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Development of an IoT-Based Environmental Monitoring, Prediction and Control System for Carbon-Momoxide and Liquefied Petroleum Gas (LPG)

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Abstract

Air pollutants pose significant threats to environmental and human health, making air quality monitoring essential for ensuring safety in various environments. This study presents the development and implementation of an Internet of Things (IoT)-based environmental pollutant monitoring system utilizing a network of sensors (MQ-2 and ESP01) integrated with an Arduino microcontroller. The system was analyzed using the Object-Oriented Approach and Unified Modeling Language (UML) notation symbols for clear design representation. A Prophet Model was employed as the prediction model, enabling the system to forecast pollutant levels based on historical data. The system was designed to monitor and analyze air quality in real-time, measuring pollutants such as carbon monoxide (CO) and liquefied petroleum gas (LPG) based on the Parts per Million (PPM) metric. It also featured a control mechanism for CO levels by triggering alerts and mitigation processes when thresholds were exceeded, while effectively detecting LPG leaks. Data collected were logged to a remote server and updated over the internet, ensuring accessibility via any smart mobile device through cloud integration. This system fits within the broader category of IoT-based Environmental and Safety Monitoring Systems. This IoT-based system provides a scalable, efficient solution for air quality monitoring and control, contributing to improved environmental safety.

Keywords: *IOT, Microcontroller, Carbon Monoxide, LPG, Sensors, Arduino, Machine Learning.*

I. INTRODUCTION

Air is an important element in man's world. The entire atmospheric air contains gases like Nitrogen, Oxygen, Carbon (II) Oxide and little quantity of rare gases. For air to be useful to both humans and animals, it has to be free from contaminants. Any change in the ideal composition of air can cause serious harm to humans and animals. Air pollution implies the occurrence of one or more contaminants in the atmosphere in such a quantity or amount that could cause harm to living things [1].

Everyone has the right to pollution free air [1]. Notwithstanding, when Carbon (II) Oxide, Nitrogen (II) Oxide and other common atmospheric pollutant infiltrate into the atmosphere, they undergo certain chemical reactions to form secondary pollutants. Some of the pollutants can remain in the atmosphere for weeks or even months. Other pollutants like methane can linger or circulate in the atmosphere for years till they are broken down into the soil through rain or snow [2]. Air quality monitoring or measurement means a methodical or regular measurement of air pollutants in order to ascertain those who may be vulnerable based on the provided standards and guidelines. Atmospheric air pollutant concentrations are affected by area or time of emission of dangerous substances and the rates with which they circulate in the air [3]. The strategies and activities that are put together to monitor air quality is described as environmental monitoring.

Polluted air does not just affect you and your family but the entire environment. It is one of the most important concerns of today's world. People are killed by bad air quality. The World Health Organization estimates that in 2016, poor outdoor air quality contributed to 4.2 million premature deaths globally, with low- and middle-income countries accounting for 90% of these deaths. Higher incidences of cancer, heart disease, stroke, and respiratory conditions including asthma have all been related to air pollution [4]. The American Lung Association estimates that air pollution puts nearly 134 million Americans—more than 40% of the population—at risk of illness and early mortality [5].

Timely detection of air pollution as well as finding out the source and nature of the pollutants is a great deal important for environmental protection. The existing environmental pollutant monitoring systems suffer from various limitations, such as high cost, limited spatial coverage, and lack of real-time data acquisition, analysis, prediction and control. Additionally, these systems often require extensive manual intervention and lack the capability to predict future pollution levels accurately. There is a need to develop an advanced system that can overcome these limitations and provide reliable real-time monitoring, control, prediction and analysis of environmental pollutants. The aim of this study is to develop a system for environmental pollution monitoring, prediction and control for carbon monoxide (CO) and liquefied petroleum gas (LPG).

II. LITERATURE

A system for tracking and predicting air pollution based on the Internet of Things was suggested in [6]. This system can be used to forecast the quality of the air, analyze the quality, and monitor its contaminants in a specific area. The suggested system leverages the Internet of Things (IoT) in conjunction with a machine learning technique known as Recurrent Neural Network, or more precisely Long Short-Term Memory (LSTM), to monitor air contaminants. Air sensors are used by the system to identify and provide this data to the microcontroller. The data is then stored by the microcontroller of the web server. To make predictions, the LSTM is used. It minimizes the training cycles accurately and with rapid convergence. This study does not mention any calibration or validation procedures for the sensors used in the system. Calibration is essential to ensure the accuracy and consistency of sensor readings, especially in environmental monitoring applications where precise measurements are crucial for detecting pollutant levels accurately.

In [7], the authors described a successful usage of the Internet of Things to tracking air pollution levels based on the Malaysia Air Pollution Index (API). The low-cost, real-time system would be able to track standard air quality contaminants, such as particulate matter (PM) of PM2.5, PM10, and CO gas, in addition to environmental temperature and humidity. The API statuses of Good, Moderate, Unhealthy, Very Unhealthy, and Hazardous can be detected by the system. In order to identify the severity of the air quality, the system is built to be able to measure a number of common air quality indices and harmonize the results with the Malaysia Air Pollutant Index. However, the data transmission over a wireless network to the internet and the data presentation on a specific webpage were not included in the system. It did not incorporate mechanisms for data aggregation, processing, or analysis.

An Internet of Things (IOT)-based approach to track a region's noise intensity and air quality index was proposed in [8]. The four elements that make up the suggested technology are the Sound Intensity Detection Module, the Cloud-based Monitoring Module, the Anomaly Notification Module, and the Air Quality Index Monitoring Module. First, the existence of the five criterion air pollutants is taken into account while measuring the Air Quality Index. Next, the appropriate sensor is used to detect sound intensity. Subsequently, the Cloud-based Monitoring Module guarantees the data acquisition procedure using the Raspberry Pi's built-in Wi-Fi module, achieving the goal of periodic information analysis. Lastly, in the event of an undesirable state, the user is notified via the Anomaly Notification Module. Although the study mentioned sending notification messages to users when unhealthy conditions are met, it lacks details on the criteria used to determine unhealthy conditions and the threshold values for triggering notifications. Clear and well-defined criteria are essential for accurately identifying and responding to potentially hazardous air quality conditions in a timely manner.

The use of a wireless sensor network to track the amounts of different contaminants in the air as a result of environmental changes was presented in [9]. This system suggests a technique that primarily focuses on extending the sustain time of a sensor network by efficient energy management, efficient processing of the data gathered, and reduced overhead in the information transfer between different sensor nodes. To identify the sensor values when a sensor grid is present, various gas sensors are used. Additionally, data mining is employed to compute the contaminants from various areas. The values based on probability are calculated using the ID3 algorithm. Using a Bluetooth module, the controller establishes a connection with the client, and the client uses web services to interact with the server. Utilizing wireless sensors, the percentage of airborne hazardous chemicals can be determined.

An integrated system that combined wireless sensor networks and machine learning algorithms to monitor and predict environmental parameters, including pollutants, was proposed in [10]. The system employed data analysis techniques to identify patterns and predict future pollutant levels. But the study does not mention any calibration or validation procedures for the sensors used in the system. Calibration is essential to ensure the accuracy and consistency of sensor readings, especially in environmental monitoring applications where precise measurements are crucial for detecting pollutant levels accurately. Without proper calibration, there may be inaccuracies or biases in the data collected, leading to unreliable results and conclusions.

The use of a Raspberry Pi 3 B+ microprocessor, gas sensors, a PM sensor, an analog to digital converter (ADC), and several filters (step-by-step filtering of particles from sizes 200 to to 0.3µm was done by different filters) was proposed in [11].The result is transmitted to Thing speak cloud through WiFi module can be viewed through any system or mobile in Thing speak cloud platform. The proposed system cannot predict future air quality of an environment.

III. MATERIALS AND METHODS

This study proposes an environmental pollution monitoring system with machine learning analysis. The system has three major parts. The first part of the system is a data acquisition system of nodes/pairs of sensors; the second part is the attendant microcontroller which is used to gather pollutant parameters at any particular point of interest, the third, implementing machine learning algorithms for real-time analysis and prediction of pollutant levels based on the collected data. The sensors gather the pollutants' information and send them to the microcontroller. The microcontroller sends the data to the internet through a Wi-fi connection to an online database. It is then fetched for data analysis and data modeling to forecast future values. The system categorizes the gaseous values as "good", "moderate", "slightly moderate", "not safe", and "dangerous". The categorization was done in line with Occupational Safety and Health Association (OSHA) Carbon Monoxide recommended safe level. 0-50ppm (parts per million) was categorized as "good"; 51-150 ppm was categorized as "moderate"; 151-200 "slightly moderate", 201-300 ppm as "not safe" and 301-950 ppm or above as "dangerous". Also, 1-250ppm was identified as carbon monoxide (CO) and 251-950ppm as Liquefied Petroleum Gas (LPG).

The software component was designed using the Unified Modelling Language (UML) notation symbols and the object-oriented approach to system analysis. Diagrams are used in the Object-Oriented Analysis and Design (OOAD) technique to describe an object-based breakdown of systems and to illustrate how these objects interact and behave dynamically.

- *Use case Diagram of the New System*

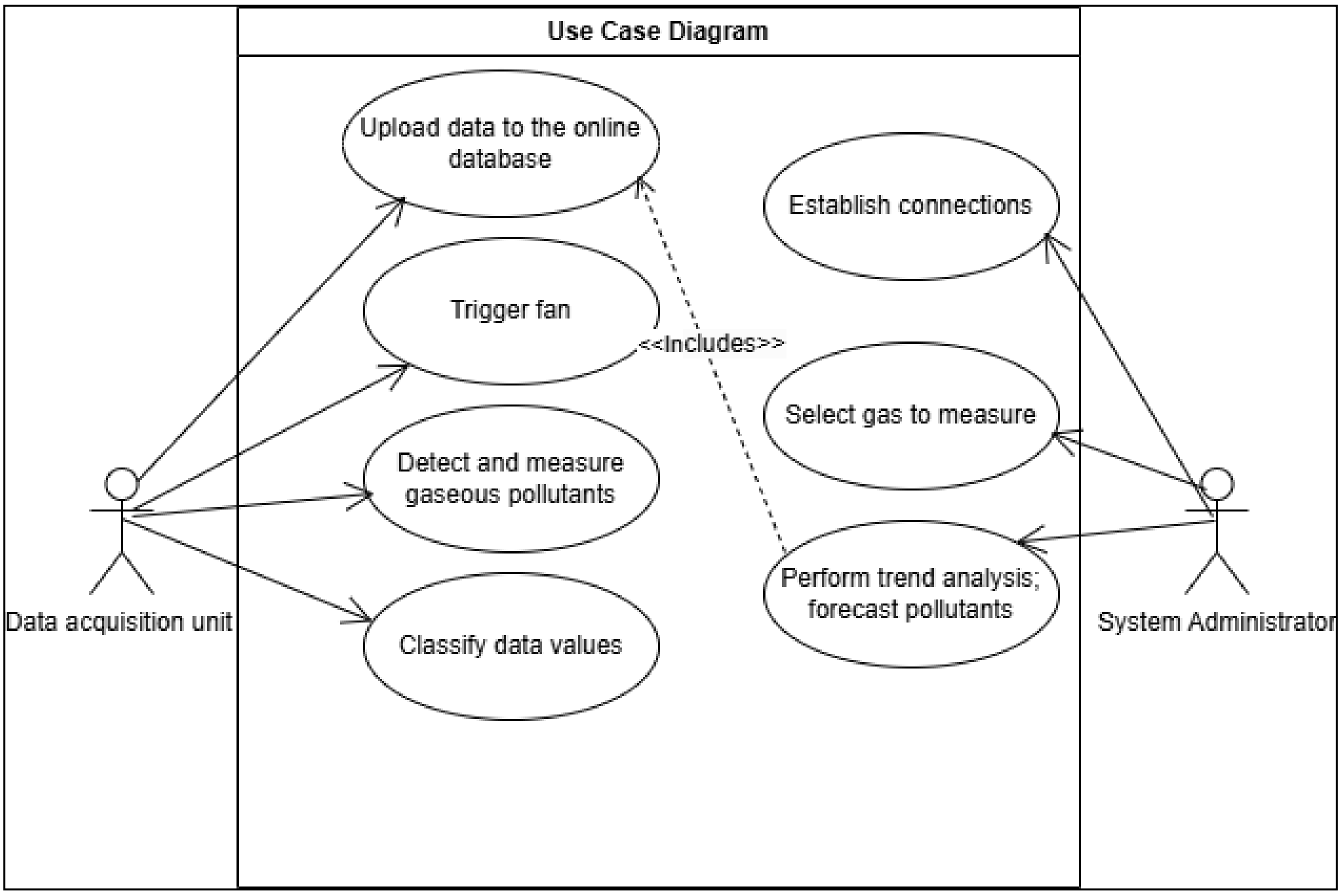

Fig 1 Use Case Model for the New Environmental Data Monitoring System

From the diagram above, the system has two major actors: the system administrator and the data acquisition unit. The system administrator establishes connection for the hardware and software components of the system, selects the gas type to measure and performs the trend analysis. The data acquisition unit on the other hand, detects and measures gaseous pollutant. Classifies data values and uploads acquired environmental data to the online database.

- *Block Diagram of the New System is Given in Figure 2.*

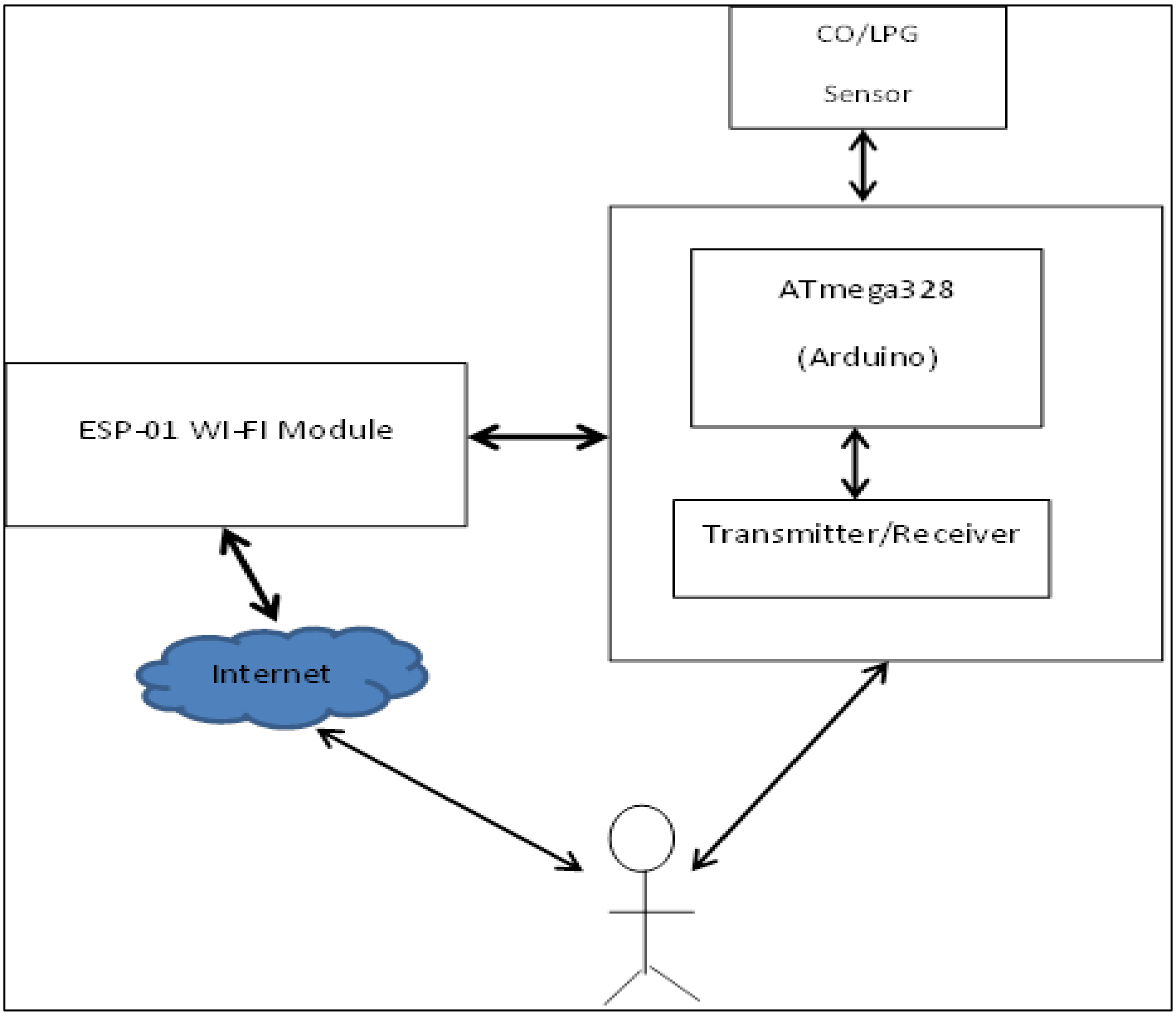

Fig 2 Block Design of the Hardware for Pollution Monitoring.

The new pollution detection and monitoring unit is made up of an *Arduino UNO* microcontroller and an MQ7 gas sensor. This unit uses the gaseous sensor as an input node and sends gaseous data to the microcontroller. The microcontroller analyses the data and transfers it through a USB port to a PC or terminal where data is presented in a visual form to the user. The obtained data is also stored in a database for future use and uploaded to the internet for real time access by the public. The workstation provides power via a USB port. The 5volts power provided by the workstation provides power for the microcontroller and the gaseous sensor. This removes the load of sourcing for external power unit for the entire system thereby reducing cost and size of the hardware.

- *The Prophet Forecasting Model*

The Prophet Forecasting Model (PFM) is used in analyzing time series data with trends, seasonal and holiday day. PFM is an effective tool for precise and better forecasting, and it does not take time to fit. The model is presented as:

$$y(t) = g(t) + s(t) + h(t) + \varepsilon t$$

Holiday outliers are denoted by *h(t)*, periodic data based on daily, monthly, or annual periods are represented by *g(t)* and *s(t)*, unanticipated error is represented by ʹ(t), and the projected value derived via a linear or logistic equation is denoted by *y(t)*. In a logistic model, maximum and minimum values are specified and used for saturation predictions; in a linear model, no maximum or minimum restriction is set. PFM is more effective to predict short term patterns easily than the parameters of the conventional exponential smoothing models allow for frequent measurement.

IV. RESULTS

This section describes the implementation of the new system described in the previous section.

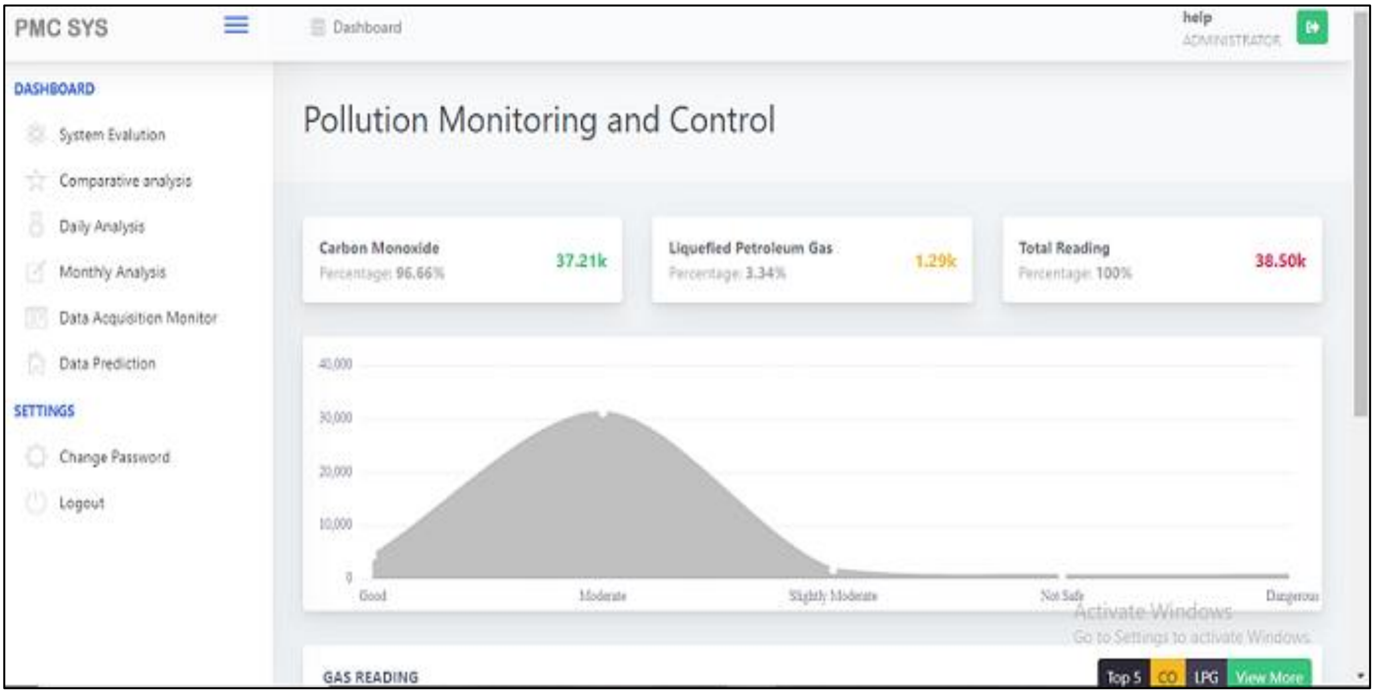

Fig 3 Dashboard of the Pollution Monitoring Application Software.

Figure 3 shows the dashboard of the pollution monitoring application. The dashboard shows the individual readings obtained from the monitoring hardware for the different gases measured (CO and LPG in this case). It also shows the total readings for the entire pollutants measured. The system also shows the data log for the gases measured. It categorizes the values as “good”, “moderate”, “slightly moderate”, “not safe”, and “dangerous”. Figures 4 and 5 show the data reading from LPG pollution.

GAS READING — Top 5 | CO | LPG | View More

#	Gas Type	Gas Value	Quality
1	CO	68.00	Moderate
2	CO	74.00	Moderate
3	CO	70.00	Moderate
4	CO	66.00	Moderate
5	CO	70.00	Moderate

Fig 4 Data Readings of CO Pollution from Environmental Monitoring Hardware

GAS READING

Top 5 | CO | LPG | View More

#	Gas Type	Gas Value	Quality
1	LPG	372.00	Dangerous
2	LPG	523.00	Dangerous
3	LPG	513.00	Dangerous
4	LPG	307.00	Dangerous
5	LPG	286.00	Not Safe

Fig 5 Data Readings of LPG Pollution from Environmental Monitoring Hardware

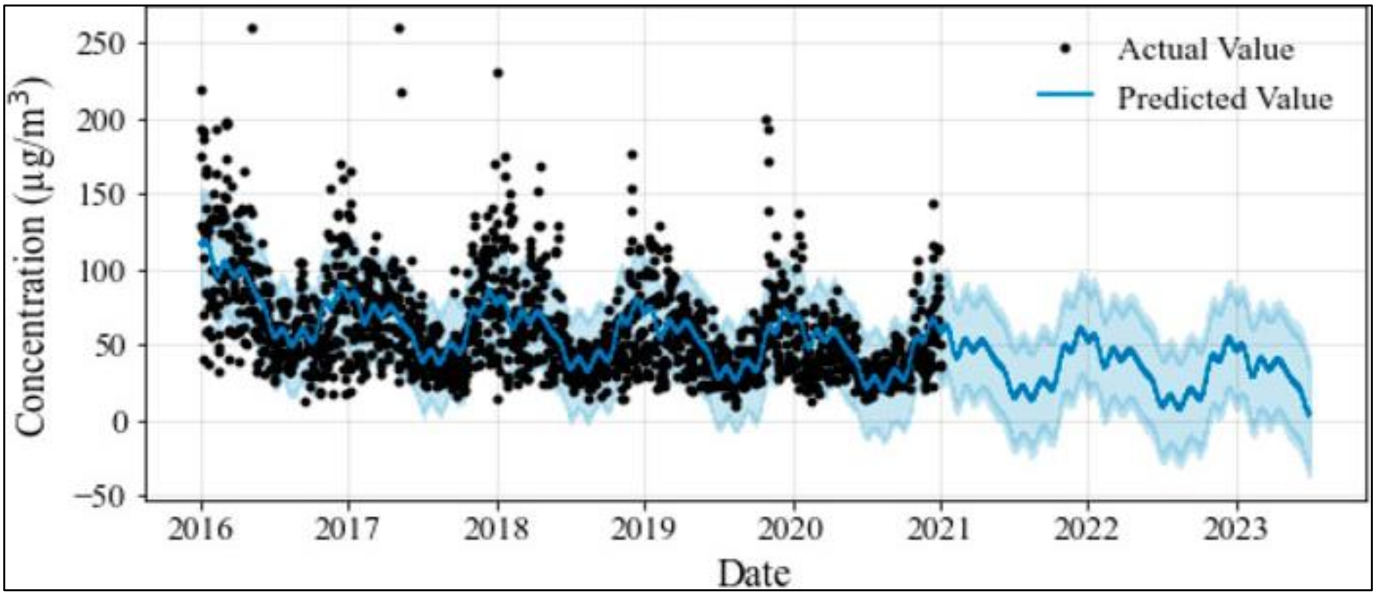

Fig 6 The System Showing Predicted Values for CO (µg/m3) Concentration

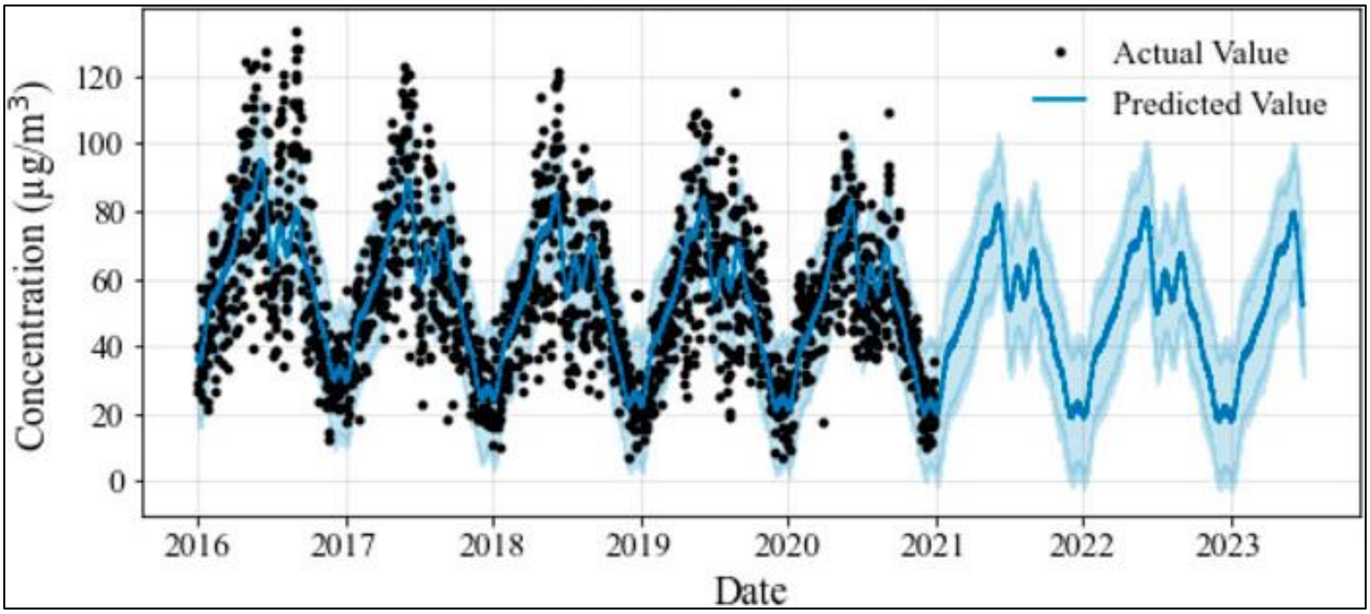

Fig 7 The System Showing Predicted Values for LPG (µg/m3) Concentration

Figures 6 and 7 show the system's predicted outputs for carbon monoxide (CO) and liquefied petroleum gas (LPG) concentrations (µg/m³). These forecasts point to the IoT-based platform's dual ability to anticipate dangerous gas trends, thereby extending its function beyond real-time monitoring to proactive environmental safety. By providing early-warning insights, the system supports timely control actions such as alarms, ventilation activation, or automated shut-off mechanisms, ensuring enhanced protection in both domestic and industrial contexts.

V. CONCLUSION

Pollution has been a major problem in cities and urban areas. As a result of this, many people had suffered polluted related disease cases [1]. Recent technological development has brought about the miniaturization of digital and wireless technologies which have led to the emergence of environmental sensors. This study presented an environmental air pollution monitoring system with machine learning that constantly keeps track of air quality in an area and provides real-time data or information that can be accessed online using personal computers and smart phones. The system also triggers an evacuating fan (in the case where it is used in an indoor facility) when the pollution concentration rises beyond a certain threshold.

The developed system has several advantages, including a real-time web-based cloud application that tracks, updates, and shows air quality data online. It also notifies the user when the air quality is harmful, or when a threshold has been reached. The study also focuses on the predictive analysis of machine learning on the gathered dataset, which forecasts two metrics related to air pollution using the prophet forecasting model (PFM).

Reliable short and long-term air pollution prediction is essential to managing the risk and lessening the harmful consequences of air pollution. This enables decision-makers at lower levels of government to develop plans and strategies for the earliest feasible management of air pollution. This study uses five years of data from Nigeria from the University of Nigeria, Nsukka, to predict air pollution parameters using the PFM. The outcomes validate the model's efficacy by showing that it has the rare capacity to predict air quality both in the short and long term with accuracy.

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