM10 each for Intake and Purified. Also had the date, time, day, filter state, and the overall purified AQI reading. The overall AQI reading in the monitoring system synchronizes the RGB Led indicators, each located in the Intake and Purified fans.

In the third phase, the filter system is built, where the air passes through and absorbs air pollutants using an Activated Carbon (AC) filter inside a filter holder attached to a filter frame. The entire filter frame is supported by an arm attached to the slider to replace the filters easily. In the arm, the Servo Motor is mounted. The researchers fabricated these filter parts through 3D Printing. They were then assembled and designed an algorithm to control the automation.

The researchers constructed an algorithm that automatically changes the filters after each is used. Since the Servo Motor is not stable and accurate, the researchers hooked up the motor inside. They connected the wires only on the positive and negative pins of the DC motor, then cut the IC's connection. Therefore, the servo motor operates the same as a normal DC motor. To control the automation, a 2-pin Limiter Switch is added to contact each point in the filter frame.

In the fourth phase, the researchers designed and assembled the body case of the entire device system. Fusion CAD software was used to design the casing. The researchers sketched the piece by piece dimensions of each part of the body to place the internal circuits and wires easily. When all the casing parts were ready, the researcher installed the main circuits and the systems.

The researchers used Acrylic plastic sheet as the casing material since Acrylic plastic is durable and lightweight, which is perfect for the device.

A thickness of 6mm acrylic plastic is recommended for the foundation and base of the structure to precisely hold the weight of the circuits and systems. After the design was cut to acrylic plastic sheets, the researchers assembled the parts.

The installed systems contain three: a Sensor system, a Monitoring System, and a Filter system. The system's main components are MQ-2 Gas and PPD42NS Dust sensors. An Arduino UNO, 3.5" TFT LCD module is used for the Monitoring system. The UNO is connected through serial communication. using the TX and RX pins to the Arduino MEGA placed in the main circuit.

RESULTS, DISCUSSION, AND IMPLICATIONS

In the last phase, the researchers evaluated the sensors' detection data and displayed it on the Monitoring System's TFT LCD. They also troubleshot the errors in the codes and the connection of wires and circuits. When all the data are evaluated, the air purifier's efficiency will be determined for final computations taken from the Intake and Purified Sensor Systems.

Since the researchers used an offline database through data logging using Microsoft Excel on a computer desktop, an SD Card module is the ideal hardware and a simple interface for the function. The data included to be stored in the Microsoft Excel file are the time, date, sensor readings, and filter state. First, the researchers will set the time and date of the RTC module and then prepare the SD Card module.

For the accuracy test, researchers calculated each data point from both sensors by absolute percentage error and subtracted it to 100% to get the accuracy. Then, they computed all CO and Smoke percentages for the MQ-2 Gas Sensor and PM2.5 and PM10 for the PPD42NJ Dust Sensor to get their average.

When substituting the data for each sensor, we already calculated the percentage if both data from Sensor 1 and Sensor 2 has a range of 1, given that Sensor 1 should be higher since it is the actual reading for it is the nearest to the CO/Smoke sample. The calculated value should be 17ppm minus 16ppm (highest data with a range of 1), then divided by 17. Following the rest of the formula, the accuracy is 94.12%. On the other hand, when Sensor 2 is higher than Sensor 1, the accuracy is 91.67%.

To determine the average accuracy of the gas and dust sensors, the researchers compared a pair of gas sensors, exposing both to Smoke and then to Carbon Monoxide (CO). Both sensors should be detected with the same readings. Both are not calibrated if a sensor is higher or lower than a similar sensor. The researcher used incense sticks to sample Smoke and Carbon Monoxide (CO) since they already contain both pollutants. The only difference is that CO is 3% larger than Smoke since it embodies it.

When calibrating the gas sensor, they should be exposed to clean air first, then adjust the potentiometer at the back of the MQ2 gas sensor. While adjusting the potentiometer clockwise to its most sensitive condition, a built-in LED indicator of the sensor should light up. In order to get the most accurate, the LED should be turned off and close to being able to light up. Turned off LED means the sensor is not detecting a pollutant; otherwise, it detects when it is on. To test if it is accurate, expose the sensor to a smoke sample and then unexposed.

The data gathered from the MQ-2 Gas Sensors in Table 1 shows ten Smoke and Carbon Monoxide (CO) results at the first sensor, the same as the second sensor. As expected, both gas sensors are equal, averaging 97.15% for Smoke and 96.57% for Carbon

Vol. 08, No. 1 (2021)

Table 1
MQ2 Gas Sensors Accuracy Test

MQ2 Gas Sensors Accuracy Test					
Sensor 1 readings		**Sensor 2 readings**		**Accuracy**	
CO	**Smoke**	**CO**	**Smoke**	**CO**	**Smoke**
25ppm	14ppm	25ppm	13ppm	100%	94.12%
17ppm	11ppm	16ppm	11ppm	94.12%	100%
14ppm	7ppm	15ppm	8ppm	94.12%	91.67%
13ppm	9ppm	13ppm	9ppm	100%	100%
12ppm	7ppm	13ppm	8ppm	91.67%	91.67%
10ppm	5ppm	10ppm	5ppm	100%	100%
8ppm	6ppm	7ppm	5ppm	94.12%	94.12%
5ppm	4ppm	5ppm	4ppm	100%	100%
3ppm	1ppm	4ppm	1ppm	91.67%	100%
1ppm	0ppm	1ppm	1ppm	100%	100%
			Average:	**96.57%**	**97.16%**

Monoxide (CO). Since this sensor operates from 200ppm to 10000ppm of concentration scope, it is easier to distinguish one gas from another if it detects from that scope for the load resistance of 20K Ohm to function, or the sensor's heating system will fail. The sensor itself will malfunction or be damaged.

The same was done with the dust sensor, but the samples are in the testing venue. When not detecting present dust, the researchers covered the sensor, then the readings of the two dust sensors should be the same; on the $PM_{2.5}$, it is absolutely zero, but the PM_{10}'s standard reading is 0.20 because PM_{10} is always present in the air. After the researchers test the gas and dust sensors' accuracy, the readings are compared to a table and determine the percentage of each.

After calculating the dust sensor's accuracy, the researchers have concluded that in their observations, the accuracy of $PM_{2.5}$ is lesser than PM_{10}. The comparison makes sense because Particulate Matters with much smaller than PM_{10} are harder to detect.

According to the ten results gathered in Table 2, there are quite big differences in accuracy, especially for Particulate Matters PM2.5, which averaged 80.34%, while PM10 has 92.06%. To explain this phenomenon, the smaller the dust, likely it is to get both PPD42NJ Dust Sensors to detect the same values even when they are at 2inches away from each other. The main causes of the big gaps in the two readings are wind disturbance, sudden changes in humidity, and temperature. Since the test happened in a closed room and dust is static, it cannot be ignored that even an inch of movement will change the particle's current and direction. Regardless of their accuracy, the PPD42NJ Dust Sensor is ideal for the study because it operates as a low-cost, portable, user-

Table 2
PPD42NJ Dust Sensor Accuracy Test

PPD42NJ Dust Sensors Accuracy Test					
Sensor 1 readings		Sensor 2 readings		Accuracy	
PM2.5	PM10	PM2.5	PM10	PM2.5	PM10
165.06 μg/m³	86.77 μg/m³	160.14 μg/m³	82.24 μg/m³	97.02%	94.78%
89.56 μg/m³	25.07 μg/m³	70.49 μg/m³	20.39 μg/m³	78.71%	81.33%
14.97 μg/m³	1.40 μg/m³	8.25 μg/m³	1.02 μg/m³	55.11%	72.86%
4.17 μg/m³	5.02 μg/m³	2.50 μg/m³	4.41 μg/m³	59.95%	87.85%
1.00 μg/m³	0.20 μg/m³	0.00 μg/m³	0.20 μg/m³	94.12%	100%
0.94 μg/m³	1.54 μg/m³	0.80 μg/m³	1.37 μg/m³	85.11%	88.96%
0.03 μg/m³	9.10 μg/m³	0.01 μg/m³	8.63 μg/m³	33.33%	94.84%
0.00 μg/m³	0.20 μg/m³	0.00 μg/m³	0.20 μg/m³	100%	100%
0.00 μg/m³	0.20 μg/m³	0.00 μg/m³	0.20 μg/m³	100%	100%
0.00 μg/m³	0.20 μg/m³	0.00 μg/m³	0.20 μg/m³	100%	100%
			Average:	**80.34%**	**92.06%**

friendly, sustainable, and real-time particulate sensor

To calculate the air purifier's purification percentage, the results taken from the Intake Sensor System and Purified Sensor System in Tables 1 and 2 are listed for final testing.

The researchers then recorded and gathered the results using testing tools. The purification percentage test showed that the Purified Sensor System detects an average of 93.14% purification. However, from trials 5 to 6, as the researchers tried to turn off the blowing fan for 6 seconds, the detected air pollutants stayed inside the casing because they were not released. Therefore, the researchers concluded that purification through a combination of Activated Carbon filers is efficient and capable of reducing indoor air pollutants.

There are instances when these filters are half-full, but the air cannot pass through the layers, which adds concerns to the Purified Sensor System's not reading. Despite not being able to pass through the filters, this can be considered a positive outcome because there are no excess pollutants that will pass through at all to be concerned about.

Moreover, the device could purify up to 99.98% or even 100% since the fans from the Intake to the Purified Sensor Systems already prevent the pollutants from dispersing. So, when the contaminants reach the Purified Sensor System with or without the Activated Carbon filters, most are already cleansed.

This is why air purifiers are more practical and efficient than essential oil diffusers and humidifiers. In terms of efficiency, air purifiers are the exact opposite of diffusers and humidifiers. Air purifiers seal the pollutants inside, disabling them from circulating in an enclosed environment. Diffusers and humidifiers don't contain any filter system, so there are probably scenarios in which they add even more particles to the air.

Humidifiers work best in air-conditioned rooms with dry air since they pour moisture into the air. The disadvantage is the moisture itself, as it needs water to operate, and this water may contain particles and bacteria when produced in the air. Another disadvantage of humidifiers is the risk of growing molds from the moisture, especially when placed near penetrable surfaces and walls.

Essential oil diffusers function similarly to humidifiers since they both pour moisture into the air. The difference is that diffusers are mainly used to scent the air using essential oils instead of water, which will not meet the study's objective of eliminating smoke, where humidifiers work least. On the latter, diffusers do not even provide better results than humidifiers.

Hence, air purifiers theoretically and practically exceed humidifiers and diffusers regarding sustainability and results. Humidifiers can produce more particles, and while diffusers apparently will not work against smoke, air purifiers can counter most of their disadvantages.

Air purifiers function best when they are more extensive because different factors should be considered regarding capacity. These factors include the size of the space involved and the size of the fans and filters. Evaluating these factors will add to the air purifier's features, especially the enclosed environment's scope of ventilation. Increasing the filters' size will also achieve much less energy for the filter automation to change and more time to add to the filter's lifespan.

Considering the efficiency result recorded from the air purifier, precisely 99.98% expected result and 93.14% observed result, the researchers recommend that people should still prevent dust and smoke from entering their home in the first place because they will not work to maintain indoor air alone. However, air purifiers reasonably will not eliminate smoke and dust because dust particles can remain on soft surfaces such as bedding, carpets, window curtains, and furniture, even on hard surfaces such as walls and ceilings since these surfaces can attract pollutants out of the air purifier's scope.

CONCLUSION AND RECOMMENDATIONS

Therefore, the researchers concluded that The Development of Smart Indoor Air Purifier with a Real-Time Monitoring System and Interchangeable Activated Carbon Filter was developed as a smart air purifier that monitors and detects air pollutants such as Smoke, Carbon Monoxide (CO), and Particulate Matter ($PM_{2.5}$ and PM_{10}) found indoors using dust and gas sensors. The capability of the interchangeable Activated Carbon (AC) filter was used to help reduce contaminants and impurities in the air. The Intake Sensor System was used to detect unfiltered air pollutants. In contrast, the Purified Sensor System detects the air passed through and adsorbed by the interchangeable Activated Carbon filter. Hence, indoor air purifiers' impact has eliminated the pollutants, namely Smoke, Carbon Monoxide (CO), and Particulate Matters ($PM_{2.5}$ & PM_{10}), to produce 93.13% cleanliness of the enclosed environment. This device's beneficiaries are children with asthma, hospital patients, house families, PWDs, and senior citizens sensitive to airborne diseases.

The researchers recommend design improvements at every Prototype system for future studies. First, each Sensor System, the Intake and Purified, should have its microcontroller, specifically the Arduino Pro Mini, not fully occupy the Main System's microcontroller, Arduino Mega. Instead of wiring and using more pins to the Mega, an RF Transmitter and Receiver Modules can be replaced so the Arduino Mega can communicate to each Sensor System wirelessly. The researchers recommend the same design for the Monitoring System. Instead of a 3.5-inch TFT LCD

Module, a pair of 0.96-inch OLED screens can be used. As an alternative to the Arduino Uno in the Monitoring System, it can also be replaced by another Arduino Pro Mini to reduce the casing dimensions of the Monitoring System. A similar concept can be added using RF Transmitter and Receiver Modules as a substitute for Serial Communication to minimize delays and interruptions throughout the connection.

The researchers also recommend that the Monitoring System's database be focused online instead of offline, as this would produce more monitoring flexibility.

Additionally, the researchers recommend to replace the two RGB LEDs at each fan, using a pair of 5v NeoPixel Ring 16xWS2812 is highly recommended since it operates with only three pins so that its programming is minimal and uncomplicated.

Lastly, the researchers recommend to improve on the prototype's entire Power Supply. It is recommended that each System requires an improved design and stable source to maintain the device's continuous filtrating cycle without interrupting each other.

REFERENCES

Aranzo, A. L. E., Javier, J. J. P., Macoy, M. S., Lorca, V. S., & Secondes, M. F. N. (2017). A Plant Design for the Production of Activated Carbon from Terminalia catappa (Talisay) Fruit. *Virtutis Incunabula, 4*(1).

Budde, M., Busse, M., & Beigl, M. (2012, June 11-14). *Investigating the use of commodity dust sensors for the embedded measurement of particulate matter* [Conference presentation abstract]. 2012 Ninth International Conference on Networked Sensing (INSS), Antwerp, Belgium. https://doi.org/10.1109/INSS.2012.6240545

Chen, W., Zhou, Q., Wan, F., & Gao, T. (2012). Gas sensing properties and mechanism of Nano-SNO2-Based sensor for hydrogen and carbon monoxide. *Journal of Nanomaterials, 2012*(1). https://doi.org/10.1155/2012/612420

Cimbala, J. M. (2019). *Activated carbon filter*: *Filters Part 3 Miscellaneous*. Pennsylvania State University. https://www.me.psu.edu/cimbala/me433/Lesson_Notes/ME433_Lesson_14_D_Filters_Part_3_Miscellaneous.pdf

Coutinho, M. (2019, July 8). Do air purifiers really work? Research suggests they have benefits. *Tastylicious*. https://tastylicious.com/do-air-purifiers-work/

Ekaterina, E. (2011). *Air pollution and air cleaning equipment in buildings* [Unpublished undergraduate thesis]. Mikkelin University of Applied Sciences. https://www.theseus.fi/bitstream/handle/10024/30987/Thesis_Evdokimova_Ekaterina_11.pdf?sequence=1

Fox, R.W. (1994). Air cleaners: A review. *Journal of Allergy and Clinical Immunology, 94*(2), 413-416. https://doi.org/10.1053/ai.1994.v94.a56025.

Gandhe, K.D., Raut, V.B., & Sarode, B. (2017). Review on automatic air filter cleaning system. *Journal of Network Communications and Emerging Technologies (JNCET), 8*(3), 52-54. https://www.jncet.org/Manuscripts/Volume-7/Issue-3/Vol-7-issue-3-M-13.pdf

Kasanen, E., Lukka, K., & Siitonen, A. (1993). The constructive approach in management accounting research. *Journal of Management Accounting Research, 5*, 243-264. https://mycourses.aalto.fi/pluginfile.php/183797/mod_resource/content/1/Kasanen%20et%20al%201993.pdf

Klar, S. R. (2016). *Wireless dust sensor network for a feedlot dust abatement study* [Unpublished master's thesis]. University of Minnesota. https://conservancy.umn.edu/server/api/core/bitstreams/79189c41-8608-47fa-91bd-8016a3a4fc88/content

Li, J. (2015, September 22). *Grove - gas sensor (mq2) user manual.* Seeed Studio. https://docs.particle.io/assets/datasheets/electronsensorkit/MQ-2.pdf

Liong, P. L. (2005). *Proposed Monitoring System for Training of the Philippine National Housing Authority* [Unpublished master's thesis]. University of Twente, the Netherlands. http://essay.utwente.nl/55730/1/Scriptie_Liong.pdf

Lizardo, A. M. (2007). Activated carbon from various agricultural wastes and their efficacy for the removal of dyes and metal ions from aqueous solutions. *Technological Institute of the Philippines Research Journal, 4*(1). https://ejournals.ph/article.php?id=9168

Lu, J. L. D. (2016). Impact of climate change on human health. *Acta Medica Philippina, 50*(2), 91-98. https://doi.org/10.47895/amp.v50i2.862

Lukka, K. (2000). The key issues of applying the constructive approach to field research. *Management Expertise for the New Millennium*,113-128. https://www.researchgate.net/publication/281549256_The_key_issues_of_applying_the_constructive_approach_to_field_research

Mazaheri, S. (2015). *Network Monitoring System* [Unpublished master's thesis]. Eastern Mediterranean University. http://i-rep.emu.edu.tr:8080/jspui/bitstream/11129/1789/1/MazaheriShirin.pdf

Nerkar, M. H., & Kumar, N. (2016). Smart Dust. *International Journal of Advanced Research in Computer and Communication Engineering*, *5*, 685-691.

Roosegaarde, D. (2018, September 23). *The smog free project*. Kickstarter. https://www.kickstarter.com/projects/1777606920/the-smog-free-tower

Santanachote, P. (2019, October 25). *Air purifiers and the cost of clean air.* Yahoo News. https://www.yahoo.com/news/air-purifiers-cost-clean-air-210011895.html

Singh, V. K., & Kumar, E. A. (2014, May 7-8). *Studies on CO 2 adsorption by activated carbon* [Conference presentation abstract]. ICERE 2014: International Conference on Environment and Renewable Energy Conference, Paris, France. https://www.researchgate.net/publication/269845780_Studies_on_CO_2_Adsorption_by_Activated_Carbon

Śpiewak, A., & Sałabun, W. (2015). A mobile gas detector with an arduino microcontroller. *International Journal of Computer Technology and Applications, 6*(4), 636-641. https://www.researchgate.net/publication/281410457_A_Mobile_Gas_Detector_with_an_Arduino_Microcontroller

Tadda, M. A., Ahsan, A., Shitu, A., Elsergany, M., Arunkumar, T., Jose, B., Razzaque, M. A., & Norsyahariati, N. D. A. (2016). A review on activated carbon: process, application and prospects. *Journal of Advanced Civil Engineering Practice and Research, 2*(1), 7-13. https://www.researchgate.net/publication/318827940_A_review_on_activated_carbon_process_application_and_prospects

Yunusa, Z., Hamidon, M. N., Kaiser, A., & Awang, Z. (2014). Gas sensors: a review. *Sensors & Transducer, 168*(4), 61-75. https://www.researchgate.net/publication/285988329_Gas_Sensors_A_Review