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Research Paper

AN ADVANCED INTERNET OF THINGS (IOT) PLATFORM FOR REAL-TIME QUALITY OF AIR MONITORING & POLLUTION DETECTION WITH AN ESP DEVICE

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Abstract—In cities, factories, and other enclosed spaces, air pollution poses a serious threat to ecosystems & human health. Inhalation of toxic gases such as carbon monoxide, tobacco smoke, and others may lead to heart problems, respiratory issues, and other long-term health complications. Conventional air quality monitoring devices are too costly, too limited in their applicability, and too impractical for continuous localized monitoring. In response to these shortcomings, this study introduces a state-of-the-art Internet of Things (IoT) framework for real-time air quality monitoring & contamination detection via the use of an ESP device. To continually identify hazardous substances and analyze environmental pollution levels, the proposed system utilizes an ESP in combination with gas detection sensors based on the MQ-series, comprising MQ2, MQ3, and MQ135 variants. In order to ascertain the air purification state and to indicate potentially dangerous situations based on specified cutoff values, the controller analyzes the observed gas levels. In addition to a local LCD display, the device has an alarm buzzer and a cloud online service that allows remote monitoring air purity measures via dashboards and real-time graphs. When pollution levels rise over acceptable limits, the system notifies users both locally and remotely, allowing them to be prepared for potentially dangerous environmental situations. Residential air monitoring, industrial pollution monitors, public place protection, or intelligent city environmental tracking are just a few potential uses for the suggested platform's small size, low cost, and scalability.

Keywords—Displayed on the IoT are gas detectors, alarms for air pollution, ecological monitoring,

smart cities, chemical purity monitors, the Internet with Things, or ESP controllers.

I. INTRODUCTION

The state of the air has a direct impact on people's health, lifespan, and sustainability. The amount of harmful gases in the atmosphere has grown significantly because to human activities such as building more cities, burning diesel, producing more hazardous chemicals for use in the home, and smoking from both indoor and outdoor sources. Prolonged exposure to pollutants may lead to a host of long-term health complications, such as respiratory ailments, reduced oxygen intake, cardiovascular troubles, and diseases caused by combustion gasses and smoke. Air quality monitoring should therefore be ongoing in all smart city buildings, laboratories, hospitals, homes, and companies.

Annual measurements by hand or large ecological monitoring stations are the mainstays of conventional methods for air quality inspections. Though these gadgets can measure levels of pollution in a specific region, they aren't always affordable, they're area-specific, and they don't capture real-time changes in local air quality. Pollutant levels could vary substantially between different rooms, sections of industries, highways, or public spaces in many real-world scenarios. This means that centralized monitoring stations cannot provide sufficient information about localized environmental threat. In addition, many older monitoring systems lack both immediate warning methods to customers and reasonably priced remote monitoring capabilities.

Intelligent ecological monitoring has just taken a giant leap forward thanks to the Internet of Things. Through the use of the Internet with Things (IoT), a compact platform that continuously monitors its environment and provides timely alerts may include gas detection, local computing, wireless connection, and cloud access. These systems are very useful for applications where early detection of harmful gas buildup is crucial, such as household ventilation, regulating pollution in factories, inspecting warehouses, keeping tabs on public health, and controlling environmental damage in municipalities. It is now feasible to build scalable, continual air quality systems by combining low-cost gas sensors with CPUs linked over WiFi.

Instead of investing in pricey, high-quality monitoring stations, researchers are shifting their attention to low-cost sensing devices that can quantify hyper-local pollution in immediate form via the Internet for Things. Accurate readings are provided by traditional stations, but they cannot cover wide regions due to the high costs of installation and maintenance. Scientists have attempted to circumvent this limitation by developing cheap and scalable tracking systems that use tiny nodes equipped with sensors, integrated controllers, a cloud connection, and AI-based calibration techniques. In particular, Jain et al. investigated a low-cost IoT system with sensors for localized air quality monitoring and exposure assessment in real time, and they showed how thick a sensor installation may improve local pollution visibility as well as private exposure estimates [1]... Similar to this, Daniel-Murillo et al. created AQuality32, an ESP32-based open-source AQ monitor that is hosted in the cloud. Simple, readily accessible hardware and internet-based environmental analysis are becoming more important in modern monitoring systems, as this gadget shows [3]. Evidence from these research suggests that current systems are moving toward distributed, low-cost, and highly-connected architectures to more accurately monitor air quality at regional and urban sizes.

Precision and dependability over time of affordable sensors provide a substantial barrier to such systems due to the influence of drift, environmental factors, and cross-sensitivity on results. Numerous studies have focused on calibrating sensors via the application of statistics and machine learning. Presenting a measurement framework for Internet of Things (IoT) air quality sensors based on creative ML, Taştan demonstrated that data-driven approaches may substantially improve the characterization performance of low-cost devices [2]. Improving prediction stability & better capturing environmental behavior in motion, Ali et al. shown that time-aware calibration, which incorporates time-related data into innovative ML

calibration algorithms, goes beyond this approach [4]. By combining information from many sensors and events in time, Niresi et al. [5] developed a technique to improve the precision of calibration for air quality monitoring systems connected to the Internet of Things (IoT). In a similar vein, Ferrer-Cid et al. showed that air pollution IoT systems may be fine-tuned by merging data from many sensors; this improves platform resilience while lowering sensor uncertainty [9]. When considering the reliability of low-cost monitoring networks, these studies demonstrate that calibration has emerged as a significant field for study. Methods such as creative ML, time simulation, etc sensor synthesis have been used [2, 4, 5, 9].

For low-cost air-quality sensors, some researchers have focused on creating field-ready evaluation tools or realistic calibration approaches, in place of model-driven calibration. The authors of an article on a new calibrated design for inexpensive sensors in Environmental Pollution Research raised the possibility of more consistent and dependable air-pollution monitoring installations [6]. Similarly, another HardwareX study unveiled a portable air-quality tracking device together with a flexible and adaptable tool for the field evaluation and calibration of affordable gas detectors [7]. Given that environmental variables such as humidity, temperature, geographical pollutants, and the inevitable aging of sensors may significantly affect performance, these investigations bridge the gap between laboratory calibration and deployment in the real world. In addition, Chu et al. conducted research on spatial validation for PM2.5 maps using low-cost air-quality sensors, demonstrating that spatial correction methods have the potential to improve the precision of pollutant distribution mapping across all monitored locations [8]. The need to explore calibration from several perspectives, such as data presentation, field execution, ability to adapt, and geographical variability, is highlighted by these contributions.

By highlighting common gaps and encouraging future research directions, reviews and surveys have also made substantial contributions to the field's progress. According to a thorough assessment and study of the external quality of breath surveillance or detector calibration of Concas et al. [12], low-cost sensing systems confront challenges with data accuracy, ecological consciousness, service, and consistency. Their research shows that low-cost Internet of Things (IoT) systems are very scalable and inexpensive, but their inconsistent performance hampers their widespread adoption. Calibration and verification are two areas where this is very relevant. In order to identify pollution in places that are either difficult to reach or constantly changing, Burgués and Marco demonstrated how mobile detection devices may augment static monitoring systems

[10]. They investigated ambient chemical sensing with the use of small drones in a comparable but broader sensing setting. With the growing importance of air-quality monitoring in urban and industrial settings, this research broadens the scope of the discipline to include mobile, adaptive, and spatially flexible monitoring devices in addition to fixed sensor networks.

Research on the communication infrastructure and Internet in Things (IoT) architecture that is required for real-time weather tracking is another substantial body of work. As a smart environmental monitoring system that relies on the Internet of Things (IoT), Rahman et al. [11] proposed collecting data on the environment and transmitting it to connected platforms so it may be monitored remotely. Using the IoT, Rai et al. developed a thorough system for monitoring air quality. A unified monitoring system that incorporates sensor units, connectivity parts, and cloud services is shown by this system [13]. An IoT system for low-cost and energy-efficient interior environment monitoring was proposed by Kumar et al. [14] because to the fact that resource-constrained sensor nodes may nevertheless provide continuous monitoring whilst using less electricity. In addition, Kumar and Hancke created a ZigBee-based weather monitoring system for distant sensing applications, which shows how important wireless sensor networks are for allowing reliable, scalable, yet low-power communication across many sensing nodes [15]. Taken together, these studies show that AQ monitoring based on the IoT encompasses more than just pollution detection. Instead, communication methods, cloud connectivity, energy conservation, or system compatibility are crucial for continuous & scalable operation [11]-[15].

II. PROPOSED MODEL

A. Block Diagram

In an integrated design, the suggested quality of air monitoring system is built around an ESP-based microcontroller that handles ambient sensing, local display, alarm generating, and Internet of Things (IoT) connection. There are four main components to the system's block diagram: the gas sensing unit, the ESP processing & decision unit, the local display and alarm unit, and the IoT communication unit.

Two MQ2 gas sensors, one MQ3 gas sensor, and one MQ135 gas sensor make up the gas detecting device. Gaseous contaminants and other potentially dangerous air components are monitored by a variety of sensors. For situations involving the release of flammable gases, smoke, or gasses similar to LPG, the MQ2 detector is used. The MQ3 detector is particularly attuned to volatile gases and vapors of

alcohol, which are known to exacerbate air pollution in confined spaces and factories. Air quality monitoring using the MQ135 sensor is commonplace since it can detect gases including ammonia, benzene, smoke-related contaminants, and other volatile chemicals linked to air pollution. Incorporating these sensors allows the system to monitor several types of air pollution, instead of relying on just one gas input.

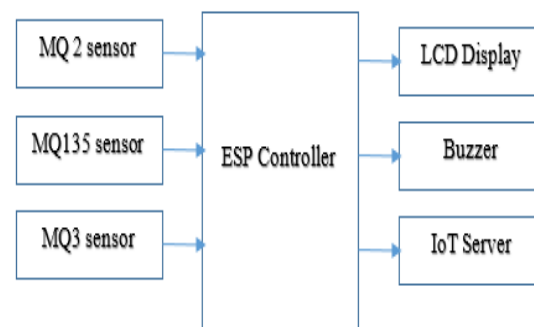


Fig. 1. Air pollution detection and monitoring system block diagram

Connected to an ESP controller—the brains and talkers of the system—are the analog output of the MQ sensors. As gas levels of concentration or relative pollution indicators, the controller analyzes the digital information obtained from the sensors, which it does continually. A normal, moderate, or dangerous air quality level is determined by comparing the measured sensor readings to established threshold levels. When the values detected stay below the threshold, it is considered a safe environment. The controller starts alerting procedures in the event that a number of sensor readings above the permissible limits, assuming that this indicates the presence of hazardous gases or increased pollution.

Two components make up the local display & alert unit: an LCD screen and a buzzer. Displayed on the LCD are real-time readings of the air quality, gas measurements, Wi-Fi status, and system warnings. Where direct observation is necessary but online interface is not sufficient, such as on factory floors, in labs, in homes, or in public locations, this is beneficial. If there is a local alarm, the buzzer will go off. A buzzer is activated by the ESP controller to notify people in the vicinity when the air pollution level has beyond a certain threshold or has reached a dangerous level, allowing for prompt mitigation measures.

Utilizing the ESP device's Wi-Fi functionality, IoT communications unit is put into action. After linking up to the nearby wireless system, the ESP sends data

about the air quality and sensor readings to an internet of things server or online dashboard. Fig. 7 shows how the dashboard uses numerical indicators, graphs, and trend plots to present the data as it happens. Also, as shown in fig. 8, it may send out remote notifications once a contamination level becomes too high. Users may track weather conditions and air quality changes over time from any distant place using the IoT platform.

The ESP controller sets up the MQ detectors, LCD, buzzer, the Wi-Fi module when the system is powered up. The controller diligently takes readings from the sensors, calculates the air purity level, shows the results locally, and then uploads them to the Internet of Things server. The system turns on the buzzer and enters warning mode if the harmful value is higher than the threshold. It also updates the online dashboard when there is an alert situation. Air quality, pollution, or remote environmental monitoring may all be addressed using this architecture's integrated solution.

B. Prototype Hardware

An Internet of Things (IoT) connection interface, a local display, a number of MQ gas sensors, an ESP-based embedded controller, and a buzzer alarm were all components of the hardware prototype for the suggested air quality monitoring platform. A small, functional prototype that can monitor air pollution levels in real time and send out notifications was the goal of the hardware implementation.

Central to the ESP system is the controller. The IoT dashboard receives data in analog form from MQ sensors, which it analyzes, compares to threshold limits, operates the buzzer & LCD, and then broadcasts the results. Remote AQ monitoring applications that need data access via a web server and mobile interface are well-suited to the ESP platform because to its integrated Wi-Fi connection.

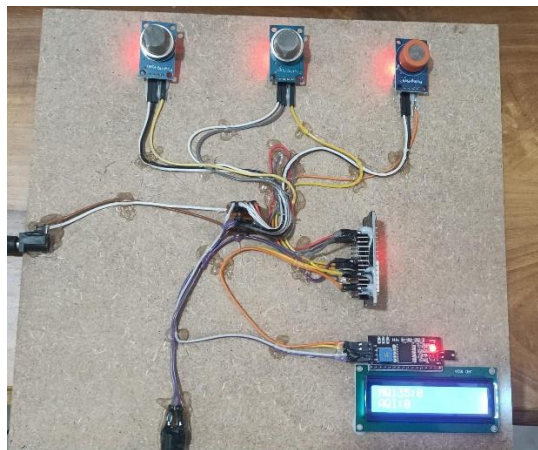


Fig. 2. Installation of pollution detection and air quality monitoring hardware

Detecting smoke and flammable gases is the job of the MQ2 gas sensor. This sensor can detect gas leaks, smoke buildup, or unexpected environmental pollution in both commercial and residential areas. Vapors of alcohol and other volatile gases may be detected with the help of the MQ3 gas detector in places like storage facilities, labs, and factories. As the principal air quality sensor, the MQ135 gas detector can detect dangerous levels of gases including smoke, ammonia, and benzene. Collected, these sensors enhance the system's capacity to identify a variety of dangerous situations and provide a more comprehensive picture of environmental contamination.

In order to provide local monitoring in real-time, the LCD display is linked to the ESP controller. Messages about unhealthy air quality, gas sensor readings, Wi-Fi status, IP address, and web interface data are all shown while it is operating. Users in close proximity to the installation site may now rapidly monitor environmental conditions without needing to visit the IoT dashboard. The buzzer serves as a method of aural notification. The buzzer is set to go off if the pollution level goes beyond a certain threshold, alerting surrounding users of the dangerous air situation.

There is a web interface for Internet of Things (IoT) air quality monitoring included into the prototype as well. Air quality status and real-time sensor readings are sent to the server via the ESP controller and shown graphically or numerically through indicators. This paves the way for distant observation of changing air quality and patterns in pollution. Urban environmental monitoring systems, smart homes, educational campuses, public buildings, and industrial facilities are some of the most ideal places to use the IoT platform.

Proving that the suggested platform can be built with inexpensive parts while still providing continuous sensing, warning generation, local display, or environmental monitoring in the cloud, the hardware implementation is now live. Future extensions to the system for sophisticated environmental analytics or smart city deployment may be made possible by the system's modular design, which allows for the integration of additional sensors like PM sensors, humidity-temperature modules, CO₂ sensors, even GPS/GSM modules.

III. Dynamic Graph

The idea for an air quality surveillance system's flowchart details the steps needed to begin the

system, acquire sensors, evaluate air quality, generate alerts, and transmit data via the Internet of Things. Step one involves turning on the ESP-based device and initializing all of its associated modules. This includes the MQ2, MQ3, or MQ135 sensors, as well as the LCD display, buzzer, or Wi-Fi communication unit. The ESP will try to connect to any accessible Wi-Fi network after startup. In order to keep tabs on environmental data via the IoT dashboard, the LCD will provide URL or website access details after the Wi-Fi link is successful.

Once the Wi-Fi connection is established, the ESP will begin the cycle of continuous monitoring. Here, the MQ2, MQ3, & MQ135 gas sensors provide their readings to the controller. The total pollution state or AQ status is determined by processing these sensor information. For on-site monitoring, the data is shown on the LCD; for remote visualization or trend analysis, it is sent to the IoT server.

After collecting data from the sensors, the controller determines whether the calculated air quality value (threshold value connected to the air quality index) or gas level of concentration is higher than the specified safe threshold. As long as the value stays below the specified limit, the system considers the environment to be safe and keeps updating the online dashboard and LCD with the current values. The controller considers the situation dangerous if the pollutant level is higher than the threshold. In such a situation, the Internet of Things web server notifies the dashboard of an alert or warning, and the buzzer sounds to inform those in the area.

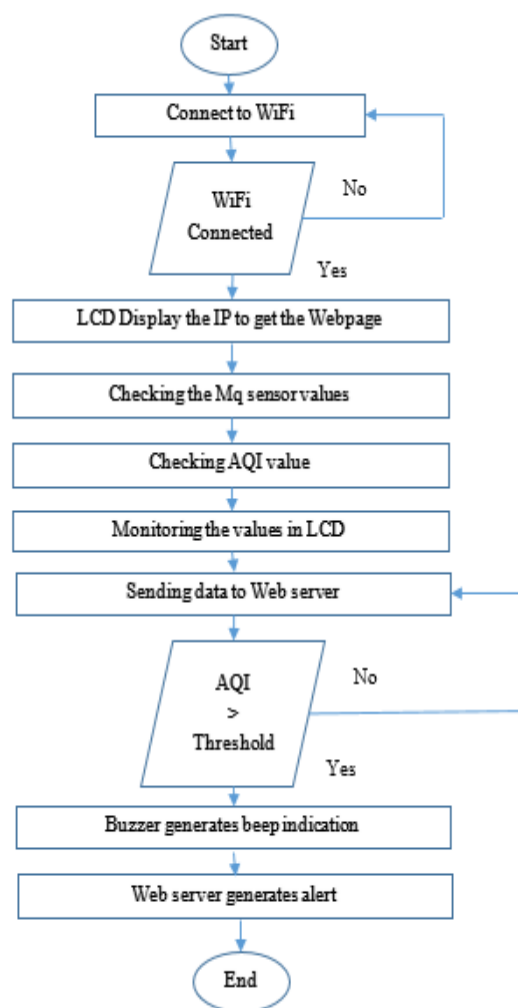


Fig. 3. Diagram depicting the process flow of an air pollution detection and monitoring system

Thanks to this process, the system can monitor the environment in real-time, notify users of impending danger, and display the air quality from a distance using an integrated Internet of Things (IoT).

IV. INDUSTRY-RANDOM FINDINGS

A hardware prototype of the proposed Advanced Internet of Things (IoT)-Based Real-Time Conditions Monitoring or Pollution Detection Platform employing an ESP Device was developed and tested in various environments to ensure the platform's sensing capacity, alarm generating, and IoT performance in monitoring. A number of components were included in the experimental setup, including an ESP control system, an MQ2 and MQ3 sensors, a MQ135 sensor, an LCD display, a buzzer, plus an IoT dashboard that allowed for the continuous viewing of data. The purpose of the experimental study was to test the system's ability to detect pollution-related substances, evaluate the current state of the air, issue alerts, and communicate

data to the online platform in both typical and experimental settings.

The system underwent testing in a room with adequate ventilation, and no significant exposure to smoke or chemicals was made during this time. Since the MQ sensor values were consistently low under these conditions, the system deemed the air quality to be safe to breathe. Standardized sensor readings in many readings fell somewhere around $MQ2 = 0$ to 10 , $MQ3 / 0-20$, & $MQ135 = 0-20$, with exact values dependent on environmental factors and how the sensors warmed up. The prototype's internal threshold logic ensured that the total air quality indicator never even came close to the alert level. Fig. 4 shows that the buzzer was turned off and the LCD showed the current sensor data and the safe-status indicators. Using the data updated every three to five seconds, the IoT dashboard allowed for continuous trend monitoring of air quality without the need to generate false alarms.



Fig. 4 Show the value of the MQ sensor on the LCD.

An evaluation of the MQ2 sensor's smoke & combustible gas detection capacity was conducted by subjecting the system to controlled exposure to smoke and light gas emissions. The MQ2 value jumped sharply from the usual range to around $10-30$ when the quantity of smoke near the detection device increased, and MQ135 also saw a comparable rise as a result of smoke-related contaminants. The prototype employed a number of 12 as a threshold to signify an exceptional amount of pollution. Immediate danger was declared by the ESP controller as soon as the dominant MQ2 air quality value exceeded this threshold. At the same time as the IoT dashboard went from Normal to Warning, the buzzer went off and a warning message about bad air quality appeared on the LCD. In the case of smoke-related pollution, the system was able to provide rapid local alerting with an average reaction time of less than 1 second from threshold passing to buzzer activation.



Fig. 5. Status of moderate air quality shown on LCD

In order to test how well the MQ135-based sensors for air quality worked, we subjected them to situations known to enhance volatile pollutants, for example confined spaces, cleaning chemicals, and perfume mist. A significant increase in air pollution was shown by the MQ135 value, which rose from the baseline spectrum of around $0-20$ to about $30-50$ under these situations. Upon exceeding the threshold, the system sent a warning, assuming that the rise indicated worsening air quality. An audio alarm was sent via the buzzer, and the LCD showed the dangerous air condition and high gas value in such instances. By keeping track of the air quality trend, the IoT technology also allowed us to see how pollutant levels rose and fell over time. The results show that the suggested approach works well for both smoke detection and monitoring the overall decline of air quality.

We exposed the MQ3 sensor to volatile gaseous environments and vapors derived from alcohol to assess its performance. The MQ3 value jumped dramatically from the typical range of around $0-10$ to about $20-40$ when the sensor was positioned near an alcohol vapor source. Because the MQ3 sensor is a part of the proposed system's total pollution assessment, this increase brought the calculated air quality level close to or beyond the danger threshold, depending on the readings of MQ2 and MQ135 taken together. Upon reaching the threshold, the controller would sound an alarm and display the current alert status on the online dashboard (see fig. 8). Whether in a laboratory, storage area, or industrial space, this experiment proved that an apparatus can identify air pollution produced by vapors of alcohol and comparable volatile chemicals.



Fig. 6. A reliable LCD screen for monitoring air quality

We also tracked the prototype's Internet of Things (IoT) connectivity performance as it went through its testing. Live numerical numbers and trend graphs were shown on the IoT dashboard, which had successfully uploaded sensor readings from MQ2, MQ3, or MQ135. On average, the dashboard would update every 3–5 seconds under steady Wi-Fi, and any changes to the alert status would be reflected globally within 1–2 seconds after local detection. In addition to showing the user's IP address and granting local access to the homepage, the LCD also served as an easy interface for remotely monitoring the surroundings over time. These findings attest to the platform's viability for Internet of Things (IoT) pollution analytics and real-time remote environmental monitoring.

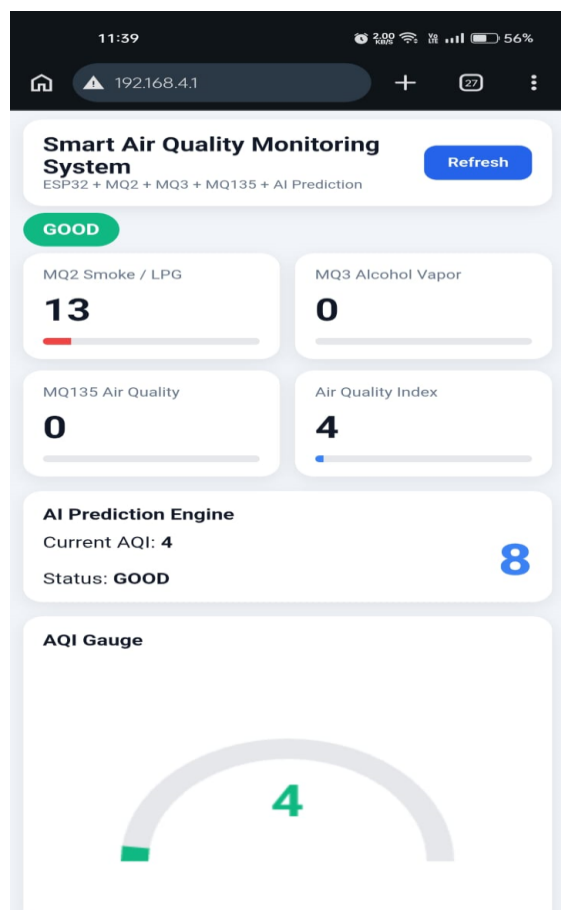


Fig. 7. A high-quality air quality webserver dataset

In summary, the trial results showed that the system did not activate an alarm when operating in typical air conditions, with average sensor readings of around 5, 10, and 15 for MQ2 and MQ3 and MQ135 respectively. A danger signal was issued when the MQ2 value surpassed 400 when exposed to smoke. The MQ3 value increased over 30 when exposed to alcohol vapor, suggesting the presence of volatile pollutants. The MQ135 value was higher than 30, indicating worse air quality, when the air quality was generally bad. All three sensors gave a strong signal under mixed pollution circumstances, and the system kept going off with an alert. These results prove that the suggested platform for monitoring air quality can accurately detect various forms of air pollution and provide immediate, far-reaching alerts.

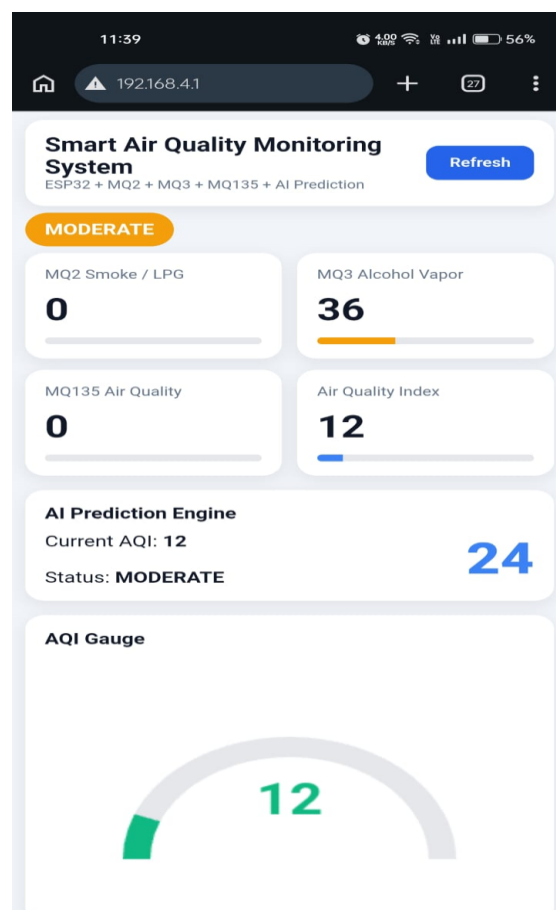


Fig. 8. Information from a web server with a modest air quality value

Experiment findings show that the suggested air quality monitoring & pollution detection system based on ESP is feasible in practice. Everything worked as it should have: gas sensor outputs were monitored, environmental conditions were shown on an LCD, alarms were triggered when pollution

levels were too high, and data was sent in real-time to an Internet of Things dashboard so it could be watched remotely. Indoor air safety, pollution from factories observation, smart building detection, public health surveillance, plus smart city green initiatives are all made possible by the suggested system's convergence of many gas sensors, threshold-dependent decision logic, regional alerting, and Internet of Things (IoT) connectivity.

V. Final Thoughts and Prospects

In this research, we introduced an advanced platform for real-time monitoring of air quality & pollution detection that is based on the internet of things (IoT) and uses an ESP device to continuously sense the environment and identify hazards. To provide real-time monitoring of pollution levels or prompt warning of hazardous air conditions, the suggested system incorporates MQ2, MQ3, or MQ135 gas sensors in conjunction with an ESP-controlled controller, an LCD display, buzzer alarm, and Internet of Things dashboard. Smoke, volatile vapor buildup, and general poor air quality may all be detected by the system's constant monitoring of gas concentration trends compared to threshold values.

This platform's ability to reliably conduct both local and distant environmental monitoring was shown by the created prototype. When pollution levels were normal, the system kept sensing steady and updated the IoT periodically; when pollution levels were excessive, it worked as intended, sounding the alarm and updating the air quality condition on the online dashboard. This system is ideal for environmental monitoring in smart cities, since it combines inexpensive gas sensors with wireless communication and threshold-based decision logic, making it applicable to smart homes, labs, workplaces, public buildings, and enterprises.

Numerous avenues exist for broadening the scope of this effort in the future. The accuracy of air quality assessment may be enhanced by integrating additional sensors, such as particulate matter sensors (PM2.5/PM10), CO₂ sensors, humidity and temperature sensors, or meteorological sensors. Classification of gas patterns, calibration of sensors, detection of anomalies, and analysis of predicted pollution are all tasks that might benefit from machine learning techniques. The combination of cloud databases and GPS-enabled geotagging may provide environmental mapping on a citywide scale. To further improve the system for massively smart ecological surveillance and public health protection, we may include mobile app alerts, outdoor nodes powered by solar energy, and multi-node sensor networking.

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