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Daet AirWatch: A Framework for Measuring and Visualizing Air Pollution Levels in Daet, Camarines Norte

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Abstract— Air pollution presents serious threats to public health and the environment, thus, effective techniques for mitigation and monitoring are required. In this study a comprehensive framework that integrates low-cost sensors, GPS technology, and data processing using an Arduino Uno and an ESP8266 Wi-Fi module is presented to address air pollution. The proposed framework allow real-time collection of pollutant data, including (PM), (VOCs), (CO), and ozone, alongside location information, temperature, and humidity. The gathered data is subjected to thorough processing, which includes converting sensor output values and calibrating and normalizing raw sensor readings. Moreover, the framework includes algorithms for translating pollutant concentrations into Air Quality Index (AQI) values, giving standardized metrics for evaluating air quality levels. The data is processed and then sent to an MQTT Broker for quick sharing of information and alerting about dangerous conditions. Additionally, the platform includes a user-friendly interface that displays pollution data on a web map, improving transparency and community awareness. By utilizing its effective data collection, processing, and visualization features, the suggested framework seeks to enhance public health results by giving people and communities the ability to make informed choices and take proactive steps to reduce air pollution dangers.

Keywords*-air quality, fog computing, Internet of Things, MQTT Broker, wireless sensor networks*

I. INTRODUCTION

Air pollution, cited as a “silent public health issue crisis” and “the new tobacco” by WHO, is a global challenge with severe implications for the environment, economy, and human health [1][1]. Particulate matter, primarily from vehicles, industry, and wildfires, contributes to 9-12 million annual deaths worldwide [2]. It detrimentally affects the immune system, diminishing macrophage function, increasing respiratory infections, allergies, asthma, and chronic lung diseases, while also impacting skin integrity and the nervous system [3][4]. [5] reveals a decline in immune function within lung-associated lymph nodes, correlated with age and linked to inhaled particulate matter accumulation. This decline suggests a compromised ability to monitor and respond to lung tissue abnormalities, highlighting the synergistic impact of environmental exposure and aging on immune health. Furthermore, the impact of air pollution extends beyond the immediate health concerns to encompass the broader environmental issues including the greenhouse effect, which exacerbates global warming.

In towns such as Daet, heightened levels of air pollution present significant dangers stemming from amplified vehicular emissions and industrial operations. Beyond its harmful impact on human health, air pollution also disrupts ecosystems, climate patterns, and the accessibility of natural resources. With the

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pressing necessity to combat air pollution, there's a critical requirement for inventive technologies capable of efficiently monitoring and mitigating its effects. Additionally, the limitations of conventional air monitoring systems, which includes partial data access, high expenses, and a lack of scalability, compel researchers to explore the creation of future air pollution monitoring systems leveraging advanced technologies like Internet of Things (IoT), wireless sensors networks (WSN), and affordable ambient sensors to overcome these challenges [6]. One promising approach lies in the integration of IoT, web-based, and data visualization tools.

IoT technology offers promising capabilities in capturing and analyzing data across various domains, including environmental monitoring [7][8]. By employing IoT devices integrated with Arduino and Raspberry Pi, sensors, real-time air quality data can be collected and analyzed efficiently [9]. However, the implementation of IoT and WSN for air pollution monitoring faces challenges, including bandwidth limitations, data processing, visualization, security issues, as well as concerns regarding reliability and availability [10]. [11] introduced a framework that incorporates fog computing infrastructure into the IoT system. It allows local data processing and analysis closer to the source of data generation, reducing the reliance on constant internet connectivity and alleviating bandwidth limitations. In addition, [12] highlighted the significance of processing data closer to the IoT nodes for enhancing the quality of service (QOS) in an IoT network. They introduced a conceptual framework for distributed fog computing aimed at optimizing cloud resources. Moreover, [13] designed an IoT architecture utilizing fog computing which effectively address challenges related to big data processing and network scalability.

IoT has become indispensable across various sectors, revolutionizing industries, and bolstering efficiency. For instance, in the healthcare industry, IoT applications linking medical equipment, sensors, and professionals have facilitated remote healthcare delivery, enhancing operational efficiency, reducing costs, improving patient safety, and increasing healthcare accessibility [14]. [15] exemplify this with a Wireless Body Area Network (WBAN) prototype at Ege University Hospital, monitoring critical patient metrics and transmitting data seamlessly to a centralized database. Similarly, in environmental sustainability efforts, IoT aids in understanding regional climates. Yet, the standard IoT architecture's complexity and inherent node limitations expose it to security threats. For instance, [16] proposed a framework utilizing low-cost sensors for air quality monitoring, yet they lack adequate security measures to protect data transmission from sensors to servers. This underscores the need to integrate robust security protocols into such frameworks to ensure the integrity and confidentiality of gathered data. Such enhancements would bolster the effectiveness and trustworthiness of air pollution monitoring systems, contributing to more informed decision-making and improved environmental health. Integrating such as a novel authentication framework for Message Queuing Telemetry Transport (MQTT) based communication into these frameworks [17]. Evaluations of MQTT for authentication and authorization, particularly in constrained environments (ACE), demonstrate alignment with device capabilities and offer cost-effective methods to enhance security [18]. Thus, while the communication layer is crucial in facilitating data transfer in distributed computing systems, selecting suitable protocols, like MQTT, must also prioritize security to ensure the integrity and confidentiality of gathered data.

Visualization is essential for gaining understanding from collected data, as it aids individuals or decision-makers in comprehending and analyzing information more easily. [19] utilized geovisualization tools like maps which proves to be indispensable assets for gaining a thorough grasp of spatial data and enabling flexible exploration and analysis of complex environmental patterns and changes over time.

Hence, the objective of this research is to present a model integrating inexpensive sensors, fog computing, and web technology to visualize collected data through geographical mapping. This visualization aims to enhance public awareness and facilitate efforts to alleviate the adverse impacts of air pollution, while also prioritizing the security of the collected data.

II. MATERIALS AND METHODS

A. Data Collection

The research will employ affordable sensors like DSM501A, MQ135, MQ131, MQ7, and SGP30 to detect pollutants such as PM2.5, PM10, nitrogen oxides, carbon dioxide, carbon monoxide, total volatile organic compounds (TVOC), and ozone in the vicinity. Furthermore, the DHT-22 sensor will be utilized for measuring temperature and humidity, which significantly impact air pollution monitoring. A GPS module will also be integrated to pinpoint locations and recognize areas with heightened pollutant levels in Daet, Camarines Norte.

Fig.1 illustrates the circuit design of the monitoring system, providing a reference for the development of the system. The circuit diagram consists of various sensors specifically designed to gather data on air pollution. Additionally, it includes a microcontroller responsible for collecting data from the sensors and executing tasks such as converting values for presentation on a website.

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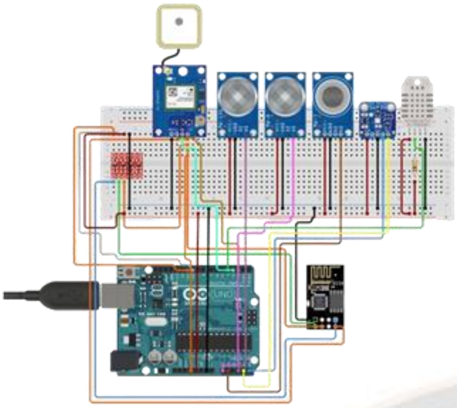

Figure 1. Circuit design of the monitoring system

B. Sensor Output Value Conversion

The DSM501A sensor measures PM2.5 and PM10 and it operates by emitting low pulses and adding them together over a predetermined 30-second interval. Then, to derive the low ratio in percentage, the low pulse recorded over a 30-second period will be divided by 30 and the result will be multiplied by 100, as illustrated in (1).

$$\text{Low ratio}[\%] = t(\text{sec}) / 30\ (\text{sec}) * 100 \qquad (1)$$

Where t is the sum of low pulses. The conversion process for sensor readings from the DSM501A relies on a graphical representation depicting the correlation between low ratio and concentration. This relationship is illustrated in Fig. 2.

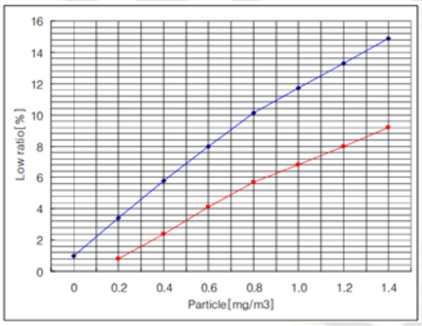

Figure 2. DSM501A Characteristics Graph

The MQ135 sensor, belonging to the MQ gas sensor series, is utilized to detect, gauge, and supervise different gases present in the atmosphere, including ammonia, alcohol, benzene, smoke, and carbon dioxide. Prior to utilization for detection purposes, the sensor requires preheating for a period exceeding 24 hours. In this study, the sensor will be employed specifically for monitoring carbon dioxide (CO2) levels. To measure C02 concentrations in parts per million (ppm), the sensitivity characteristics curve specific to the MQ135 sensor will be utilized. This curve serves as a reference for converting the sensor's resistance (Rs) into ppm, as illustrated in Fig.3, wherein a decrease in Rs corresponds to higher concentration of hazardous gases.

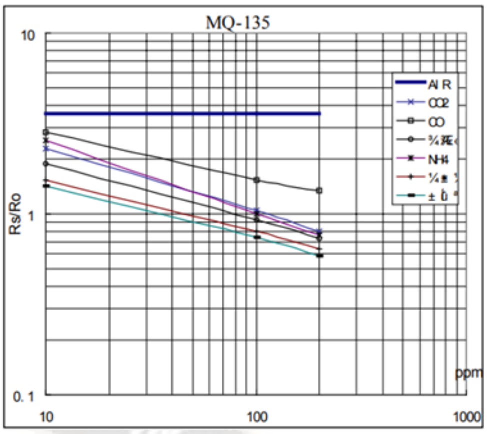

Figure 3. Sensitivity Characteristics of the MQ135

The MQ131 sensor comprises both a heater circuit and a sensor circuit. The heater circuit consumes at least 150 mA and necessitates a preheat time of at least 48 hours to yield consistent results. When the ozone gas concentration rises, the sensor's conductivity correspondingly increases. The MQ131 gas sensor has high sensitivity to Ozone, and it is also sensitive to CL2, NO2, but in this study this sensor will be used to measure Ozone. To get the ozone concentration the conductivity change must be converted. As shown in Fig.4, the sensitivity characteristics of MQ131 will also be used as a guide to convert the Rs into ppm.

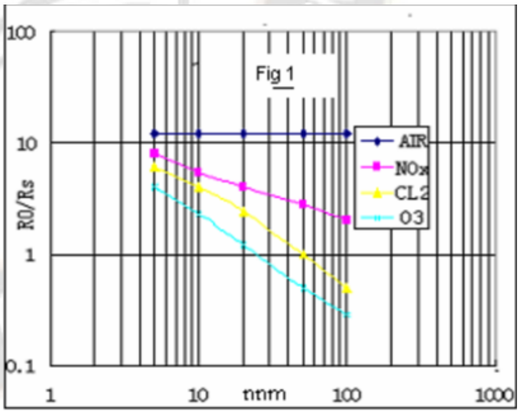

Figure 4. Sensitivity Characteristics of MQ131

The MQ7 sensor operates on the principle of chemoresistance where the electrical resistance of the sensor changes when it comes into contact with carbon monoxide (C0) gas. The surface resistance of the sensor (Rs) is obtained through voltage signal output of the load resistance (RL), which is connected in series. This sensor is specifically designed to detect C0, and it needs a preheating time of at least 48 hours before detection. The MQ-7 carbon monoxide sensor can detect 20 to 2000 parts per million of CO in the air, per its datasheet. Fig.5 shows the relationship

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between gas concentrations in ppm and Rs/Ro, wherein *Ro* is the resistance in clean air, while *Rs* is the sensor's resistance in the target gas.

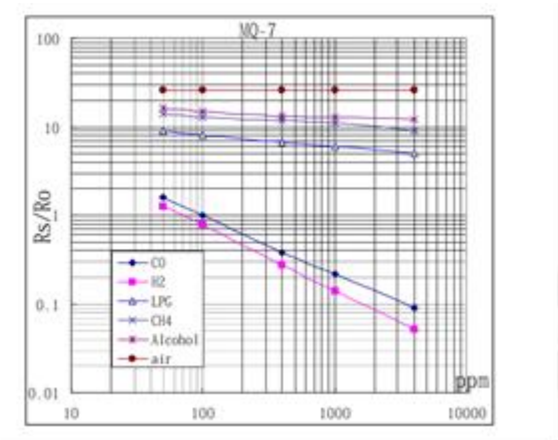

Figure 5. Sensitivity Characteristics of the MQ7

The SGP30 sensor is used to measure Total Volatile Organic Compound (TVOC) and eCO2. Its output equivalents for TVOC in parts per billion (ppb) and C02 in ppm. However, in this study the SGP30 is intended to be used in detecting TVOC. This sensor can measure TVOC concentrations from 0 to 60,000 ppb and it uses a metal oxide sensor technology that changes the resistance of the sensor when it is exposed to different gases. For stabilize readings the sensor requires a 20-minute burn-in period before using for detection.

C. *Conversion of Concentration Values to AQI Values*

The Air Quality Index (AQI) is a unitless measure, represented by colors, which effectively communicates the level of air pollution to the public. It evaluates air quality and its effects on health. (2) illustrates a simple formula for converting concentration measurements (ug/Ncm) and ppm to AQI values (unitless). This formula is from the manual of the Environmental Management Bureau.

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}\left(C_p - BP_{Lo}\right) + I_{Lo} \quad (2)$$

Where I_p is the AQI value for the pollutant, C_p is the pollutant concentration, BP_{Hi} is a breakpoint that is greater than or equal to C_p while BP_{Lo} is a breakpoint that is less than or equal to C_p. I_{Hi} is the AQI value corresponding to BP_{Hi} and I_{Lo} is the AQI value corresponding to BP_{Lo}.

III. Proposed Framework

The proposed framework's architectural design, depicted in Fig 6, involves utilizing a low-cost sensor to detect pollutants in a given area, alongside a GPS module for pinpointing the location of pollutant readings. Data including pollutant levels, location, temperature, and humidity will be collected and transmitted to an Arduino Uno through an ESP8266 Wi-Fi module for local processing. This processing involves determining pollutant concentrations before publishing the prepared data to an MQTT Broker. The system will issue notifications to the public when air quality becomes hazardous. Additionally, the website will visualize the air pollution status in the designated area. Furthermore, to secure data transmission, the MQTT connection will implement authentication measures between clients and the broker.

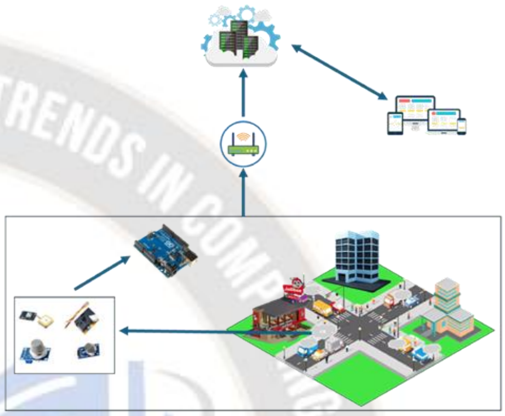

Figure 6. Architectural Design of the monitoring system

The web mapping visualization will be constructed using Leaflet, an open-source JavaScript library. This will be complemented by layering satellite imagery onto the Leaflet map. On the website, alongside the map, pollutant data will be displayed, accompanied by additional information such as health impacts. The process of the proposed framework is shown in Fig.7.

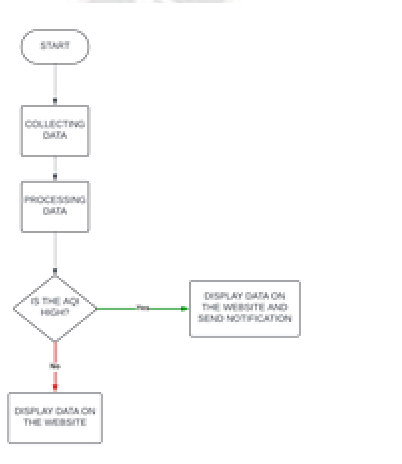

Figure 7. Flowchart of the AirWatch monitoring system

IV. Conclusions

This study introduces a framework designed to mitigate the effects of air pollution through the utilization of cost-effective sensors, GPS technology, Arduino Uno, and ESP8266 Wi-Fi module. By integrating these components into an IoT system with Arduino, real-time air quality data can be collected and analyzed efficiently, addressing the limitations of traditional air monitoring systems. The proposed framework tackles key challenges in IoT-based air pollution monitoring, including issues related to bandwidth, data processing, visualization, and security. By employing affordable sensors like DSM501A, MQ135, MQ131, MQ7, and SGP30, alongside a GPS module for location tracking, a wide range of pollutants can be detected and measured in the surrounding area. Converting the sensor output values into Air Quality Index (AQI) values aids in providing a comprehensible assessment of air pollution levels and their potential health implications. The primary goal of the framework is to raise public awareness by offering easily understandable information about air quality. The researchers anticipate that increasing public awareness of air quality conditions and associated risks will inspire proactive action and foster collaboration in addressing the issue.

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