Design and Development of an Iot-Based Air Quality Monitoring System for Libjo Mining Corporation

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Design and development of an Internet of Things (IoT)-based Air Quality Monitoring for Libjo Mining Corporation

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Abstract:
The study developed an IoT-based air quality monitoring system for Libjo Mining Corporation, using DHT22, MQ sensors, Nova PM Dust Sensor SDS011, and WS3 Weather Station. It demonstrated high accuracy, comparable to laboratory-grade devices, with regular calibration needed for precision. Researchers used Root Mean Square Error (RMSE) to evaluate sensor accuracy. The system facilitates real-time monitoring, remote access, and accurate data collection. DHT22 sensors reliably measured temperature and humidity, while MQ gas and dust sensors provided consistent results for harmful gases. However, MQ-135 sensors require cautious use due to accuracy discrepancies. The study detected higher gas concentrations near the CSU gymnasium and main gate, indicating toxic gases from construction and vehicles. In contrast, other areas maintained good air quality. The wind speed and direction sensor were essential for precise measurements. This system addresses key air quality issues for Libjo Mining Corporation and highlights the importance of IoT technology in industrial applications.

Keywords: Air quality monitoring system; Root mean square error, Internet of Things (IoT); Harmful gases; Real-time monitoring; Sensors.

1. INTRODUCTION

Air quality monitoring and health hazard indicator systems are critical for maintaining the safety of people living in mining communities. Mining activities emit pollutants and dangerous gases into the air, harming the environment and human health. The closeness of mining operations to residential areas increases local communities' exposure to these contaminants [1]. According to the World Health Organization, major air pollutants consist of carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), particulate matter (PM2.5/PM10), and nitrogen dioxide (NO_2). Particulate matter (PM) comprises liquid droplets and solid particles suspended in the air that contain dangerous components. PM is divided into PM10 (2.5-10 micrometers) and PM2.5 (less than 2.5 micrometers). PM10 mostly comprises dirt, dust, and smoke from mining operations, whereas PM2.5 comprises oil, diesel fuel, gasoline, metals, and toxic organic compounds from metal production and automobiles. PM2.5 may have a more significant influence on health due to its content of hazardous chemicals [2]. Leveraging Internet of Things (IoT) technology offers a promising solution to address the limitations of traditional air quality monitoring stations. Real-time monitoring becomes feasible by employing a network of sensors capable of detecting common pollutants such as carbon monoxide, sulfur dioxide, and particulate matter coupled with data processing tools and cloud platforms. IoT-enabled systems enhance the accuracy and efficiency of monitoring and provide accessibility and portability, empowering authorities, and individuals to take timely actions to mitigate air pollution risks [3]. This study uses sensors for detecting common pollutants, conducting data analysis, and implementing real-time air quality monitoring.

2. METHODOLOGY

This chapter will explain the methods for gathering and analyzing relevant data. This includes outlining the general study framework, illustrating the system architecture, and setting out the data analysis procedures.

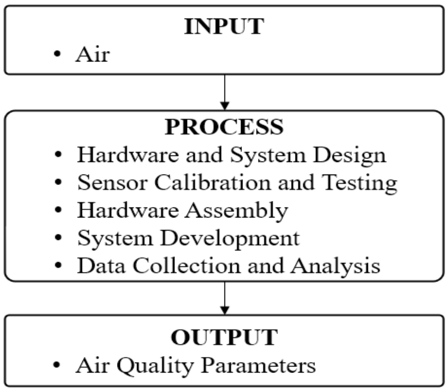

Fig. 1. General Framework of this study

The system development process in Fig. 1 starts with selecting components for the hardware, followed by designing the farmhouse and the system using SKETCH UP software. The final design is then executed manually and put through various processes. Components are installed and programmed accordingly, and performance evaluation is conducted to ensure system functionality.

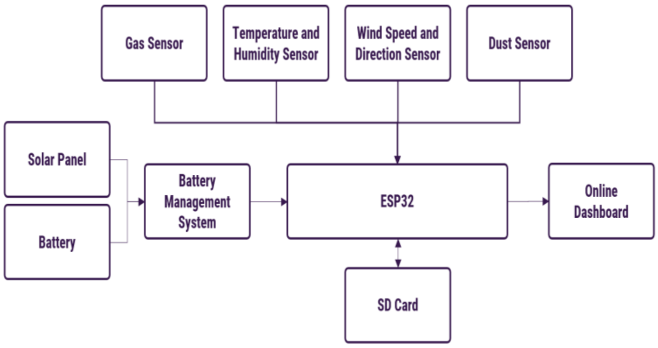

Fig. 3. Block diagram of the system.

2.1 **System Overview**
Fig. 2 demonstrates the complete block diagram of the system. The system diagram is divided into three (3) categories: input, process, and output. Various sensors, including gas, temperature, humidity, wind speed, direction, and dust sensors, will be purposefully integrated into the prototype to monitor multiple changes in data at the mining site. These sensors will collectively form the foundation for a real-time scenario detection system that continuously assesses incoming data streams. When dangerous gases or other serious disturbances occur, the algorithms will immediately recognize the issue via multiple outputs, such as storing the analog data to the SD card, web application, and mobile application.

2.2 System Design and Implementation

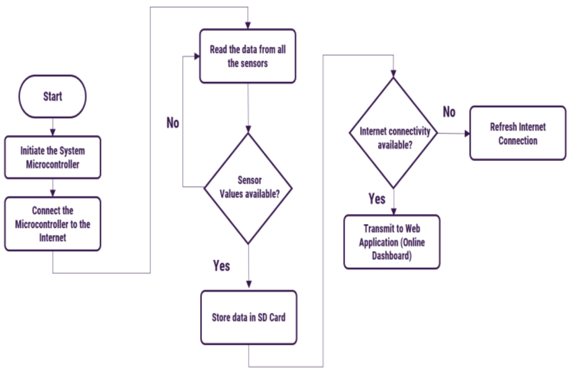

Fig. 4. Flowchart of the system.

As shown in Fig. 3, The hardware system demonstrates the integration of sensors and IoT cloud communication with the ESP32. The procedure begins with the system microcontroller's initialization, followed by a check for internet connectivity. The microcontroller connects to the internet via Wi-Fi and reads analog data from all the sensors. The system validates sensor data that surpasses specific criteria. If not, it keeps reading the sensor values and stores the data in the SD Card. The system also checks if there is internet connectivity involved in the system. The data is transmitted to the web and mobile applications if the internet is available. If not, the data is stored in the SD Card to give easier access to the user. Furthermore, the data will be transmitted to Firebase's online application via its API, while the mobile application talks with Firebase's API, allowing users to retrieve data and rapidly access sensor information.

2.3 Air Quality Monitoring System Casing

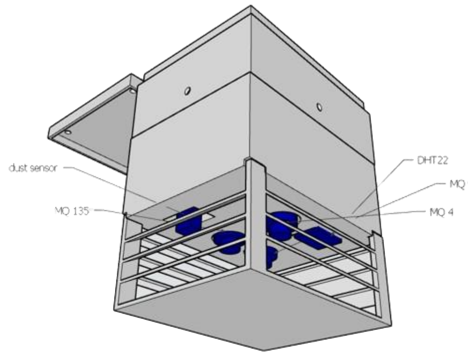

Fig. 2. 3D model of the IoT-based air quality monitoring system (side view).

The acrylic glass casing designed for the air quality monitoring system is a sturdy yet transparent enclosure, protecting the internal components and user visibility. With a simplistic box-like structure, the casing houses sensors, including the DHT22, MQ gas sensors, and Nova PM dust sensor at its base, ensuring optimal positioning for accurate data collection. This design not only enhances the durability and longevity of the device but also facilitates easy access for maintenance and calibration.

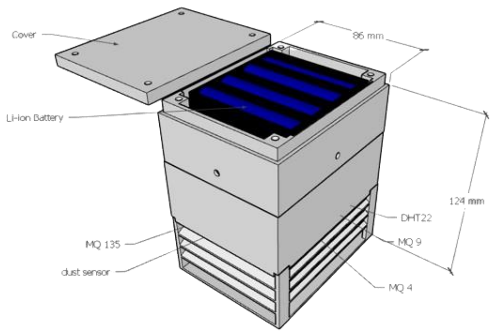

Fig. 5. 3D model of the IoT-based air quality monitoring system (top view).

2.4 Validation and Calibration of Sensors
Validation and calibration testing were conducted to ensure the accuracy of the Air Quality Monitoring system. The Lutron PM-1064SD was the control variable, providing precise temperature, humidity, and air quality measurements. By comparing the readings from the DHT22, MQ-Gas sensors, and dust sensors to those of the Lutron PM-1064SD, any discrepancies were identified and corrected for optimal conditions. The DHT22 sensors underwent validation by collecting data over an hour and storing it in the SD Card Module, enhancing measurement reliability and precision. For the MQ-135 sensor, specifically calibrated for carbon dioxide (CO_2) readings, a 48-hour preheating process and exposure to various carbon dioxide concentrations measured by the Lutron PM-1064SD were involved. A linear regression analysis was conducted to establish the relationship between sensor output voltage and carbon dioxide concentration. This calibration data was incorporated into the source code to accurately convert MQ-135 readings to carbon dioxide concentrations, then compared to the Lutron PM-1064SD readings for validation. These processes ensured the system's accuracy and reliability in monitoring air quality.

2.5 Data Gathering and Testing

The data collection process will involve a thorough testing phase, including extensively simulating different environments to study the IoT-based air quality monitoring system. The specific number of simulated locations will be compared with a highly accurate air quality monitoring system. This comparison will ensure a statistically valid and comprehensive approach to testing and gathering data. Such a method guarantees that the study's findings are strong and dependable, as it examines the system's performance and reliability across various conditions. This monitoring will occur for fifteen-thirty minutes, ensuring comprehensive data coverage. The collected data will be transmitted at regular intervals of 15 seconds to the online dashboard. This frequent data transmission allows for real-time detection in the designated area, enabling swift evaluation of the machine based on the gathered information.

2.6 Statistical Analysis of the Data

Examining IoT-based air quality monitoring systems requires precise and reliable data analysis methods. Various statistical techniques will be employed to ensure the validity of the findings. These methods include statistical measures like percentage error, root mean square error (RMSE), allowable error, and accuracy rate. Using these analytical tools, researchers can assess the system's effectiveness, detect deviations from expected detection outcomes, and validate assumptions. This thorough analysis enables the evaluation of system efficacy through continuous monitoring of air quality, including corresponding dust levels, wind direction, and wind speed analog readings, thereby providing valuable insights for future energy management endeavors.

2.7 Comparison of Data Values using Lutron PM-1064SD

The Lutron PM-1064SD is a cost-effective air quality monitoring device with a built-in SD card for storing data. This functionality allows users to evaluate any air quality issues that may arise effectively. The information gathered by the device is saved in a simple format, facilitating straightforward transfer and analysis using spreadsheet software. Comparing air quality monitoring devices to lab-graded sensors like the Lutron PM-1064SD ensures the data's accuracy, reliability, and quality. It helps validate the performance of monitoring devices, ensures compliance with standards and regulations, and enhances confidence in the results obtained from air quality assessments.

2.8 Fabrication of Device Casing

The Caraga Fabrication Laboratory (FABLAB) designed and fabricated the air quality monitoring system enclosure using a laser cutting machine, as shown in Fig. 6.

Fig. 6. IoT-Based air quality monitoring device.

3. DATA RESULTS AND ANALYSIS

The following figures present the results of the air quality monitoring system testing. These include the calibration testing results, which validate the accuracy of the system's sensors, as well as an analysis of the system's performance in 6 different locations.

3.1 Sensor Accuracy Results

Fig. 7 compares temperature readings from the DHT22 sensor and the Lutron PM-1064SD Indoor Air Quality Monitor. The RMSE values of both DHT22 sensors (0.258199) indicate relatively small errors, affirming their accuracy as temperature sensors. For the Fig. 8, the DHT22 sensor gauges temperature and tracks humidity levels in the surroundings. With an RMSE value of 0.529307724, the sensor demonstrates commendable accuracy in humidity measurement. The data suggests a direct correlation between the two sensors regarding humidity readings, implying that as one sensor's output rises, so does the other's. This correlation likely stems from the known relationship between temperature and humidity, where alterations in one factor can impact the other.

RMSE = 0.258199

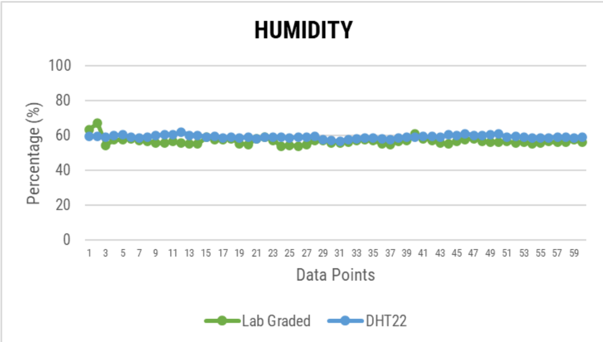

Fig. 7. DHT22 sensors calibration on temperature reading.

RMSE = 0.529308

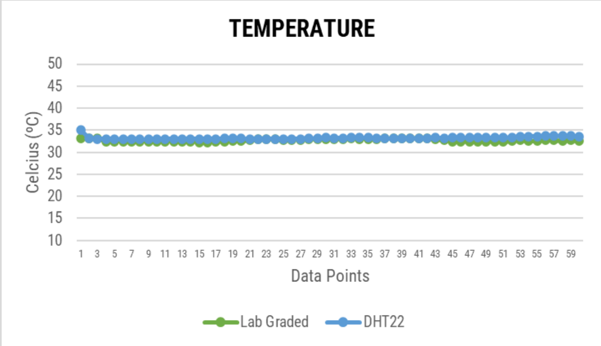

Fig. 8. DHT22 Sensors Calibration of Humidity Reading.

Fig. 7 compares temperature readings from the DHT22 sensor and the Lutron PM-1064SD Indoor Air Quality Monitor. The RMSE values of both DHT22 sensors (0.258199) indicate relatively small errors, affirming their accuracy as temperature sensors. For the Fig. 8, the DHT22 sensor gauges temperature and tracks humidity levels in the surroundings. With an RMSE value of 0.529307724, the sensor demonstrates commendable accuracy in humidity measurement. The data suggests a direct correlation between the two sensors regarding humidity readings, implying that as one sensor's output rises, so does the other's. This correlation likely stems from the known relationship between temperature and humidity, where alterations in one factor can impact the other.

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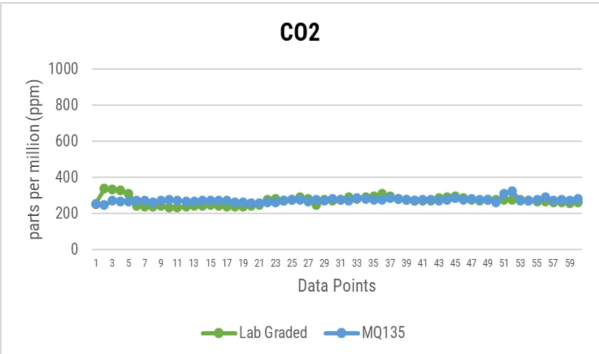

Fig. 9. MQ135 sensors calibration on air quality (CO_2 Level) reading.

RMSE = 0.167829

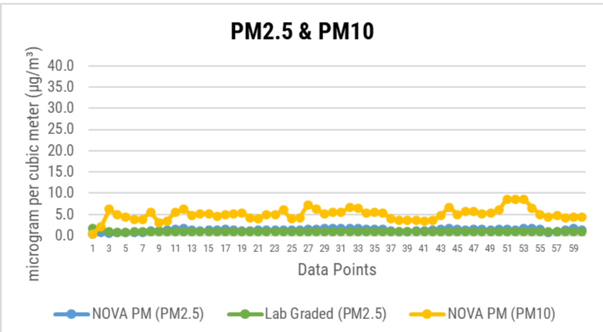

Fig. 10. Nova PM dust sensor calibration on dust sensor (PM2.5) reading.

In Fig. 9, the carbon dioxide (CO_2) readings consistently align, indicating strong accuracy with a low RMSE value of 0.25819889. This highlights the MQ135 sensor's excellent performance. In Fig. 10, comparing air quality readings between Nova PM Dust sensors and the Lutron PM-1064SD Indoor Air Quality Monitor regarding ppm levels reveals an inverse relationship: as one sensor's readings decrease, the other sensor's readings increase. Specifically, as the ppm readings of the Nova PM Dust sensor increase, the Lutron PM-1064SD also increases.

3.2 Comparison of the Temperature, Humidity, Carbon dioxide (CO_2), & PM2.5 (Particulate Matter) Readings among the Six Locations

Upon analyzing the data collected from these locations, significant variations in temperature and humidity were observed. Notably, the CSU Admin Building exhibited the highest temperature readings.

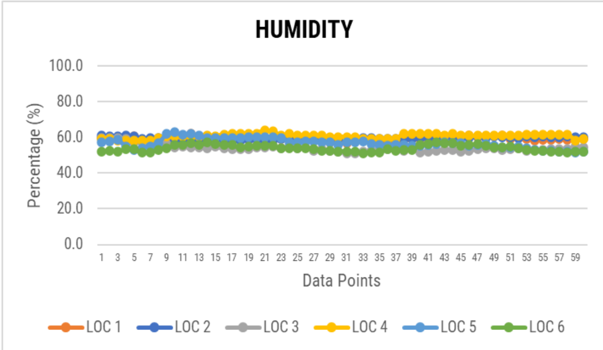

Fig. 11. Comparison of the temperature readings among six locations.

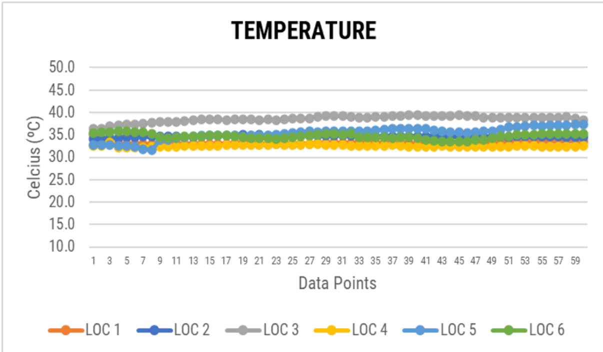

Fig. 12. Comparison of the Humidity Readings among six locations.

This phenomenon could be attributed to its direct exposure to sunlight and its adjacency to vehicular pathways, which likely contributed to increased heat absorption and retention. Moreover, the humidity levels were notably elevated at the CSU Main Gate location. This observation can be attributed to the proximity of passing vehicles, which could have influenced local wind patterns and moisture content in the air.

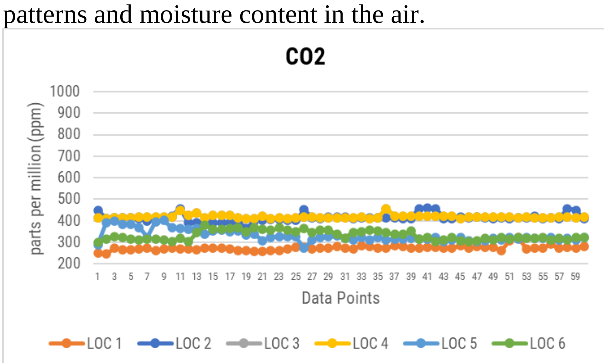

Fig. 13. Comparison of the Carbon Dioxide (CO_2) Readings among six locations.

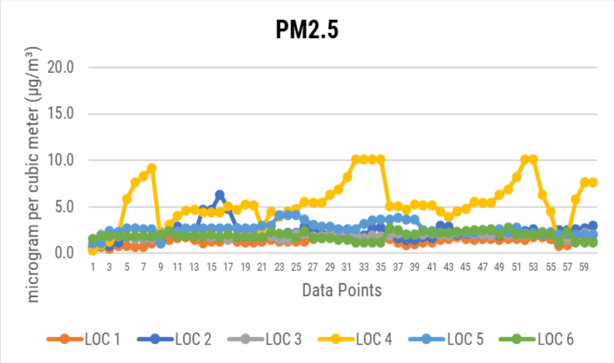

Fig. 14. Comparison of the PM2.5 Readings among six locations.

Elevated carbon dioxide (CO_2) concentrations were identified at the CSU Gymnasium and CSU Main Gate. This phenomenon can be attributed to several factors, including construction sites near these locations, which may have contributed to heightened emissions of hazardous gasses. Additionally, the emission of exhaust fumes from passing vehicles near these areas could have increased carbon dioxide levels in the surrounding atmosphere. Upon analysis of PM 2.5 (particulate matter) dust sensor data, it was observed that the CSU Main Gate consistently recorded significantly higher dust particles than other monitored sites. This disparity can be attributed to multiple factors identified during the study period. Firstly, vehicular traffic emissions contributed significantly to elevated dust levels from exhaust emissions and tire abrasion. Additionally, the presence of road dust, intensified by frequent disturbances to road surfaces due to high traffic volume, further increased the situation. Moreover, local wind patterns played a crucial role in dispersing particulate matter, potentially transporting pollutants from nearby sources to accumulate at the main gate location.

3.3 Functional Online Dashboard

The dashboard showcased (see Figures 15 and 16) serves as a tool for remotely monitoring data, facilitated by an Internet-of-Things (IoT) platform called Firebase, which is also accessible online. Utilizing this platform makes accessing information about environmental conditions straightforward. The dashboard provides a convenient method, such as showing the data in terms of cards, gauges, charts, and tables, for remotely monitoring the environment's conditions.

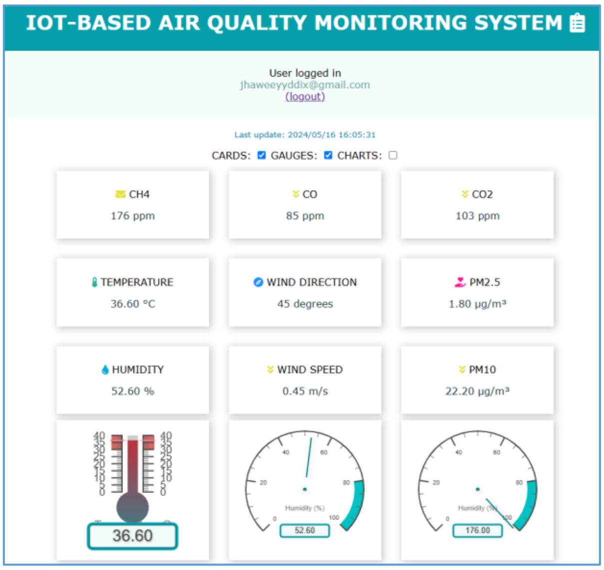

Fig. 15. Online dashboard cards and gauges.

Timestamp	CH4 (ppm)	CO (ppm)	CO2 (ppm)	Temperature (°C)	Humidity (%)	Wind Direction (degrees)	Wind Speed (m/s)	PM2.5 (μg/m³)	PM10 (μg/m³)
2024/05/16 16:05:31	176	85	103	36.60	52.60	45	0.45	1.80	22.20
2024/05/16 16:04:58	208	87	101	36.40	53.30	315	20.12	1.70	23.90
2024/05/16 16:04:18	205	95	108	36.10	54.00	90	0.89	2.70	27.40
2024/05/16 16:04:02	165	99	112	36.30	54.10	225	20.12	2.50	21.00
2024/05/16 16:03:46	272	105	107	36.20	53.70	113	0.89	1.70	12.90
2024/05/16 16:03:28	162	102	109	35.90	54.10	0	1.79		
2024/05/16 16:03:13	183	102	112	35.80	52.50	45	0.00	1.40	17.80
2024/05/16 16:02:57	209	96	110	35.60	52.90	45	2.24	1.20	17.00
2024/05/16 16:02:40	201	97	107	35.40	52.70	203	1.79	1.40	13.60
2024/05/16 16:02:24	167	97	110	35.70	52.10	315	0.00	1.60	17.60
2024/05/16 16:02:09	149	103	110	35.80	51.50	45	1.34	1.90	19.90
2024/05/16 16:01:53	221	99	110	36.00	51.30	0	0.89	2.10	23.10
2024/05/16 16:01:38	228	98	112	36.20	50.70	90	0.00	1.60	23.90
2024/05/16 16:01:23	162	99	106	36.30	51.70	45	0.89		
2024/05/16 16:01:08	197	95	108	36.30	51.00	315	0.89	1.10	7.50
2024/05/16 16:00:52	256	100	107	36.40	50.60	225	0.00	1.30	10.10
2024/05/16 16:00:37	157	103	112	36.30	51.40	0	0.89	1.40	13.10

Fig. 16. Online Dashboard Table.

4. CONCLUSIONS

This paper has successfully designed and developed an IoT-based air quality monitoring system for outdoor environmental conditions. The integration of IoT technology is vital for air quality monitoring, particularly in industries like mining, as it enables real-time monitoring and remote accessibility and ensures data accuracy and precision. The study demonstrated the reliability of DHT22 sensors for measuring temperature and humidity in environmental monitoring. The MQ gas and dust particle sensors also provided reliable findings when exposed to harmful gases. However, caution is recommended when using MQ-135 sensors due to potential discrepancies in accuracy compared to laboratory-grade sensors. The results highlighted higher gas concentration levels, notably within the CSU gymnasium and main gate entrance areas, attributed to dust from nearby construction sites and vehicular emissions. Other areas consistently maintained low gas concentration levels, signifying good air quality. Including wind speed and direction sensors proved integral, enabling precise determination of wind speed and direction over specific time intervals. The developed IoT-based air quality monitoring system can now detect harmful gases in the atmosphere and monitor data values through an online dashboard. This device is ready for deployment at Libjo Mining Corporation to address environmental monitoring needs effectively. For future research, it is recommended to add mobile application features for convenient access to real-time monitoring data on smartphones or tablets, facilitating widespread dissemination and engagement.

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