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Design and development of a PID-controlled home air quality monitoring and purification system

Josamae Salas, and Allain Jessel Macas*

Department of Electronics Engineering, University of Science and Technology of Southern Philippines, **Philippines**

*Corresponding Author: allain.macas@ustp.edu.ph

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Abstract: Asthma continues to be a major health concern in the Philippines, with about one in ten people living with the condition. Among its common triggers are fine airborne particles such as PM2.5 and PM10, which can easily aggravate symptoms and affect daily living. In response to this problem, we developed a home-based air quality management system, intended to help individuals with asthma by maintaining safer indoor conditions. The system was equipped with a Proportional-Integral-Derivative (PID) controller, which allowed the purifier to respond more intelligently by tracking air quality in real time and adjusting its operation before the condition became unsafe. To test this feature, a prototype was set up in a bedroom and small amount of smoke was introduced to simulate pollution. In both setups, one with PID control and one without, the purifier successfully reduced particle levels and brought the Air Quality Index (AQI) back to its baseline of 79–81. The key difference, however, was that the PID-controlled system reacted ahead of time, activating the purifier before the thresholds were crossed. This shortened the period of exposure to poor air quality and produced more stable results overall. These findings demonstrate that incorporating a PID controller can enhance the reliability and effectiveness of home-based air purifiers, providing practical support for individuals managing asthma at home.

Keywords: Air Quality Index; PIC Controller; PM2.5; PM10

1. Introduction

Asthma remains a pressing public health concern in the Philippines, affecting an estimated 11 million individuals, or roughly 12% of the population [1]. This chronic respiratory condition is marked by airway inflammation and hypersensitivity to environmental triggers, particularly airborne particulate matter (PM) such as PM2.5 and PM10 [2], [3]. Elevated concentrations of these pollutants can aggravate asthma symptoms, resulting in frequent hospitalizations, reduced productivity, and diminished quality of life [4]. The impact of poor air quality in the country extends beyond individual health, contributing to significant social and economic burdens [5]. Recent studies have highlighted the rising costs associated with respiratory diseases linked to air pollution, underscoring the urgent need for effective and affordable interventions [6]. Existing research on indoor air quality (IAQ) monitoring systems has shown encouraging results, providing valuable insights into how technological solutions can mitigate exposure risks [7], [8].

However, many of these systems are either limited to monitoring functions or lack adaptive mechanisms to regulate indoor environments dynamically [9], [10], [11], [12]. To address this gap, the present study focuses on the design and development of a home-based air quality management system tailored to the needs of asthma patients and other sensitive groups. Central to this system is the integration of a Proportional-Integral-Derivative (PID) controller, which enables predictive and proactive air purification [13], [14]. By continuously analyzing sensor data, the controller can activate the purifier in advance of threshold exceedances, thereby stabilizing indoor air quality and reducing exposure to harmful pollutants [15], [16], [17].

This research introduces an innovative approach by combining real-time monitoring with intelligent control, offering a user-friendly and efficient solution for households. Beyond improving health outcomes for asthmatic individuals, the system demonstrates the potential for scalable application in enhancing indoor environmental quality across a wider population.

2. Material and methods

This study employed a system prototyping approach with actual implementation to evaluate the effectiveness of a home-based indoor air quality monitoring and purification system. The system was designed to measure the concentration of airborne pollutants, particularly particulate matter (PM2.5 and PM10). To simulate indoor pollution, small amounts of paper were burned inside the test environment, and the resulting data were analysed to assess the system's performance in detecting and reducing pollutants. The study followed a descriptive and qualitative design, focusing on the capability of the prototype to maintain safe air quality levels and identifying factors that influence indoor air purification.

The experiment was conducted in a controlled bedroom environment in Libona, Bukidnon. The measured 3 meters in length and 2.2 meters in width, providing a compact but functional space for testing. A bed was positioned along one wall, serving as the reference point for arranging other elements of the setup. The prototype was placed adjacent to the bed to ensure easy access and effective interaction during trials. This layout was designed to replicate a realistic indoor setting while maintaining accuracy and consistency in data collection.

The experimental procedure followed a structured sequence as outlined in the system flowchart (Figure 1). Air samples were continuously collected and transmitted to the Proportional-Integral-Derivative (PID) controller for analysis. The controller evaluated pollutant levels, focusing on PM2.5 and PM10 concentrations, to determine whether the air quality remained within safe thresholds.

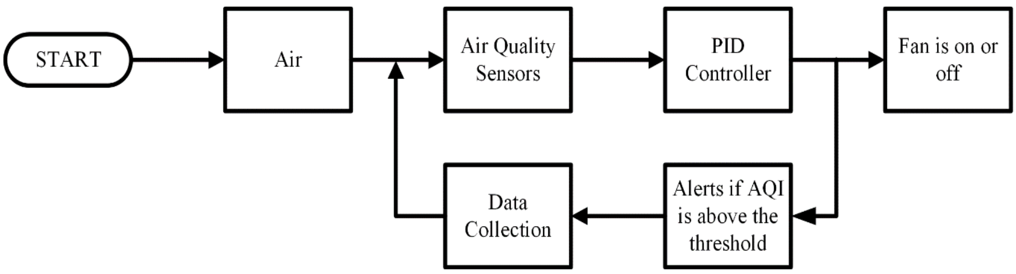

Figure 1. System flowchart

Threshold values were based on the Air Quality Index (AQI) guidelines, where an AQI of 0–50 is considered "Good," 51–100 "Moderate," and values above 100 potentially harmful to sensitive groups. Specifically, the PM2.5 threshold was set at 35 μg/m³ and the PM10 threshold at 155 μg/m³, in line with established international standards. These benchmarks provided the reference for determining when the air purifier should be activated, as summarized in Tables 1–3.

Table 1. General AQI categories

Category	AQI range
Good	0 – 50
Moderate	51 – 100
Unhealthy for sensitive groups	100 – 150
Very unhealthy	151 – 200
Acutely unhealthy	201 – 300
Hazardous	301 – 500

Table 2. AQI Breakpoints for PM2.5

Category	AQI Range
Good	0 – 25.0
Fair	25.1 – 35.0
Unhealthy for sensitive groups	35.1 – 45.0
Very unhealthy	45.1 – 55.0
Acutely unhealthy	55.1 – 90.0
Hazardous	Above 90.0

Table 3. AQI Breakpoints for PM10

Category	AQI Range
Good	0 – 54
Fair	54 – 154
Unhealthy for sensitive groups	155 – 254
Very unhealthy	255 – 354
Acutely unhealthy	355 – 424
Hazardous	425 – 504

When values were within the acceptable range, the fan remained inactive, and monitoring continued in a loop. If the controller predicted an increase in pollutant levels based on historical and real-time data, it activated the air purifier in advance, reducing the time spent above unsafe thresholds. This predictive control mechanism offered significant benefits by providing proactive rather than reactive air quality management.

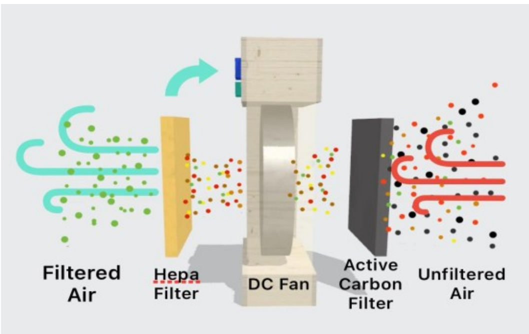

Figure 2. Purification Process of the System

The purification system employed a multi-stage filtration mechanism (Figure 2). Initially, unfiltered air passed through an activated carbon sponge, which adsorbed gaseous pollutants and odors. A DC fan then circulated the air through the device, directing it toward the final stage of purification. A High-Efficiency Particulate Air (HEPA) filter captured particles as small as 0.3 microns, including dust, pollen, pet dander, and some bacteria and viruses. This process ensured that the air exiting the purifier was substantially cleaner, providing a healthier indoor environment.

The prototype was designed with an integrated monitoring and purification system (Figures 3). The external hardware consisted of the purifier casing, fan, and filter components, while the internal system comprised sensors, an Arduino Uno microcontroller, and the PID algorithm. The combination of these components enabled real-time detection, proactive control, and continuous display of Air Quality Index (AQI), PM2.5, and PM10 readings.

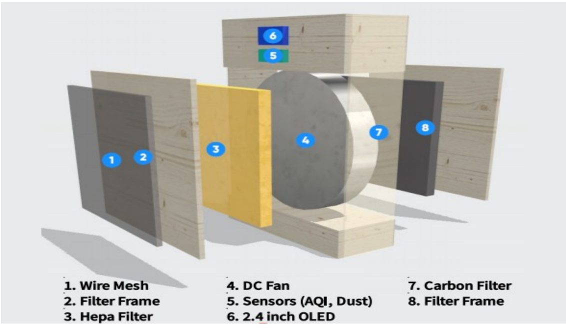

Figure 3. Prototype design

3. Results and discussion

3.1 Experimental setup

The prototype was first placed in an isolated bedroom environment to evaluate its functionality. Upon powering the device, a green LED indicated good air quality while a red LED signaled poor conditions, particularly relevant for sensitive groups. To simulate pollution, paper was burned inside the room to introduce particulate matter and observe the system's response (Figure 4).

Figure 4. Experimental setup

3.2 Real-time air quality monitoring

The first objective was to design and develop a system capable of providing real-time air quality measurements. Calibration was carried out using the MQ135 sensor for Air Quality Index (AQI) and the PMS5003 optical dust sensor for PM2.5 and PM10 detection. Thresholds were defined in accordance with international guidelines: AQI = 100, PM2.5 = 35 μg/m³, and PM10 = 155 μg/m³. These thresholds were coded into the Arduino Uno to allow automated comparison against real-time sensor data. Figure 5 illustrates the OLED display of AQI, PM2.5, and PM10 during calibration. The real-time display allowed users to immediately assess changes in air quality and respond accordingly. By aligning sensor calibration with established safety standards, the system demonstrated reliable detection of deviations and issued timely alerts when pollutant levels exceeded safe limits.

Figure 5. Calibration of the system

3.3 Purification capabilities

To address the second objective, purification capabilities were integrated into the system. This involved combining a High Efficiency Particulate Air (HEPA) filter and activated carbon sponge with a fan mechanism controlled by the Arduino Uno. The HEPA filter targeted fine particulate matter, while the carbon sponge adsorbed volatile organic compounds (VOCs) and odors. Initial tests confirmed that activation of the fan significantly reduced pollutant levels. AQI, PM2.5, and PM10 values dropped below threshold levels following purification. These findings validated the dual-filter design and demonstrated that the system could effectively mitigate a wide range of indoor air pollutants.

3.4 PID-controlled purification

The third objective involved incorporating a Proportional-Integral-Derivative (PID) controller to enable predictive purification. Baseline room conditions showed AQI values of 79–81, PM2.5 levels of 6–8 μg/m³, and PM10 levels of 7–9 μg/m³. After paper burning, pollutant concentrations rose sharply above thresholds, simulating an unhealthy air quality scenario.

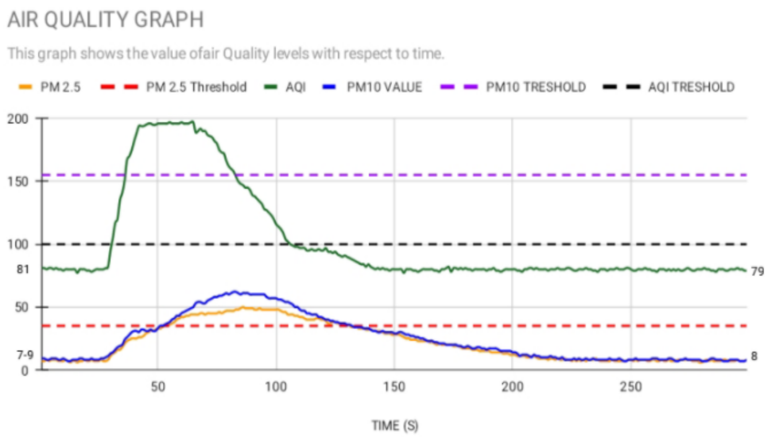

Figure 6. Data collected with PID

Both systems, with and without PID control, successfully reduced pollutants and restored baseline AQI. However, the system with PID demonstrated superior stability (Figure 6). The PID algorithm anticipated pollutant increases based on historical and real-time data, activating the fan before thresholds were exceeded. As a result, the duration of exposure to unsafe air quality was shortened, and dust concentrations returned more quickly to baseline levels. By contrast, the non-PID system relied solely on threshold exceedance for activation (Figure 7). This reactive approach led to fluctuations in pollutant levels and a longer recovery time, with dust concentrations failing to consistently stabilize at baseline values.

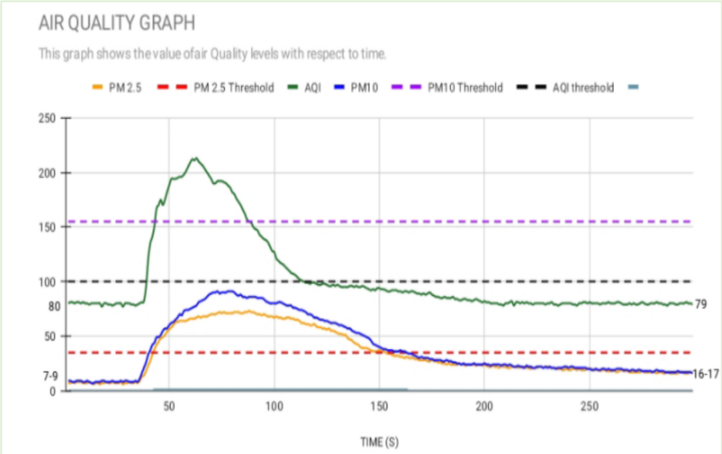

Figure 7. Data collected without PID

The results highlight the advantage of integrating PID control into home-based air quality systems. While both configurations improved air quality after pollutant introduction, the PID-enabled system demonstrated proactive regulation, enhanced stability, and shorter exposure durations above threshold limits. These findings suggest that predictive control mechanisms can significantly benefit individuals with asthma or other respiratory conditions by reducing the likelihood of pollutant-triggered health problems.

4. Conclusion

This study achieved its objectives by designing and testing a home-based air quality monitoring and purification system tailored to the needs of asthmatic individuals. The system successfully provided real-time measurements of indoor air quality, integrated purification processes using HEPA filters and carbon sponges, and demonstrated improved performance through the incorporation of a PID controller. Results showed that the PID-enabled system was more effective in stabilizing pollutant concentrations and reducing exposure to unsafe air quality compared to threshold-based activation alone. The findings highlight the potential application of such systems in supporting healthier indoor environments for sensitive populations. Beyond residential use, the approach could be adapted for broader applications, including schools, hospitals, and office buildings, where proactive air quality management is equally critical. Future work may focus on enhancing purification capacity for larger areas, exploring more powerful microcontrollers for improved performance, and enabling smart-home integration for seamless user experience.

Author's declaration

Author contribution

The first author, **Josamae Salas**, handled the conceptualization of the study, system design, prototyping, experimentation, data gathering, and the initial drafting of the manuscript. The second author, **Allain Jessel Macas**, provided supervision, refined the methodology, carried out data analysis, validated the results, and revised the manuscript to strengthen its intellectual content.

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Data availability

The datasets generated and analyzed during this study, including raw sensor readings (AQI, PM2.5, and PM10) and performance results of the prototype with and without PID control, are not publicly available due to storage limitations but can be obtained from the corresponding author upon reasonable request.

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Conflict of interest

The authors declare that they have no competing interests.

Ethical clearance

This research does not involve human as subjects.

AI statements

The grammatical structure and coherence of this article were improved using ChatGPT. The authors have rechecked the accuracy and correctness of the generated sentences in relation to the study's data and topic. The language and content were further validated by manual review to ensure clarity and fidelity to the original work.

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