International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Real-Time Environmental Monitoring Using Low-Cost Sensors in Smart Cities with IoT

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Abstract:

In recent years, people are getting aware of environmental pollution which results in a growing demand for robust systems that is capable of monitoring environmental conditions in real time. An efficient air quality monitoring system is not only essential for public awareness but also has significant industrial applications. For instance, in mining and heavy industries, there is a risk of air pollution from various hazardous gases, and having an effective monitoring system could be life-saving for employees. Within the context of expensive sensor networks, challenges such as data acquisition, management, connectivity, and energy consumption is getting too high. Internet of Things (IoT) technology addresses these challenges. This study introduces an IoT-based framework designed to track environmental conditions with the help of several sensors. This system enables users to measure temperature, humidity, and the presence of dangerous gases in both indoor and outdoor settings. Data collected is stored on a web server, accessible globally via the internet. Moreover, a specially designed web application provides critical information and allows users to receive notifications for significant environmental fluctuations detected by the sensors. Compared to similar systems, our proposed solution stands out due to its affordability, precision, user-friendly interface, cloud-based architecture, and its comprehensive monitoring and data visualization capabilities. The system underwent rigorous evaluation in various scenarios, demonstrating a high level of accuracy and dependability in its performance.

Index terms: Environmental Monitoring Systems, Internet of Things (IoT), Low Cost Sensors.

I. INTRODUCTION

This Nowadays Pollutants in the air have a significant impact on human lives and climate change. Climate change and air pollution are inextricably linked and both can directly or indirectly affect the health of livings. Poor air quality degrades our planet's and initiates the climate change. The amount of incoming sunlight is affected by air pollutants such as tropospheric ozone, methane, carbon and aerosols which causes the rise in temperature of the Earth, which also effects icebergs, and glaciers to melt [1]. Climate change research has primarily concentrated on the physical climate system, such as weather, temperature rise and fall, humidity, mq2 and sea level rise, among other things. From the last two decades the interconnected nature of air pollution and climate change problems has been recognized in such a way that, both air pollution and climate change affect public health as well as ecosystem of health [2]. Globally, 90% of individuals are exposed to polluted air, which causes premature death. due to diseases such as lung cancer, stroke, obesity, and respiratory illnesses, all linked to poor air quality [3], so that's why ensuring clean, safe and pollution free environment is crucial for humanity's long-term survival and the progress of nations.

To ensure the healthier and safer environment for all livings, it is essential to manage the climate change and maintain the air quality. Nowadays, Government and Public organizations are preparing themselves to tackle these upcoming challenges related to the social and environmental levels, aiming to improve environmental conditions within a specific region. To adapt with the ever-changing environments, researchers have proposed variety of IoT based intelligent systems. These systems include the technologies for home automation [4], traffic and accident surveillance [5], smart city initiatives [6], automated irrigation systems [7], robotics for solving real-world problems [8], wireless sensor networks [9], and web-based services [10], among others. According to the systems referenced in [4], [5], [6], [7], [8], [9], [10] have proposed several method to observe and analyze environmental conditions. Internet The IoT sensors such as Air sensor track and monitor the air quality and IoT based systems that incorporates several IoT components to gather data through IoT-enabled devices serve as an effective mechanism for assessing both indoor and outdoor environments. For the comprehensive understanding of environmental conditions, IoT sensors enable us to monitor several parameters which include Smoke, Methane, Liquid Natural Gas (LNG), Nitrogen-based gases, Carbon-based gases, as well as Air Temperature and Humidity. By monitoring these key parameters, we can monitor environmental conditions and can take necessary initiatives to maintain the sustainability inside our environment . In this research, our proposed system offers a real time tracking and monitoring environmental parameters within a specific area through IoT technology and later it can be extended over different areas for effective monitoring using IoT technologies. The project includes the features to identify harmful gases and several type of compounds in the atmosphere and allow us to track and record the information continuously. Moreover, the system also transmits the information to the cloud and from cloud the information is transmitted to the applications.

II. LITERATURE REVIEW

Several studies Monitoring the air pollution and environmental climate change has become challenge to keep an eye, especially the air we breathe. Sustainability in our environment is the crucial part to maintain good air quality. Air quality is not just the statistic value, it is all about how healthy or harmful our surroundings are. It affects everything from our health to the health of our planet. Recognizing this, many projects are turning to something called the Internet of Things which helps us to monitor our environment. Inside IoT, several devices or sensors connects with each other and shares their data for further processing or for further predictions. Connecting different sensors inside a city can be a powerful setup because it can quickly indicate the area, when and where the air gets dirty and take steps to clean it up. Many researchers have proposed different architectures to monitor the environmental quality, such as in [11], authors has developed an IoT-based low-cost weather station and monitoring system for the agriculture in India. In this project, authors used several components like sensors for measuring weather parameters (such as wind speed, wind direction, temperature, relative humidity, and dew point), a microcontroller to collect and process the sensor data, and a Wi-Fi module to send the data to a cloud-server database. Moreover, in this project, authors also included an OLED display for visualizing the weather parameters and providing user alerts aiming to bring agriculture closer to technology and make it more profitable, less labor-intensive, and sustainable. Moreover, in another project, [12], authors developed an IoT-based weather monitoring system. This developed system includes several sensors measure wind direction, wind speed, temperature, and humidity. In this project, authors used Arduino MKR1000 as the microcontroller unit (MCU) to receive sensor data which is communicated via Modbus protocol and can be access through Wi-Fi connection and stores the data inside MySQL database. Additionally, in this project, Raspberry Pi has been used as the hardware. The website was based on PHP script-language which can be access via web-page to visualize the data and analyze the charts for weather monitoring. Similarly, the authors of [13] has developed a low-cost IoT-based climate monitoring and controlling system. This system measures the weather parameters, and store them in a remote server. Thes system consist of several sensors for measuring CO2 level in the air, temperature, relative humidity (RH), pressure, light intensity, wind speed, wind direction, rain gauge, and soil moisture. Moreover, this proposed system also uses microcontroller as a gateway to connect with the server Python coded program to push the data to the server. Additionally, the authors also developed data modeling using TensorFlow and Python to model the greenhouse controlling mechanism. By using several machine learning models, authors used multivariate regression with parameters such as temperature, humidity, light, pressure, and CO2 to determine the time for switching on the exhaust fan and sprinklers.

III. SYSTEM ARCHITECTURE

In this section, the proposed environmental monitoring system is designed to collect and evaluate data on different environmental factors without interruption. In the upcoming sections, initially the system model, architecture and functionalities of the system will be explained. Moreover, the upcoming section will also explain the process of collecting, storing and processing the data to provide insights into environmental conditions.

1) System Model

In Figure 1, the overall system architecture is depicted, in which the sensor nodes are randomly deployed at the bottom in an environment. Whereas all of the sensor nodes are connected with a central server which maintains the infrastructure of star topology. The star topology is selected because of it's reliability. In the star topology, if any sensor node failed to connect or stops responding, it will not effect the whole network, moreover, in star topology, because of lack of interconnecting lines between the sensors indicates that data travels directly to the central node, which reduces the chance of data collision. To connect the nodes with internet a specific gateway is used. This gateway acts as intermediary between the local network (sensors) and the bigger network (Big Data cloud). The gateway facilitates communication and can be either wired or wireless, offering flexibility as per availability of resources. The gateway also manages the data processing and transmission to the Big Data cloud. This centralization is designed to keep the power consumption low at the node level, which aligns with the energy efficiency in the sensor nodes.

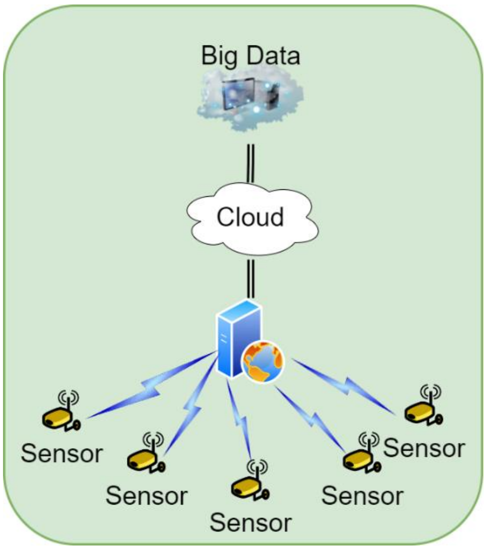

Figure 1: System Model in Sensor Nodes.

2) Logical Data Model

Figure 2 illustrates the logical data flow model of the proposed system. In the proposed system, multiple nodes collects data and send the realtime information to centralized system for processing via specific router or internet. Once the data from the nodes is received by ThingSpeak API. ThingSpeak is a service which allows for the creation of channels for each node, where data can be sent and organized. The API Key associated with each channel ensures that the data is securely managed and properly segregated in the database. After the data is collection process, it begins with aggregation and analysis process which store the data inside database and aggregate the data which is processed via Big Data tools including BigQuery, and Cloud Datalab. These tools process the data in several stages—Dataflow for stream and batch data processing, BigQuery for storage and SQL queries, and Cloud Datalab for advanced analysis and machine learning. Finally, the output from these tools can be visualized, as shown by the monitor with graphs. This indicates that the system allows for the graphical representation of processed data, making it easier for users to interpret and derive insights.

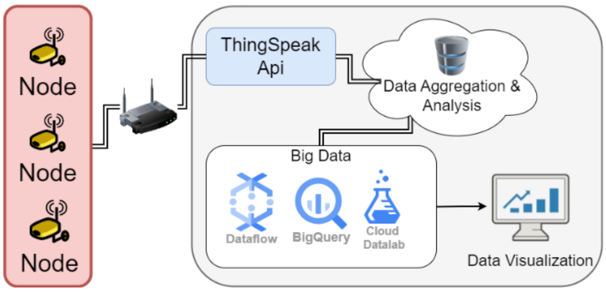

Figure 2: logical Data Flow Model

3) Device Design

Figure 3 illustrates the design of the device which consists of the connections between multiple components of the device's power management and data handling systems. Initially, the device is featured with multiple input options for the power supply. In the device the power options are switchable, so if one power source is not avalible it can use the other source such as, this device can run on Solar Cells, AC Supply or can also use the battery. Solar cells and the main AC supply are the primary sources for the device. In cases of AC supply failure or absence of solar power, such as in night times, or in unrealistic weather the system seamlessly transitions to battery power for uninterrupted operation.

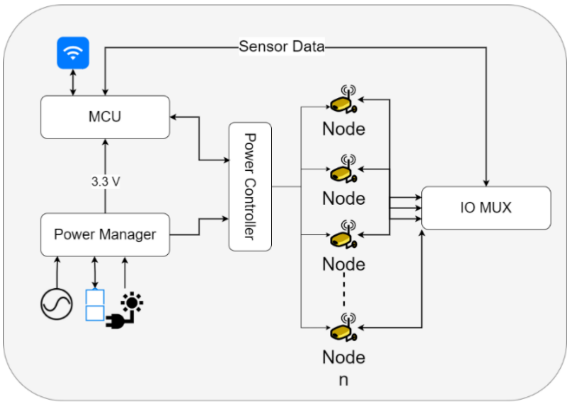

Figure 3: Device Design

The integration of a buck-boost converter stabilizes the variable output from the solar cell. It helps in standardizing any input between 3V to 18V down to a steady 15V for the battery charging system. The power supply consists of 1500 mAh, having 12.5-volt with lithium-ion battery. The battery is safeguarded by a charging protection circuit to prevent overcharging or deep discharge. Moreover, dual buck modules are also employed to the device to efficiently step down the voltage to meet the different requirements of the system components which includes the ESP8266 and nodeMCU board at 3.3V, and the various sensors at either 5V or 12V.

Figure 4: ESP8266-Node MCU

At the heart of the device is the ESP8266 (as shown in figure 4), which functions as the main processing unit. It is responsible for the data collection from several sensors, and format the data, and send it to sensor gateway. The incorporation of an IO mux in the design allows the system for additional sensors if needed. Furthermore, a dedicated power controller manages the energy supplied to the sensors, adjusting the voltage as per their individual requirements and even disconnecting power to inactive sensors to conserve energy. This power controller can analyze the unused sensors and to operate efficiently it can stop the power supply to unused sensors and adapts to varying power conditions, and provides scalability for sensor integration.

The power controller unit consists of 12v boost converter and MOSFET array. When the power control unit receives the request by the MCU, it activates a specific sensor as instructed by MCU and also ensures the regular and correct current and voltage levels. By following this, the MCU receives the data from the activated sensor and process it. Once the MCU receives whole required data, it deactivates the sensor by sending a command to power control unit, which results in minimizing the current useage, and optimizing power efficiency.

4) Used Sensors

The proposed device is designed to be compatible with multiple number of sensors that detect different environmental conditions and gas concentrations. In this project, several environmental sensors has been used such as MQ2, MQ4, MQ135 and DHT22 Sensor as shown in figure 5.

Figure 5: Used Sensors

The MQ2 sensor utilizes MOS (Metal Oxide Semiconductor) technology. This sensor works with 5V DC power supply and consume power up to 800mW. MQ2 sensor is capable to detect a variety of substances, including LPG, alcohol, smoke, propane, methane, hydrogen and carbon monoxide, within a specific detection range of 200 to 10000 parts per million (ppm). Another sensor called MQ4, which also uses MOS technology and is specifically designed for sensing methane. MQ4 sensor produces an analog voltage output that corresponds to the concentration of methane it detects in the air. Moreover, it detects the gasses from 300 parts per million (ppm) to 10,000 ppm, and is mostly used to identify gas leaks. Similarly, MQ-135 sensor which also uses MOS technology. This sensor is used to identify a range of hazardous gases, which includes Ammonia (NH3), Sulfur (S), Benzene (C6H6), CO2, as well as smoke. This sensor is mostly used in industrial places for leakage detection. These sensors have digital and analog output pins. The digital output is triggered when the concentration of gases exceeds a pre-set threshold in the environment. We can adjust the threshold to the desired level by using the integrated potentiometer on the sensor. And the last sensor used in the project is DTH22 sensor. Which comes with improved specifications within less cost. It's main usage is to measure temperature and humidity. It uses humidity sensor and thermistor to measure air temperature. The measurement range of sensor is from -40 to +125 degrees Celsius, and maintain the accuracy of ±0.5 degrees.

IV. DATA COLLECTION PROCEDURE

The device transmits data to the gateway, accompanied by its API key. Subsequently, the gateway uploads this data onto the ThingSpeak server. Noteworthy is the device's rapid startup capability. A scheduler is in place to periodically gather data from the sensor, which it then temporarily stores in the RAM, along with a time stamp. In an effort to minimize power usage, the device sends all accumulated sensor readings to the server in a single batch. The frequency of data collection by the scheduler is adjustable; in the scenario presented, it is set to activate every five minutes. Users have the flexibility to tailor the scheduler's timing to their specific requirements. When inactive, the scheduler switches the device to sleep mode as a measure to save energy.

Data visualization on the ThingSpeak platform is achieved through an array of graphs and charts that display both time stamps and sensor readings. Users can set up alerts on the ThingSpeak server that trigger when readings from a particular sensor exceed set threshold values. Additionally, there is an option to export the collected data from the ThingSpeak server in CSV or JSON formats for further analysis. To halt the data collection process, one must simply power down the system.

V. IMPLEMENTATION AND TESTING

The device is enclosed within a 3D-printed (FDM) box. All of the components were enclosed inside the box the components include different sensors as mentioned above, circuit board, and the battery. The Connections between the sensors, microcontrollers, and the main project board were established by using detachable connectors that reflects the versatility of microcontrollers in a wide range of applications. In the FDM box, the design segregates the battery into a lower compartment, which allow for easy insertion and removal of battery, while the upper compartment accommodates the circuitry and sensors, with the gas sensors specifically positioned along the enclosure's sides.

The device's electrical architecture includes a dual-voltage buck converter system, supplying 5v for the sensor suite and 3.3v for the NodeMCU module. The NodeMCU processes the data from each sensor, and organize it, and transmits it to an online database as shown in architectural diagram Figure 3. The battery backup for this system was 1500 mAh, 12.5-volt battery. Moreover, the online database maintains the record of various environmental metrics, such as levels of carbon monoxide, smoke, carbon dioxide, methane, natural gas, and particulate matter, serving as an important resource for further data analysis and research.

Figure 6: Hardware Implementation Design.

When the device is powered on, the sensors activate, ready to detect gases. Inside each gas sensor is a filament that heats up upon exposure to gas. Normally, in clean air, heated tin dioxide (the sensing material) reacts with oxygen, preventing electrical current from flowing due to high resistance. However, when volatile gases are present, they reduce the oxygen concentration, allowing the tin dioxide to conduct electricity more effectively due to lower resistance in the reduced oxygen environment. This change in the filament's resistance indicates the presence and concentration of specific gases, with the sensor outputting analog signals that vary proportionally to the detected gas levels. Contrastingly, the device's temperature and humidity sensor operates digitally, utilizing a resistive thermistor to gauge temperature and a capacitive element for humidity detection. These digital sensors offer precise measurements that are then transmitted to a server for analysis and display. The collected data from all sensors is visualized on charts that include time and date stamps, allowing for easy monitoring of environmental conditions over time. This data is accessible on the ThingSpeak platform and can be downloaded in CSV or JSON formats for further analysis. The flexibility of the system enables detailed tracking of conditions from minute to minute or over extended periods, as illustrated in Figures 6 which detail the system's design and functionality.

VI. RESULTS

In this section, the outcomes of the conducted indoor experiments have been discussed. In the project, the sensor were placed to monitor the environment. To test the sensors' responsiveness, the environment was artificially manipulated by introducing several type of gasses such as smoke, igniting LPG fuel, etc., resulting in deviations from baseline environmental readings. These variations were captured and displayed in real-time, as illustrated in Figure 5. In the experiment, MQ2 sensor immediately respond to the presence of smoke, indicating its detection on the display. Similarly, the MQ4 sensor also identified the methane gas which was released within the laboratory setting. The experiment also involved the release of NOx gases, which the MQ135 sensor detected immediately, displaying its concentration in parts per million (PPM) in real-time. The DHT22 sensor proved its efficacy by accurately measuring temperature and humidity levels, with these readings visualized on the ThingSpeak dashboard through real-time graphs. This setup allowed for the analysis of gas behaviors relative to changes in humidity and temperature.

Additionally, a dust sensor quantified airborne particulate matter in micrograms per cubic meter, and a GPS sensor provided precise geographical coordinates during outdoor operation, enhancing the environmental data's context. The experimental setup was placed within a box-shaped unit integrating all sensors, microcontrollers, and a Vero board inside the box. This unit featured designated compartments for the battery, circuit boards, and sensors, with a user-friendly design allowing easy access for maintenance or adjustments. Gas sensors were strategically placed on one side of the box, with dust and humidity sensors on the opposite side, ensuring a tidy and efficient arrangement of the various components.

The main challenging aspect in the project was managing the power supply system which required to support 24 distinct processes and data collection tasks. The design incorporated three power sources: a 12V adapter for AC mains connection, a battery backup, and a solar panel, ensuring continuous operation. This redundancy is crucial, as any malfunction in the power supply could lead to a complete system failure, underscoring the importance of having reliable alternative power sources.

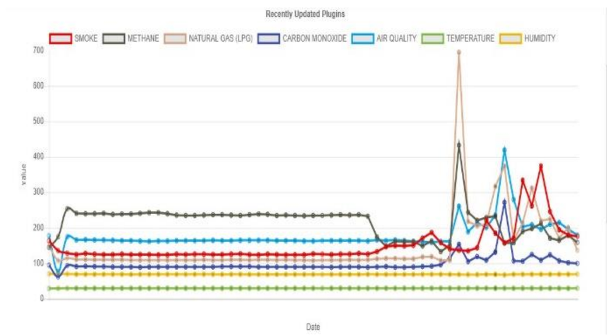

Figure 7: All Sensors Data Graph in Unstable Environment.

The figure 7 presents a comprehensive graph that tracks the concentrations of various gases and environmental parameters over time. The graph shows fluctuations in the levels of smoke, methane, natural gas (LPG), carbon monoxide, air quality, temperature, and humidity, with each parameter represented by a distinct color. Notably, there are peaks in the graph which represents the release of gases during the experiment to test sensor responsiveness. The graph also illustrates the sensors' ability to detect real time changes in the environment, with the smoke sensor, for instance, showing a significant rise,

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indicative of smoke detection. This real-time monitoring is crucial for early warning in safety-critical applications

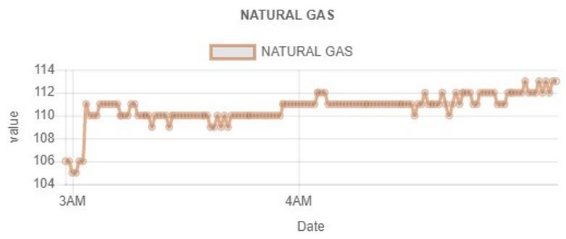

Figure 8: Natural Gas

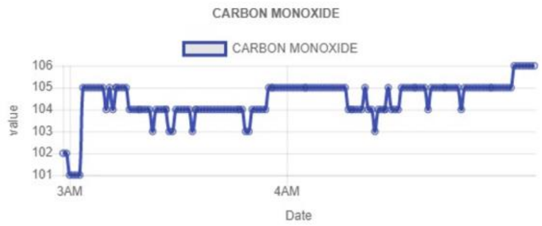

Figure 9: Carbon Monoxide

Figure 10: Air Quality

Figure 10: Temperature

While the figure 8-11 appears to be a collection of four separate graphs, each monitoring a specific gas or environmental variable which includes natural gases, carbon monoxide, air quality, and temperature. Each graph presents a steady trend with minor fluctuations over time, providing detailed insights into the stability and sensitivity of the sensor array under controlled conditions. The data visualization on the ThingSpeak platform, as depicted in both figures, underscores the system's effectiveness in capturing and relaying real-time environmental data, thus affirming the viability of the deployed sensor network for continuous monitoring and data-driven decision-making in various applications.

CONCLUSION

In this study, we have developed an Environment Monitoring System using cost-effective and widely available components. This system offers adaptable solutions for monitoring a wide array of environmental conditions. Designed to be versatile, it can be effortlessly utilized in both indoor and outdoor settings. The system has undergone multiple tests across various controlled environments to validate its real-time performance. Additionally, its connectivity options, which include Bluetooth, Infrared, and WiFi, enable smooth integration into diverse settings without the need for significant design modifications. The framework of the proposed system is both flexible and scalable. In the future, we aim to enhance the system's capabilities by integrating advanced machine learning algorithms, which will provide users with deeper insights and increase the system's practical utility and efficiency.

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