



# CHITETEZO IoT-Based Air Pollution Monitoring System in Malawi using Raspberry Pi

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## **Abstract:**

Air pollution is a mounting concern in Malawi, especially in urban areas where particulate matter pollution consistently surpasses the World Health Organization's (WHO) recommended guidelines of 10  $\mu\text{g}/\text{m}^3$  for PM<sub>2.5</sub>. This severe air pollution, exacerbated by the use of solid fuels for cooking in rural regions, has led to respiratory ailments and poses a significant threat to public health. To tackle this problem, a solution named "CHITETEZO" has been introduced. CHITETEZO is an IoT-based air pollution monitoring system that employs a Raspberry Pi 3 microprocessor and an MQ-135 gas sensor to detect harmful gases such as Carbon Monoxide, Particulate Matter, Nitrogen Monoxide, Ozone, and Smoke. It also integrates a backup MQ-2 gas sensor and a DHT22 sensor to measure temperature and humidity. The system provides alerts using a buzzer and a light-emitting diode (LCD) when hazardous gases are detected. The results of CHITETEZO's implementation have been promising. It offers accurate and timely air quality information, emphasizing affordability and accessibility. Data is transmitted wirelessly to web dashboards, mobile applications, and ThinkSpeaks platforms for storage, visualization, and analysis. This enables government agencies, researchers, and the public to access real-time air quality data conveniently. The CHITETEZO system has been successfully deployed in various indoor settings, including hospitals, offices, households, classrooms, and laboratories. It holds the potential to address the air pollution issue in Malawi by providing actionable data for stakeholders and raising public awareness about pollution sources and cleaner practices.

## **Keywords:**

Air pollution · Internet of Things (IoT) · Raspberry Pi · Air Quality · Real-time Data Monitoring

## **1. Introduction**

Air pollution stands as a significant global environmental threat to public health, contributing to an estimated 7 million premature deaths annually. The connection between air pollution and climate change is strong, as the primary pollutants responsible for air pollution share common sources with greenhouse gases [1]. Enhancing air quality promises substantial benefits in terms of health, socioeconomic development, and environmental preservation. Addressing this critical concern, this paper outlines the conception and deployment of an Internet of Things (IoT)-based system for monitoring air pollution, named "CHITETEZO," tailored specifically for the unique context of Malawi, that means protected. Situated in Sub-Saharan Africa, Malawi faces a diverse array of air pollution

sources, encompassing both indoor and outdoor environments. In urban settings, the menace of particulate matter pollution looms large, primarily stemming from industrial processes, vehicular emissions, and open-air burning practices. The World Health Organization (WHO) estimates that the yearly average concentration of PM<sub>2.5</sub> in urban regions of Malawi surpasses the recommended WHO limit of 10 µg/m<sup>3</sup> [2], [3]. These elevated levels of particulate matter have dire health implications, especially for susceptible demographic groups like children, the elderly, and individuals with pre-existing respiratory conditions. Furthermore, indoor air pollution remains a prevailing concern, particularly in the rural regions of Malawi. Conventional cooking and heating methods reliant on solid fuels such as wood, charcoal, and agricultural residues contribute significantly to indoor air pollution. This, in turn, amplifies the risk of respiratory illnesses and health complications, with the WHO reporting that nearly 90% of the Malawian population relies on solid fuels for their cooking needs [3]. Efforts to tackle the challenges posed by air pollution necessitate the accurate and timely monitoring of key air quality parameters. Nevertheless, conventional monitoring systems often grapple with drawbacks such as high costs, limited geographical coverage, and delays in data availability. To address these issues, the CHITETEZO system harnesses the capabilities of the Internet of Things (IoT) and the flexibility of the Raspberry Pi platform to develop an economical and accessible solution for air pollution monitoring. The CHITETEZO system integrates multiple sensors linked to Raspberry Pi, enabling the simultaneous tracking of various air quality parameters, including particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), and ozone (O<sub>3</sub>) [4], [5]. By capturing real-time data on these pollutants, the system's objective is to furnish precise and comprehensive air quality information across diverse locations in Malawi. This is accomplished through wireless connectivity options like Wi-Fi or cellular networks, ensuring the seamless transmission of data from monitoring devices to a central server or cloud-based platform. Such connectivity guarantees secure data storage, analysis, and visualization, thereby facilitating more informed decision-making processes. Furthermore, the CHITETEZO system offers a user-friendly web interface and a mobile application, providing convenient access to air quality information for various stakeholders, including government agencies, researchers, and the public. The system not only analyzes the gathered data and discerns trends but also generates air quality indices (AQI) that are easily comprehensible and can be effectively employed in decision-making processes. The implementation of the CHITETEZO system in Malawi holds substantial promise in ameliorating the adverse impacts of air pollution. By delivering real-time, localized air quality information, the system empowers policymakers to take proactive steps in enhancing environmental conditions. Additionally, it fosters public awareness and engagement, encouraging collective endeavors to reduce pollution sources and adopt cleaner practices.

A crucial element in our continuous effort to combat the harmful impacts of air pollution is a comprehensive understanding of existing research, which forms the foundation for the development and deployment of advanced air pollution monitoring systems. Several initiatives have been undertaken across various sectors to implement such systems, and one notable example is the Wireless Sensor Network Air Pollution Monitoring System (WAPMS) in Mauritius [6]. This system employed wireless sensors, which were deployed in substantial quantities throughout the island of Mauritius.

The WAPMS initiative introduced the Air Quality Index (AQI), which was previously unavailable in Mauritius. To enhance the WAPMS, they devised and executed a novel data aggregation algorithm known as Recursive Converging Quartiles (RCQ). This algorithm was utilized to amalgamate data, eliminating duplicates, filtering out erroneous readings, and summarizing them into a more straightforward format. This optimization significantly reduced the volume of data that needed to be transmitted to the central data collection point, resulting in substantial energy conservation. Additionally, for efficient power management, they integrated a hierarchical routing protocol within the WAPMS, enabling the sensor motes to enter a low-power sleep mode during idle periods [6]. Diverse

approaches have been explored in the development of air pollution monitoring systems, showcasing the ingenuity and adaptability of these solutions. One such approach involved the utilization of a Geosensor Network to create an Air Pollution Monitoring System. This system was designed with a context model and a flexible data acquisition policy. The context model's primary function was to assess air pollution conditions in remote areas, providing alerts and safety guidelines based on the context model's status. Additionally, it allowed for the adjustment of the sampling interval to strike a balance between data collection frequency and battery life. The sampling interval could be adapted based on pollution conditions, thus conserving the limited geosensor batteries by reducing data transmissions [7]. Another innovative endeavor to combat air pollution issues introduced an Environmental Air Pollution Monitoring System based on the IEEE 1451 Standard for Low-Cost Requirements [8]. This system measured gas concentrations, including CO, NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub>, using semiconductor sensors. The Smart Transducer Interface Module (STIM) was implemented with the Analog Devices' ADuC812 microconverter. A Network Capable Application Processor (NCAP) was developed, connecting to the STIM via a transducer-independent interface. Calibration of three gas sensors was performed using standard calibration methods. The NCAP featured a graphical user interface displaying gas concentration levels and STIM information. Notably, this system had the capability to issue warnings when pollutant levels exceeded predetermined thresholds and had the potential to be adapted into a low-cost version suitable for developing countries. In Bangladesh, a real-time air quality monitoring system was developed, specifically tailored to the country's perspective, based on the Internet of Things (IoT) [9]. This system introduced a smart real-time Air Monitoring System that provided users with the ability to monitor the air quality in their homes, offices, or industries from anywhere. It incorporated an emergency alert feature that would notify users in life-threatening situations, enhancing safety and awareness.

This project focuses on the creation of a real-time air monitoring system, which utilizes Raspberry Pi and gas sensors. The Raspberry Pi operates as the central control unit, responsible for gathering air quality information from the sensors and relaying it to both the Chitetezo web-based dashboard and the Chitetezo mobile app. The system comprises various hardware components, including gas sensors such as MQ135 and MQ-2 which detect gases including Carbon Monoxide, Particulate Matter, Nitrogen Monoxide, Ozone, and Smoke, an LCD display, Raspberry Pi, a breadboard, an analog-digital converter (ADC), and a stable power supply. Additionally, it employs several software components, such as Python scripts for data collection, a database for data storage, and MQTT and Google Firebase for real-time data transmission. The Chitetezo web-based dashboard, developed using JavaScript, offers real-time visualization of the sensor data. On the other hand, the Chitetezo mobile app, which is cross-platform compatible, retrieves data from Firebase and presents it on both Android and iOS devices. A significant aspect of this project is the emphasis on security and user authentication measures to safeguard the integrity of the data. Additionally, it requires ongoing maintenance and monitoring to ensure the system's reliability and the accuracy of the data it provides.

## **2. Methodological Approach**

### **2.1 Simulating the System with Proteus Software**

The initial phase of project implementation involved a critical step, the simulation of the entire project. This marked the first pivotal stride towards realizing the project's objectives. The principal goal during this stage was to attain a thorough comprehension of the project's functionality and pinpoint areas where improvements and optimizations could be incorporated before full integration into the live system. This simulation phase encompassed a range of activities. It encompassed the creation of a virtual environment that closely mirrored the Chitetezo air pollution monitoring system, the integration of the

Chitetezo web-based dashboard and the Chitetezo mobile app, and the rigorous testing of various system functionalities. These activities allowed the project team to evaluate the system's performance under diverse scenarios, identify potential bottlenecks, and make refinements to the design as necessary. Moreover, the simulation phase provided invaluable insights into the project's feasibility and viability. It served as a platform for fine-tuning the project's specifications, identifying potential risks, and determining the requisite resources. By gaining a comprehensive understanding of the project's inner workings through simulation, the team was well-prepared to make informed decisions and streamline the subsequent phases of implementation. This pivotal step laid the groundwork for a successful transition from the testing and simulation environment to the actual production system. In Figure 1, you can observe how the system was simulated in Proteus Software, while Figure 2 shows the block diagram.

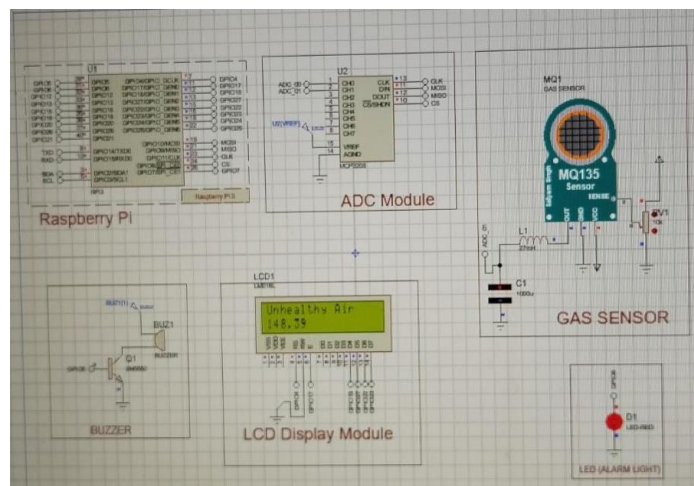


Figure 1: Schematic Diagram of developed system

## 2.2 Development of an Air Pollution Monitoring System

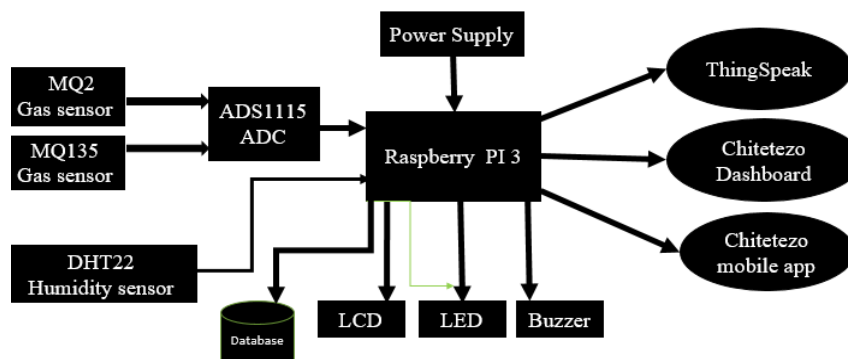


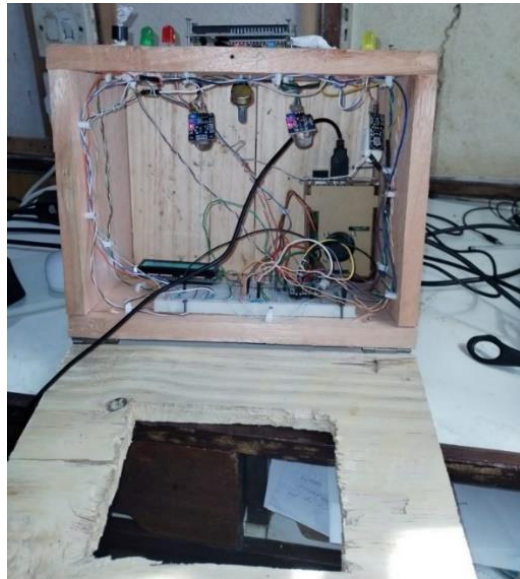
Figure 2: Block Diagram

The real-time data acquisition in this project was carried out using the MQ-135 and MQ-2 sensors in Figure 3, which effectively captured crucial information such as gas concentrations from the surrounding environment. These sensors transmitted the collected data to a Raspberry Pi for further processing. The processed data was then presented on various platforms, including an LCD screen, a web-based dashboard, and a mobile app. To enhance user awareness and safety, the system integrated a buzzer. The buzzer was programmed to emit an audible alert only when the presence of harmful gases was detected, effectively drawing immediate attention to the situation. Simultaneously, a red LED indicator would illuminate, providing a visual cue to reinforce the warning. Furthermore, the system

incorporated a DHT22 sensor, designed to serve a dual purpose. It measured both humidity and temperature in the environment, contributing to a more comprehensive understanding of the environmental conditions. This additional functionality ensured a holistic approach to data collection and monitoring within the system, enhancing its overall effectiveness. Figure 4 and Figure 5 depict the mounting of all system components.



**Figure 3: Sensors and analog-digital converter**



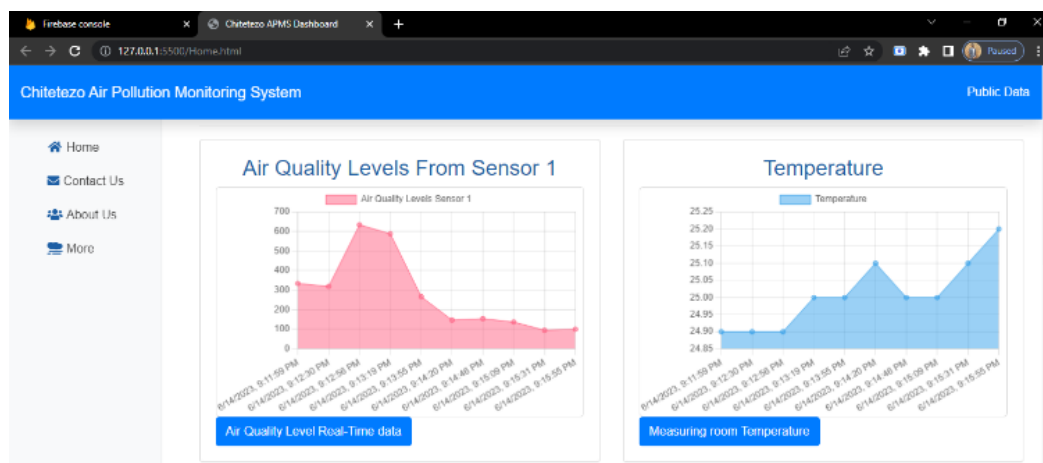
**Figure 4: Housing and placement of components**



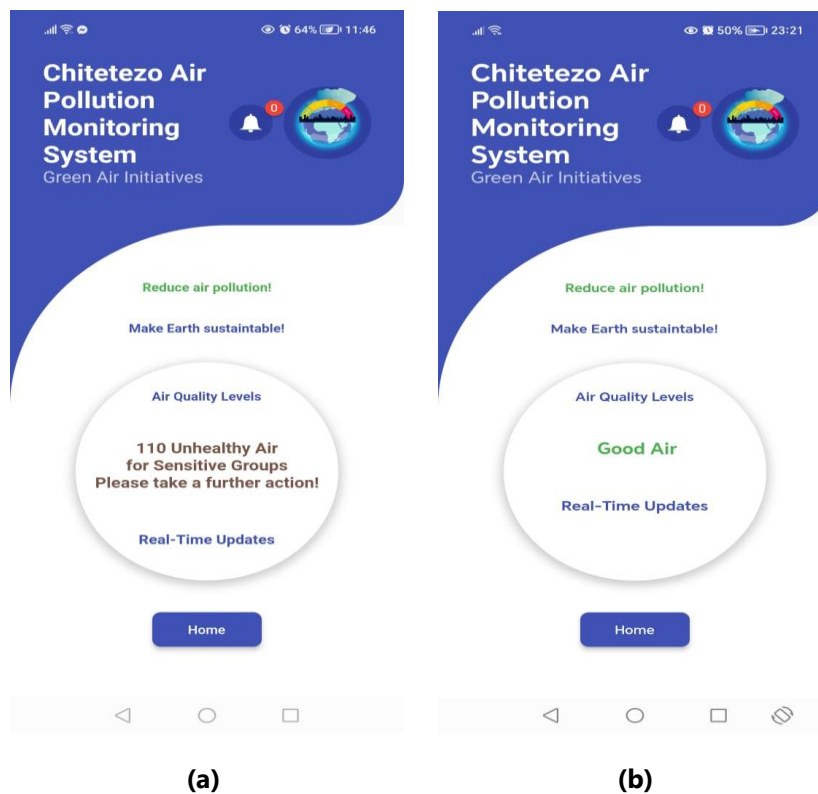
**Figure 5: System powered by a 5-volt power supply**

### 3. Results and Discussion

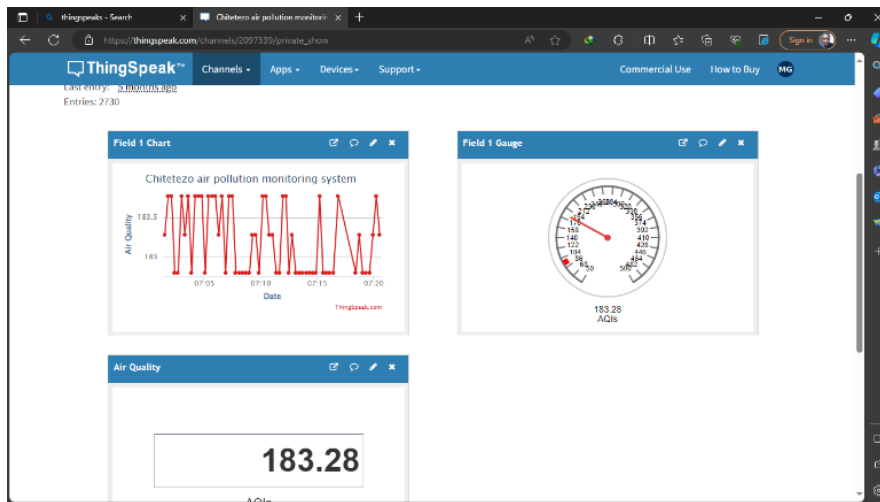
Figure 6 until 10 display the results obtained from the system, offering visual representations of various data points, including air quality measurements and sensor readings. These figures provide essential insights into the system's performance, presenting the data prominently on both the user-friendly web dashboard and the convenient mobile app. This user-friendly approach allows users to effortlessly monitor and analyze real-time information. The MQ135 sensor collected the data presented in these figures, and after processing, it was efficiently transmitted to the Raspberry Pi for further analysis and visualization. Subsequently, the Raspberry Pi seamlessly relayed this processed information to the web dashboard and mobile app, ensuring that users have access to up-to-date and comprehensive data at their fingertips. The use of these figures aids in clearly conveying the system's capabilities and the value it brings to users by providing valuable real-time data and insights.



**Figure 6: Real-time data on the Chitetezo web-dashboard**



**Figure 7: Real-time (a) unhealthy data and (b) good data on the Chitetezo mobile app**



**Figure 8: Displaying real-time data on the ThinkSpeaks web dashboard in a different format**



**Figure 9: Displaying real-time data on the LCD during the night**

#### 4. Conclusion

The Chitetezo air pollution monitoring system has emerged as an indispensable tool for the assessment and management of air quality, both locally and remotely. By deploying sensors like the MQ135, the system has successfully gathered real-time data on various pollutants, granting us a comprehensive understanding of air quality in our targeted areas. This system, seamlessly integrated into both the Chitetezo web dashboard and the Chitetezo mobile app, empowers users with convenient access to critical information, enabling them to make well-informed decisions. Consistent monitoring and in-depth data analysis have enabled the identification of pollution trends, hotspots, and potential contamination sources. Consequently, this has facilitated timely corrective actions and policy recommendations, contributing to the mitigation of air pollution and the enhancement of public health. The system's efficiency in managing and disseminating data, from sensors to the Raspberry Pi, and then to the web dashboard and mobile app, underscores its effectiveness. As a result, it has become an invaluable asset, benefiting both researchers and the nation as a whole, by raising awareness and promoting an understanding of air quality concerns. Looking ahead, continuous system enhancements and the expansion of sensor networks hold the promise of further improving our capacity to monitor and combat air pollution. The integration of advanced analytics and the adoption of more precise sensors have the potential to ensure cleaner and healthier environments. This system underscores the importance of ongoing innovation and investment in air quality monitoring, not only for the well-being of our communities but also for the health of our planet.

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