Detection, Monitoring, and Early Warning System for Sulfur Dioxide Emissions from Volcanic Activity

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***Abstract*— During the Taal Volcano eruption in January 2020, which inflicted damage in its 17 km radius danger zone as well as neighboring areas, many infrastructures were destroyed. Ash spread even to Manila, resulting in soil deformation, sulfur dioxide emissions, and other issues. Exposure to extremely high quantities of sulfur dioxide can be fatal, and its effects can harm the eyes, mucous membranes, and respiratory tract. In severe cases, it has proven to be deadly. With that in mind, the researchers proposed a system: a detection, monitoring, and early warning system for sulfur dioxide emissions from volcanic activity. The system consists of a sensor node and utilizes a cloud for storage and data display. The sensor node comprises a sensor module connected to a microcontroller and a Wi-Fi module for sending the data through the cloud.**

Keywords— Air Quality, Sulfur Dioxide, Internet of Things, Microcontrollers, Sensors

I. INTRODUCTION

Taal Volcano, located in Luzon, Philippines, is an active stratovolcano with a history of eruptions [1]. The recent eruption in January 2020 resulted in various impacts, including continuous earthquakes, ash falls, and sulfur dioxide emissions. Sulfur dioxide, a hazardous gas emitted during volcanic activity, poses immediate health risks, and can contribute to long-term health problems and environmental issues such as acid rain and air pollution [2]. Monitoring sulfur dioxide emissions is crucial in predicting volcanic eruptions. The residents of Laurel, Batangas, living near the volcano, are concerned about the health effects of sulfur dioxide exposure but lack information and awareness. To address this, the researchers propose a detection, monitoring, and early warning system using sensor nodes and cloud-based data transmission. This system aims to provide timely warnings and enable residents to take necessary precautions against sulfur dioxide gas emissions.

The main objective of this study is to implement a system capable of detecting and monitoring the Sulfur Dioxide emissions around the vicinity of Taal Volcano and sending warnings to the community. Specific goals were set forth to accomplish the study's main objective, including the following: To create a system capable of detecting and monitoring sulfur dioxide from volcanic emissions; To implement a system that can warn the community about the sulfur dioxide from volcanic emissions; To evaluate the system's efficiency and accuracy in detecting, monitoring, and warning the community about the presence of sulfur dioxide from volcanic emissions.

Current research and studies have been found to measure the air quality; each having the same theory but different implementation and algorithm.

A. Air Pollution Mapping Using Mobile Sensor Based on Internet of Things

The proposed air pollution mapping system, according to Wonohardjoa & Kusumaa (2019), measures and monitors the carbon monoxide pollution levels in real time. The sampling was tested with two sampling methods: time-based and distanced-based sampling. Based on the results, distanced-based sampling produced well distributed data and closer to the expected between samples distances compared to the latter. Evaluating the measurement and monitoring, the mapping system maps the results using mobile sensors into heat maps overlaid on Google Maps. [3]

B. Monitoring System of a Sulfur Dioxide Gas Using Web-Based Wireless Sensor

Sunarno, Purwanto, & Suryono (2020) proposed a design of the air quality monitoring system. The system consists of several components, such as sensor systems, internet connections, databases, and computers. The sensor system consists of SO2 sensor, temperature and humidity sensor, wind speed sensor, microcontroller, and GSM module. Data stored in the database are SO2 data (ppm), temperature data (OC), relative humidity (%), and air velocity (km/hour). The measurement results are displayed in two forms, including graphs and tables. The data can be accessed via the web. [4]

C. Development of IoT-Based Volcano Early Warning System

Amaliya proposed a system with integrated gas, temperature, and humidity sensors (2021). The ESP8266 operates as a Wi-Fi module and connects to the internet to create TCP/IP protocol. All sensors are connected to an Arduino Pro Mini, which serves as a microcontroller and analyses sensor data. Data sent to the cloud can always be retrieved on the service page online. Solar cells will be used to create the required power for this system. [5]

Each research is very similar to the others, with the key differences being the components, algorithm, and application. Research A focuses on air pollution in general, rather than SO2 in particular, and has mapping capabilities. Research B, on the other hand, employs wind speed sensors to aid in the detection of sulphur dioxide gas. In addition to the SO2 sensor, Research C IoT-Based Volcano Early Warning System incorporates a temperature sensor and a CO2 sensor.

II. METHODOLOGY

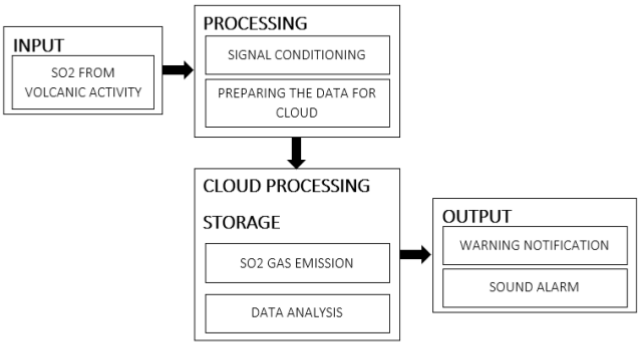


Fig. 1. Conceptual Framework of the System

For the initial part of the diagram, input acquisition by the proposed system will be by means of detecting, monitoring the sulfur dioxide gasses that were released due to volcanic activity. The data captured will be then processed by means of signal conditioning, the detected information is processed so that it will be suitable for use and be prepared to be transferred to the cloud. In the cloud, the data processed is stored in the cloud for later viewing and further analysis and the data is analyzed and prepared for the next stage. For the last stage, which is the output, data from the cloud is checked to know where the signal is coming from. After recording the sulfur dioxide, it sends an alert to the community about the sulfur dioxide gasses in the area.

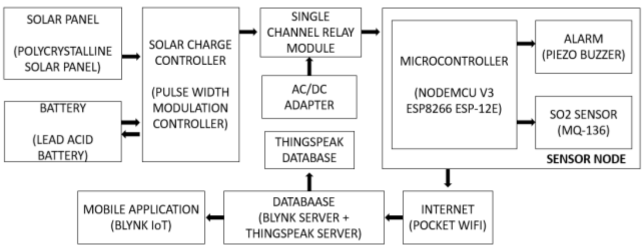


Fig. 2. Block Diagram of the System

Fig. 2 depicts the block diagram of the proposed system which shows the connection between the components used in the system to gather data and monitor for sulfur dioxide. The device consists of a power supply, sensor node, and IoT platform. The solar panel and battery connect to the solar charge controller and is connected to the single channel relay module along with the AC/DC adapter which supplies two modes of power to the microcontroller. The microcontroller NODEMCU is responsible for reading and processing the data gathered via MQ-136 sensor and sound the alarm whenever the sulfur dioxide level reaches the threshold amount. The data gathered is then sent to the database and the internet provided by the pocket Wi-Fi integrated with the system. The database which is Blynk and ThingSpeak saves the data that is gathered and Blynk IoT displays the detection data and notifies the user about the e detection data.

The device is equipped with two power supply modes to provide it with a 5V power source. The first mode utilizes a solar panel, which passes through a solar charge controller to regulate and step down the power to 5V. The second mode draws power from the grid through an AC/DC adapter, converting high voltage AC power to 5V DC power. These two power modes are connected to a single-channel relay, so that when the grid power is unavailable, the solar power seamlessly takes over. The sensor can tolerate sulfur dioxide concentrations ranging from 1 to 100ppm and can operate within temperatures ranging from -10°C to +50°C. The device utilizes 2.4GHz Wi-Fi to connect to the internet and transmit data.

The device's software relies on the Blynk App and ThingSpeak to display the readings captured by the hardware. The Blynk App is compatible with both mobile devices and computer workstations. On the other hand, ThingSpeak is primarily supported on PCs but can still be accessed through web browsers on mobile devices. The Blynk App provides a two-week trial period, which is sufficient for evaluating the hardware. The Blynk IoT dashboard is highly customizable, allowing users to tailor the graphical user interface (GUI) according to their preferences, making it suitable for IoT applications. Although ThingSpeak may not have the most visually appealing user interface, it excels in providing a detailed overview of the received data, including timestamps for each data entry, a feature that the Blynk App lacks. Both the Blynk App and ThingSpeak can be accessed directly through an internet connection.

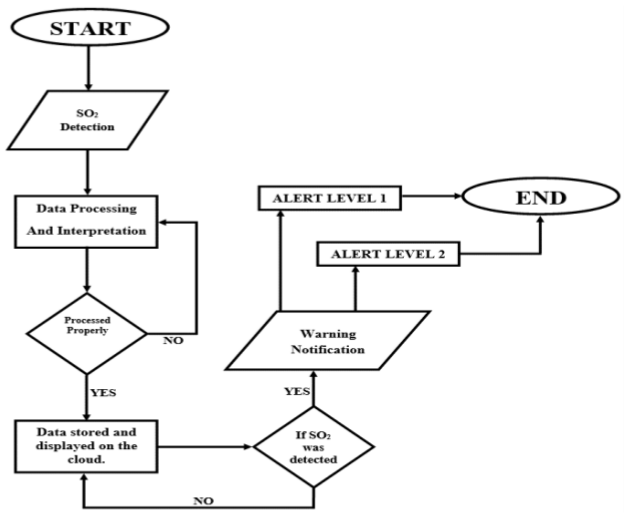


Fig. 3. Sensor Node Flow Chart of the System

Fig. 3 shows the flowchart of Detection, Monitoring, and Early Warning System for Sulfur Dioxide Emissions from Volcanic Activity. The sensor node depicted in the diagram begins with the initialization of the devices. Its main function is to measure the concentration of sulfur dioxide (SO_2) in the environment. Once sulfur dioxide is detected, it serves as input for the device, which then analyzes and interprets the data before proceeding to the next step. Upon detecting the presence of sulfur dioxide, the cloud (Blynk IoT and ThingSpeak) stores the data in its channels and displays it in the respective user interface. However, if no sulfur dioxide is detected or its concentration is low, the device stores the detection data in the database and displays a low value. After the analysis confirms a high detection of sulfur dioxide, the device sends a warning notification in the form of alert levels 1 and 2.

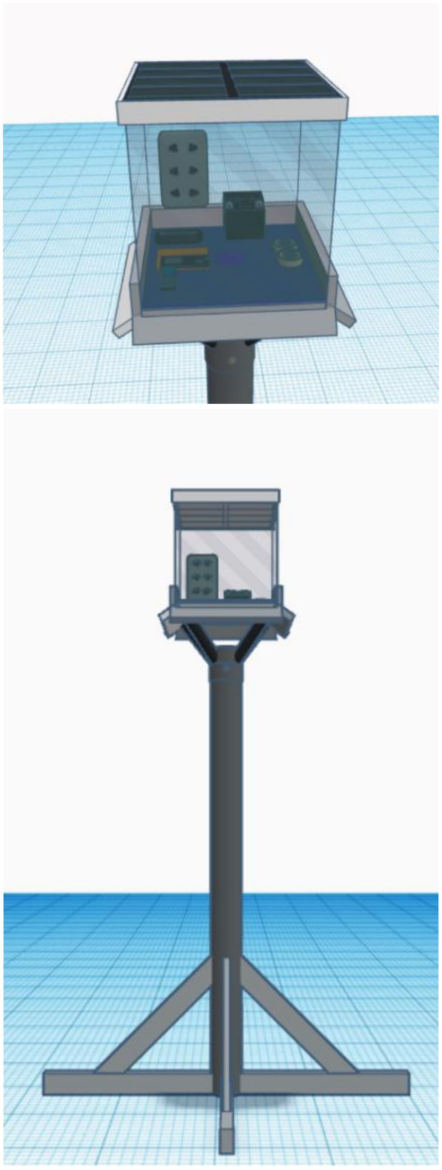


Fig. 4. 3D Model of the System

III. RESULTS AND DISCUSSION

A. Application Signing Process, Dashboard and Device Prototype

All data collected during testing is displayed in an application called Blynk App. This application requires the user to sign through the researcher's invitation code provided by the Blynk App itself. After confirming the invitation code, Blynk app will let the user have his own password which is unique with others. The following figures show the process of signing into the application.

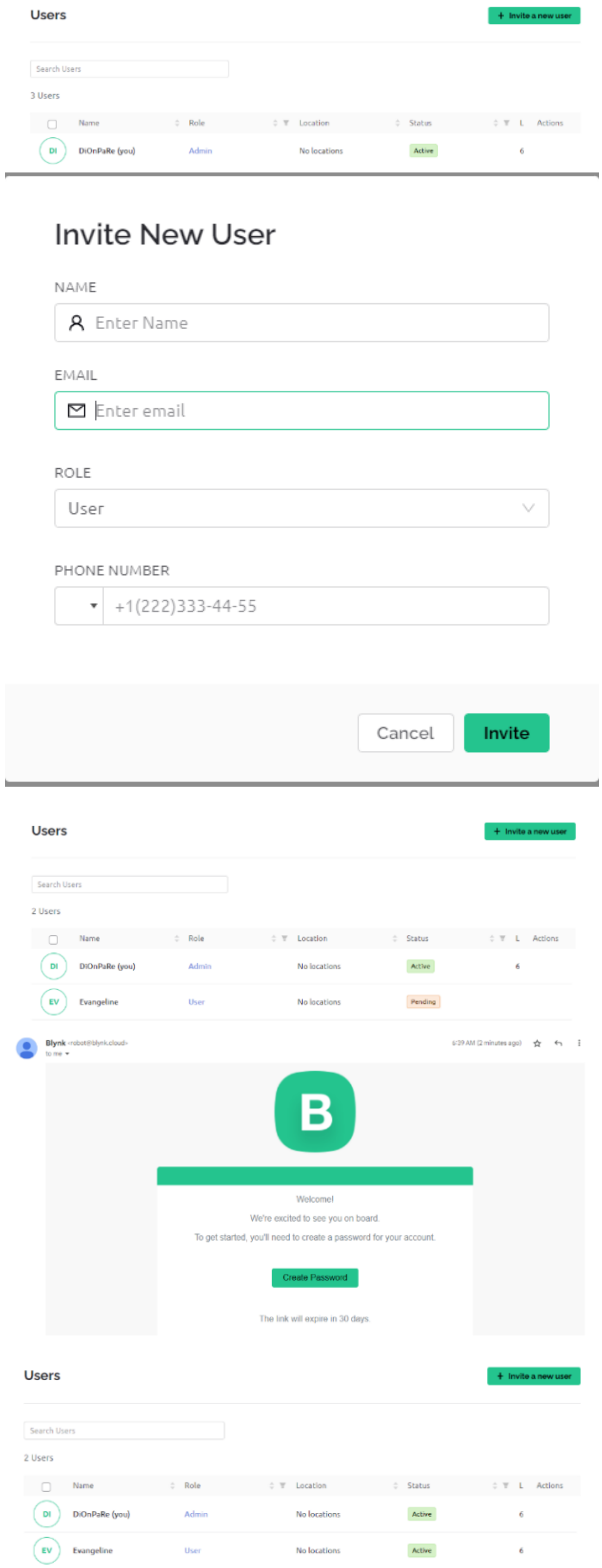


Fig. 5. Steps of Signing Process

Fig. 5 Depicts the signing process to view the detection data of the system. The admin will click the invite a new user for the users to access the researchers' database. The invited user must then fill up the following details indicating their name, an email that is working and active, the role they must sign as a user, and lastly, their active phone number. After the previous step, in the admins' view, the user will appear as a pending user. This pending login requires users to check their email to see if the Blynk app has notified them of their login. Upon checking the email, users must receive an email and upon making a password the user will soon be active.

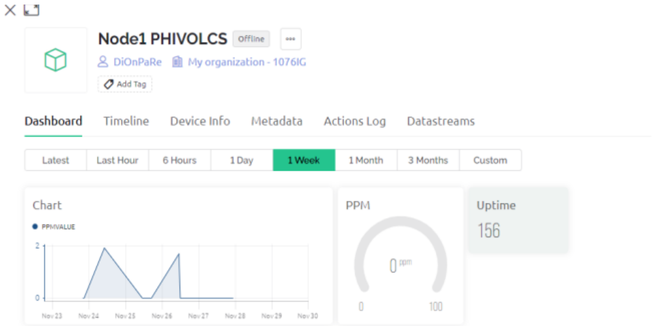


Fig. 6. Node Dashboard for real-time data readings of SO2

Fig. 6 shows the actual dashboard of the system. The node dashboard is where the past and live data readings can be viewed and watch out if there will be alarming readings during the actual testing of the device in the target location.

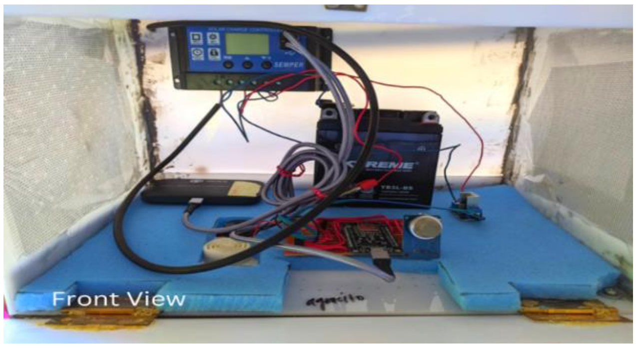


Fig. 7. Detection, Monitoring and Early Warning System Device Prototype

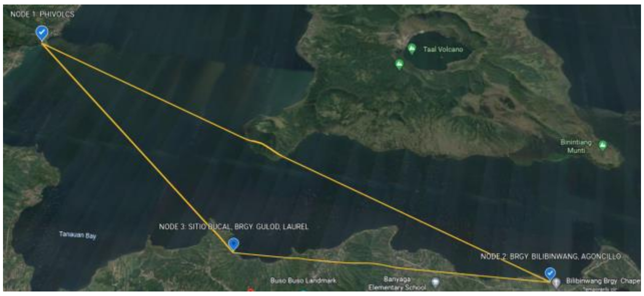
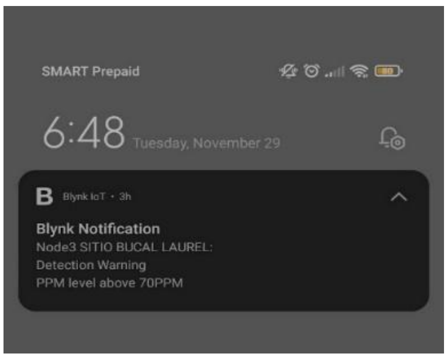


Fig. 8. Positioning of Nodes

Fig. 8 shows the precise positioning of three (3) sensor nodes in a strategic triangular configuration, expertly mapped by the researchers. These nodes are strategically located near the volcano, ensuring both easy accessibility and safety during installation. The close proximity to the volcanic source significantly improves the accuracy of gas measurements by minimizing the effects of dispersion and dilution that would occur at greater distances. Consequently, this positioning greatly enhances the detection of SO2 emissions, providing reliable and representative data on volcanic gas concentrations. The meticulous selection of these specific locations highlights the researchers' dedication to optimizing the node deployment's performance and effectiveness in monitoring volcanic emissions.

B. Notification System

Below is an example of a notification through pop-up notification, push notifications, and Gmail notifications. The system is designed to notify after every 30 minutes, even with or without detected sulfur dioxide emission, since the device requires changing averaging times. The following figures show the notifications a user will receive.



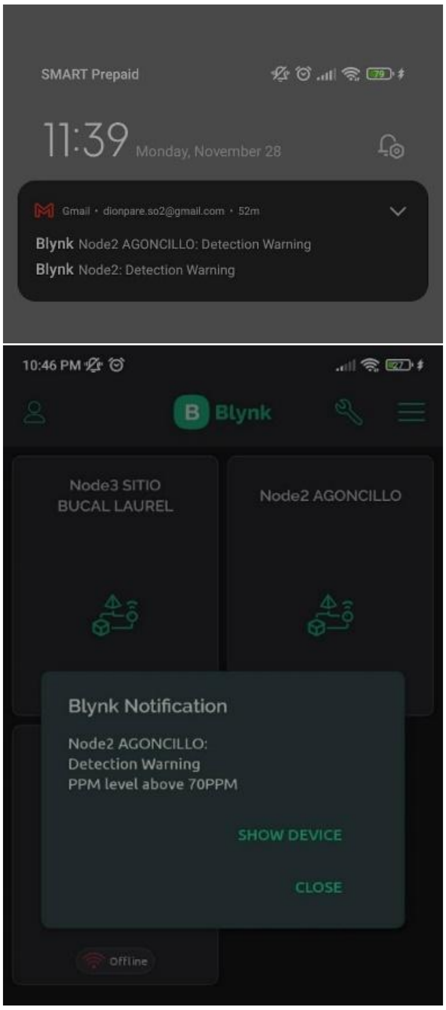


Fig. 9. Pop-up, Push, and Gmail notification

C. Calibration Test Results for Sensor Nodes

To ensure the device generates precise outcomes, it is necessary for the system to undergo testing. This allows the device to be fine-tuned to accurately detect the desired parameters. The researchers carried out various tests, including calibration testing and controlled environment testing.

Fig. 10. Calibration Testing Setup for Sensor Nodes

Fig. 10 shows the researchers setup of calibration and initial testing of sensor nodes. Data gathering happened at a testing facility of the school, FAITH Colleges at #2 Pres. Laurel Highway Tanauan City Batangas. For the chemical, the researchers combined the sulfur powder to the distilled water resulting in sulfur powder floating in the distilled water. It is because sulfur powder is insoluble in water. Note that if water is added to concentrated sulfuric acid, it can boil and spit dangerously. One should always add the acid to the water rather than the water to the acid.

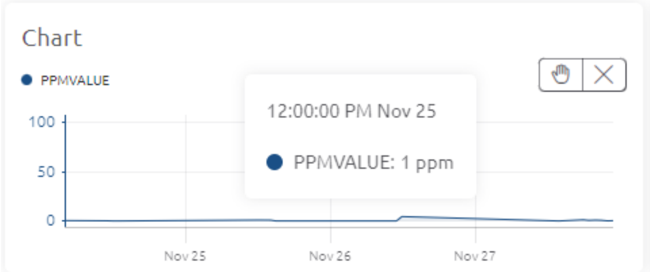


Fig. 11. Data Readings from Sensor Calibration Testing

Fig. 11 shows the data readings from Setup 1 of the calibration test of the sensor. Looking at the chart above, the data readings from 1:00 pm to 2:00 pm on November 25 are stable at 0 ppm. It means the sensor node, specifically the MQ-136 sensor, is not reacting to a different type of gas. The test only takes an hour due to the toxicity of the gas, and exposure to such gas can have adverse health effects.

D. Open Environment Test Results

Fig. 12. Data Readings of Node 1: PHIVOLCS

Fig. 12 presents the readings of Node 1, which is in Brgy. Buco, Talisay, Batangas. The measurement was conducted between 10:00AM and 12:00 PM on November 27, 2022. The chart shows that no sulfur dioxide emissions were detected during this period, and the recorded level was at 0 parts per million (ppm) for the past 14 hours

Fig. 13. Data Readings of Node 2: AGONCILLO

Fig. 13 presents the data readings of Node 2, located in Brgy. Bilibinwang, Agoncillo, Batangas. The measurements were taken between 2:00 pm on November 28 and 11:00 am the next day. The chart shows that no sulfur dioxide emissions were detected from 2:00 pm to 8:00 pm, and the recorded level was at 0 ppm during this period. However, at around 10:00 pm, the level suddenly rose to 91 ppm, then to 94 ppm, and eventually peaked at 100 ppm at 11:00 pm.

Fig. 14. Data Readings of Node 3: SITIO BUCAL, LAUREL

Fig. 14 displays the data readings of Node 3, which is in Sitio Bucal, Brgy. Gulod, Laurel, Batangas. The testing took place between 2:00 pm on November 27 and 11:00 am the following day. The chart indicates that no sulfur dioxide emissions were detected from 2:00 pm to 5:00 pm, and the recorded level was 0 ppm during this period. However, at 6:00 pm, there was a sudden increase in the level of sulfur dioxide emissions, which rose to 1 ppm. It then decreased to 0.5 ppm at 7:00 pm, followed by a fluctuation to 0.75 ppm at 8:00 pm, and then to 0.65 ppm at 9:00 pm. Finally, between 10:00 pm and 11:00 pm, there were no detected sulfur dioxide emissions, and the recorded level was 0 ppm.

Fig. 15. Data of Taal Volcano Readings

Fig. 15. In the figure above, we can observe the data readings of Taal Volcano from November 24 to November 28, 2022. Based on the available data, it can be inferred that Taal Volcano is currently in a state of low-level unrest. The measurement of the Sulfur Dioxide Flux, a significant volcanic gas, is recorded at 1150 tonnes. The plume, which indicates the direction of the volcanic gas emission, is observed to be heading southwest - the same direction where the nodes, instruments that measure volcanic gases are installed.

Considering the data readings from the three nodes, it can be concluded that the measurements are close when compared to the readings gathered by the Philippine Institute of Volcanology and Seismology (PHIVOLCS). The data obtained from the nodes range from 0 parts per million (ppm) to 1 ppm and then back to 0 ppm, which corresponds to the volcanic activity at Taal Volcano.

IV. CONCLUSION AND RECOMMENDATION

The researchers were able to create a system that is capable of detecting, monitoring, and providing an early warning system for the presence of sulfur dioxide emissions around Taal volcanic activity. The system was also able to provide users with real-time data readings of sulfur dioxide emissions using NodeMCU V3 ESP8266 ESP-12E 32 microcontrollers, which leverage the Blynk App IoT platform for data interpretation. Additionally, the system implemented a buzzer for a more effective early warning system, along with push and pop-up notifications.

Based on the findings, it is recommended to use a larger battery bank and a larger panel to power the device for longer durations in adverse weather conditions or with additional functions. It is also advisable to use better sensors if they are available in the market, as they would improve the accuracy and widen the range of detection values. Offline PPM monitoring should be implemented to save data for on-site monitoring in cases where internet services are unavailable. Additionally, improved internet services and a more efficient method of sending data to the cloud should be considered to reduce internet usage, along with a more reliable internet module that is less susceptible to power outages. Overall, the build quality should be improved, and enclosures and insulation should be used to provide better protection against weathering and extend the lifespan of the IoT device. Lastly, incorporating more nodes would help detect a wider range of sulfur dioxide around the volcano.

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