International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I5P231
Volume 71 Issue 5, 290-302, May 2023

Original Article

Development of a Module for the Detection and Measurement of Greenhouse Gases

Maritza Cabana-Cáceres[1], Cristian Castro-Vargas[2]

[1,2]*Facultad de Ciencias e Ingeniería, Universidad Tecnológica del Perú, Lima, Perú.*

[2]*Corresponding Author : C18683@utp.edu.pe*

Received: 25 March 2023 Revised: 13 May 2023 Accepted: 19 May 2023 Published: 25 May 2023

Abstract - *The greenhouse effect produced by the emission of gases generates a lack of protection in the environment that grows more and more annually due to the millions of CO2 emissions in the different environments, for which a greenhouse prototype was built through a set of engineering areas. An automated system for monitoring and detection of methane, CO2 and CO gases with a solar panel, for which the design of the circuit, design of the printed plate and design of the solar panel recharging system, selection of polluting gas sensors was carried out, assembly of the components on the PCB, development of the control and automation program with the ATMEGA328P microcontroller, an adaptation of the cubicle and assembly, tests of sending the data by GPRS to a server in different zones and times of high contamination.*

Keywords - *Greenhouse gases, Greenhouse gas measurement greenhouse, Greenhouse Gas Detection Module.*

1. Introduction

Global warming caused by greenhouse gases is increasingly worrying. In the last 50 years, Peru has contributed 1,300,000 ktons of CO2, representing 0.1% of global emissions in the same period [1]; although we have forests only in the high jungle that exceed 15 million hectares [2] and neutralize the gases emitted by the industry in Peru, should not be oblivious to the global pollution that affects us all.

Within air pollution, the maritime industry also generates the gases that makeup GHG (greenhouse gases), such as CO2, SF6, CH4, N2O, HFCs, PCFs and others considered as water vapor [4], and that globally represent 0.022% of maritime emissions according to the list of ships that the Shipping Registry has, must be analyzed and studied. GHG contamination must be measured in all contexts and areas. However, the data is referential and inferred. There is no precise data, nor are there levels of GHG indicators at different points in the community or within the community. The maritime industry, so it is necessary to start taking records of these gases. Likewise, the IDB requires that data be extracted from the effect of climate change, and thus, they can have a quality database that allows them to evaluate and control each global zone [5].

The International Maritime organization has the mission of reducing the GHG impact through various global projects through CO2 reduction strategies [6]. The world meteorological organization permanently controls gas concentration measurements through satellite systems and sensors, among others [8]. In Peru, the Ministry of the Environment prepares a guide for measuring the carbon footprint to make the correct quantification in order to develop optimization projects in reducing GHG emissions [9].

Due to the increase in levels of air pollution, producing the greenhouse effect in the city of Lima and Callao, the main objective is to design and develop a portable module for measuring the level of greenhouse gases. For the measurement of gas emissions, the following specific objectives of the project are also carried out: Carry out the design of a system for the measurement of greenhouse gases, Identify the points where there is a greater presence of GHG, Implement the prototype of the system for measurement of the main greenhouse gases, validate the prototype of the system for the measurement of the main greenhouse gases.

2. Literature Review

This is how it is in the research work that I carry out a prototype: a module with Arduino portable gas sensor for monitoring greenhouse gases [11] through the use of sensors (MQ-02, MQ-135 and TGS2602). Various measurements were taken at various points in the city of Solapur to validate the prototype's usability from a correct reading of corresponding greenhouse gas concentrations (ppm).

The research [12] implemented an automated gas collection chamber using a gas accumulation and quantification unit with an integrated sensor to validate the performance of greenhouse gas measurement efficiency in rice fields during the growing season. Growth, cultivation, and achieving low-cost GHG estimation system proposals in rice fields, significantly reducing GHG emissions and increasing rice production.

In [14], a modular wireless system was developed, combined with MOS sensors, calibrated for the detection of methane (MQ2, MQ4 and TGS2611) and carbon dioxide (MQ-135), using an Arduino-nano microcontroller and Python to link the computer with the XBee wireless communications modules. The system stores and reads data from analog electrical signals by sending it to the computer via the Arduino's analog-to-digital converter (ADC). As a result of measurement in different parts of the city, they show gas concentrations due to traffic congestion and waste from the municipal market.

In [15] this study, I developed a methane sensor module to detect low concentrations below 5000ppm and measure up to the detection limit of 50ppm with the NDIR method, with a long lifetime and high precision. Methane (CH4) is one of the representative greenhouse gases, which is very explosive. Thus, it allowed him to quickly and accurately measure the methane concentration in the air. Achieved adjusting the methane sensor for industrial field applications, implemented and characterized a small sensor based on NDIR with a response time of less than 30 sec.

In [16], I carry out a study of the construction of different modules for the measurement of greenhouse gases (GHG); using the method of construction of open and closed chambers, I determine the quality of the flow measurements utilizing the transport of intakes gas made in the rural field for analysis in the laboratory.

3. Materials and Methods

This research made the following points:

3.1. Module Design

It consisted of designing the circuit, simulation and finally obtaining the design of the module's printed board (PCB), for which the Module development software is used: IDE PROTEUS 8. In general, complex devices use plates multi-layered, while the simpler ones are single-layered. For the development, bridges were used between tracks of the faces of the prototype. In addition, a plastic casing of outdoor lighting equipment was adapted as a cubicle for the GHG module.

3.2. Final Result of the PCB LAYOUT of the Development Module

Figure 1 shows the front view of the PCB in more detail, in which we show the layout of all the required components:

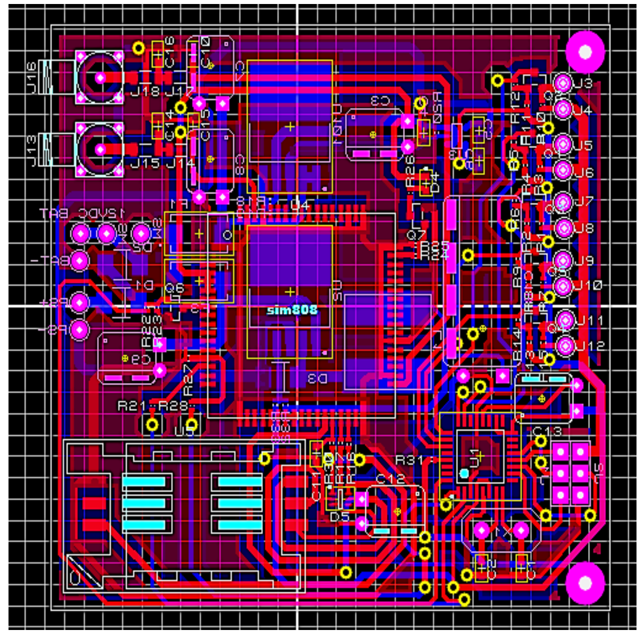

Fig. 1 Front view of the PCB

Figure 2 shows the rear view of the PCB in more detail.

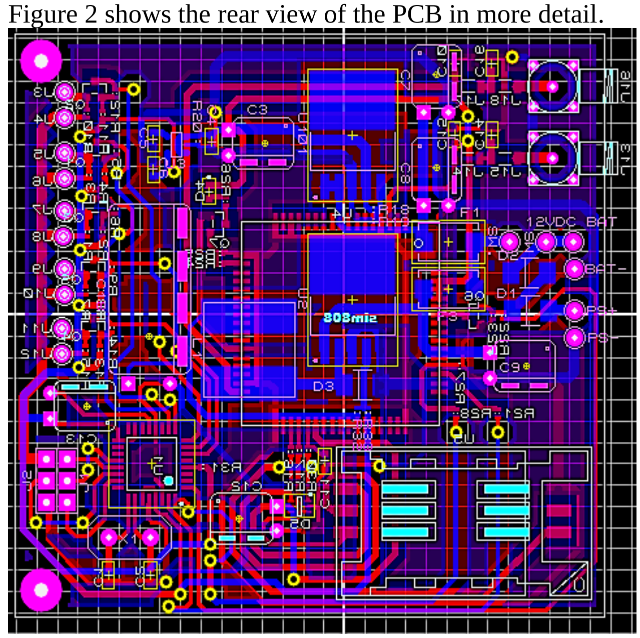

Fig. 2 Rear view of the PCB

3.3. View

The PROTEUS 8 software offers the possibility of showing 3-dimensional views that facilitates the best arrangement of the components in the box containing the PCB board and the different sensors.

Figure 3 shows the 3D front view obtained because we have the electronic components that we are going to use for the development of the prototype. It has been defined by design to separate the source stages from the RF emission stages and to be able to obtain a more efficient prototype.

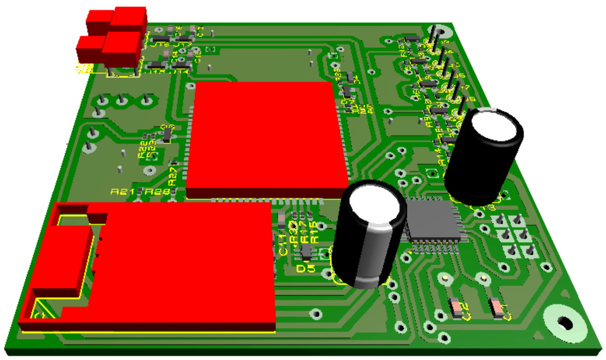

Fig. 3 Front view in 3D

Figure 4 shows the rear view in 3D; here, we show the components made up of the voltage regulators, capacitors and commutation coil.

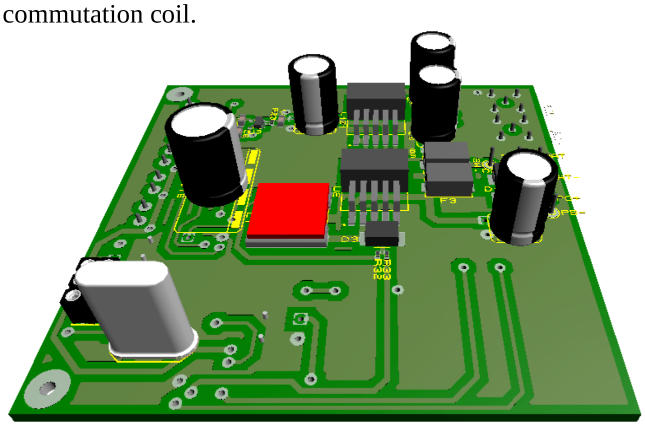

Fig. 4 Rear view in 3D

3.4. PCB Manufacturing

For the development, the 2-sided fiberglass PCB boards were chosen. Figure 5 shows the result of the method used.

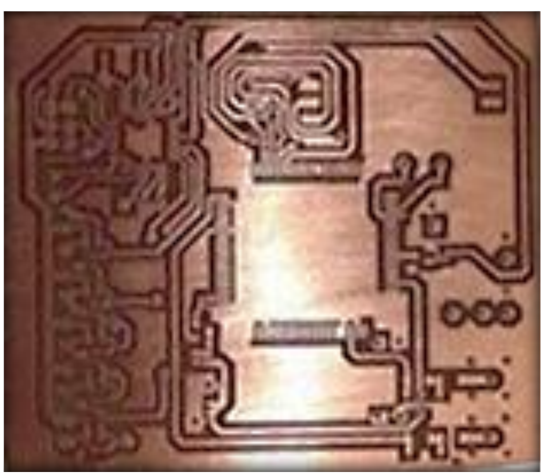

Fig. 5 PCB Manufacturing View

3.5. Container Model of PCB Board and Sensors

For the model of the box that will contain the components, a box prototype was obtained that will be used to dimension the final size of the PCB board shown in Figure 6.

Fig. 6 Plastic box that will contain the PCB board and sensors

It consisted of designing the circuit, simulation, and finally obtaining the design of the printed board (PCB). The PCB board size measurements are 11 x 11.5 cm. It is calculated for the box size that will contain the PCB board and the sensors we see in Figure 7.

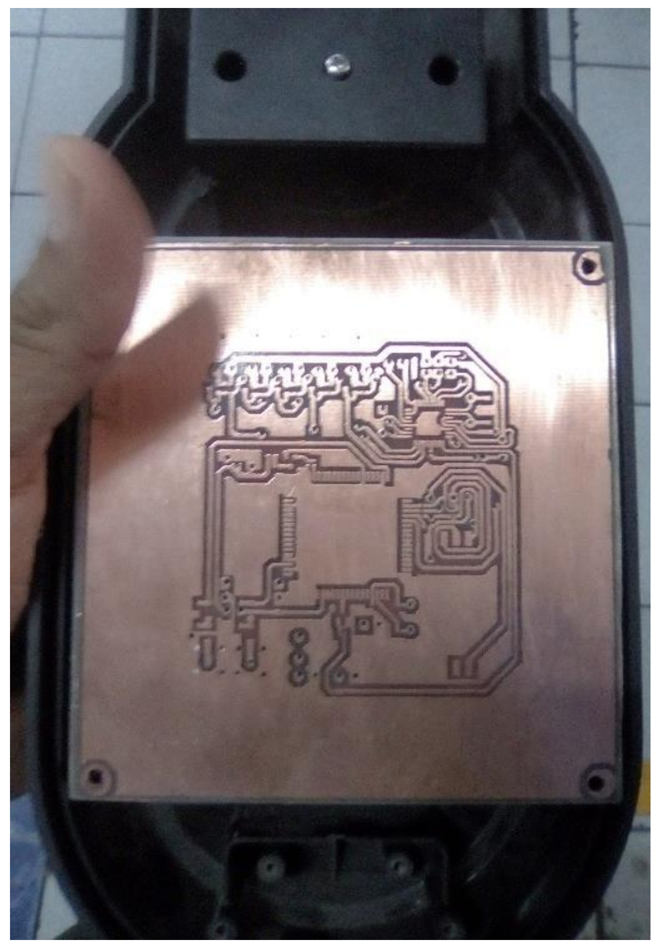

Fig. 7 Installation of the PCB in the module

3.6. Soldering of Components on the Front Face of the PCB

In the proposed design, we proceeded to divide the 2 faces of the PCB with respect to the stages that form the circuit. In the prototype, there is a main or upper face and a back face. The front face of the PCB is intended for the components that carry out the communication between stages and the RF transmission stage, which is shown in Figure 8 and Figure 9.

- The stage made up of the SIM808 GSM Module is placed on the upper face.
- The RF Tx and Rx antennas are placed as close as possible to the GSM808 Module.
- The interface connection to the chip card and the GSM808 Module is as close as possible.
- In addition, the logic stage is mainly constituted by the ATMEGA328P Microcontroller.
- The interface that communicates the Gas Sensors with the microcontroller is made up of NPN SMD transistors.
- The feed, by design, is placed on the back or rear face.

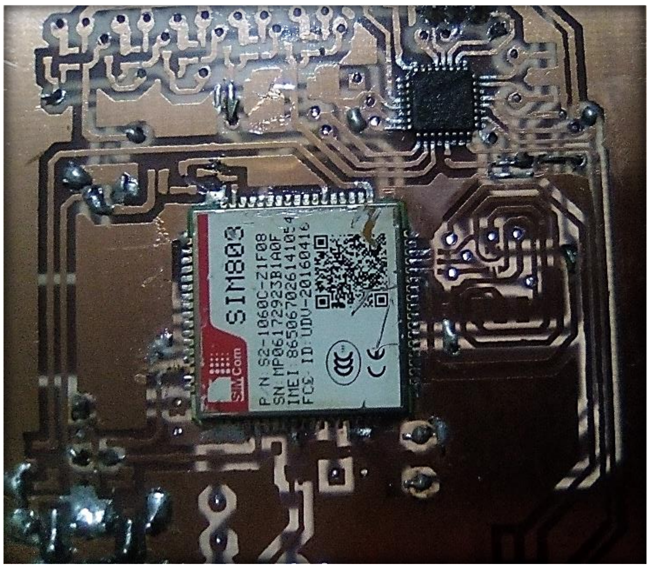

Fig. 8 SIM808 GSM module, soldered on board

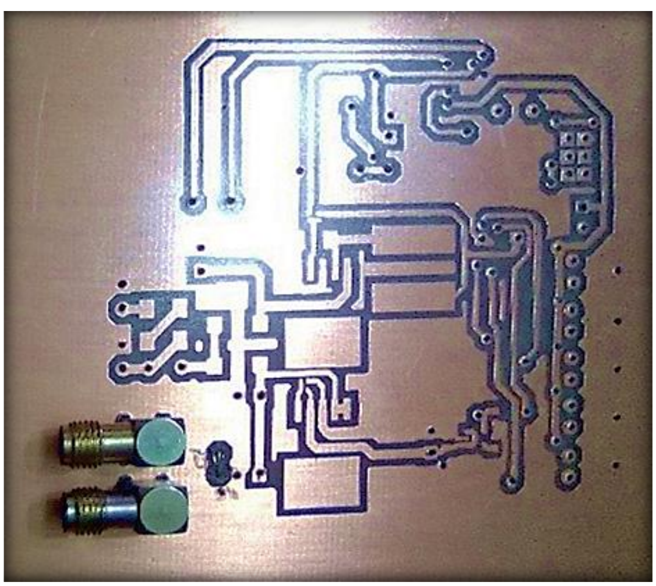

Fig. 9 Location of the connectors for SMA model antennas

3.7 Soldering of Components on the Back or Rear Face of the PCB

In the prototype, there is a main or upper face and a back face. The back face of the PCB is intended for the components that power the different stages of development, according to Figure 10:

- LM2576S regulator.
- MIC29302 Regulator.
- Commutation coil.
- LB33 voltage
- ATMEGA328P Microcontroller ISP Programming Pins.
- Capacitors are made up of NPN SMD transistors.

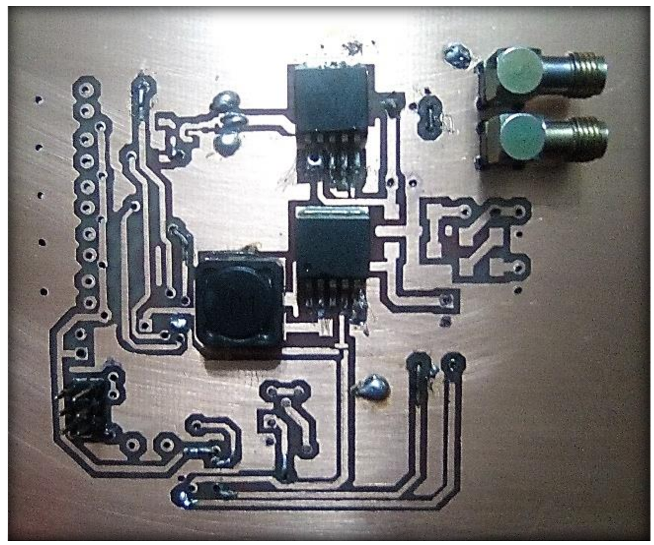

Fig. 10 View of the Energy Regulators

3.8. Assembly of Components and Assembly in the cubicle for the Passage of Gases

The chosen components are mostly manufactured to be welded on the surface. The components are assembled and assembled on the previously designed PCB board.

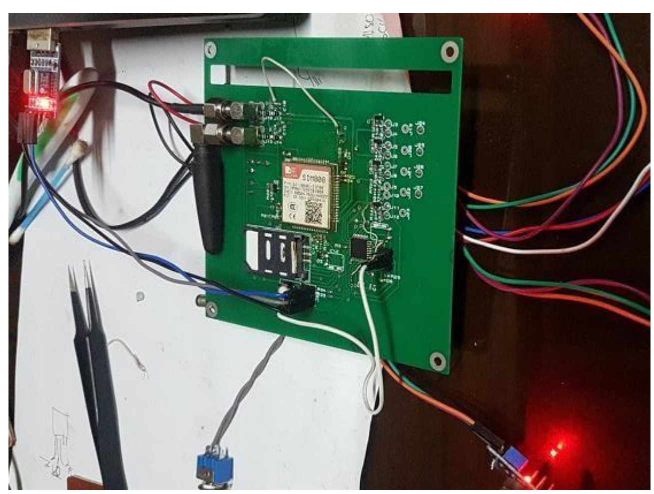

Fig. 11 Finished plate with sensors

For the cubicle's design, we opted for a plastic case model already made of outdoor LED lighting equipment, according to Figure 12 and Figure 13.

Fig. 12 Case used as a model for the gas sensor cubicle

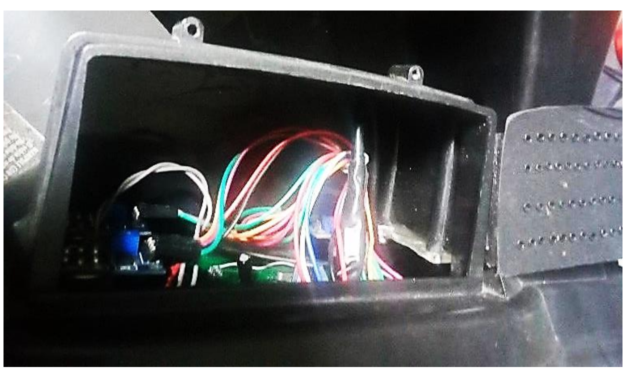

Fig. 13 Assembly of the circuit in the gas sensor cubicle

3.9. Module Operation Verification

In Figure 14, we proceeded to carry out the functional tests of the module outdoors for the proper positioning of the GPS antenna with the satellites, and connection tests previously configured for the reception of the sending frame of the GEI module, being the elements of the plot:

- Id: Frame sending number identifier.
- A: GPS positioning latitude.
- Lo: GPS positioning longitude.
- m4: Voltage emitted by the Methane Sensor.
- m7: Voltage emitted by the CO Sensor.
- m1: Voltage emitted by the Air Quality Sensor.
- Z: Parts per million emitted by the CO2 Sensor.

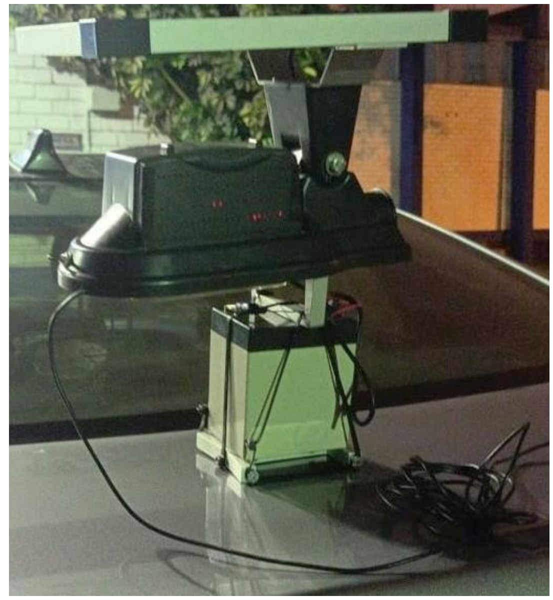

Fig. 14 Outdoor testing of the GHG module

3.10. Complementary Information: Recording the bootloader-Procedure

The necessary interface was taken into account; the ISP protocol will be used to be able to record the bootloader in the ATMega328p microcontroller, as shown in Figure 15.

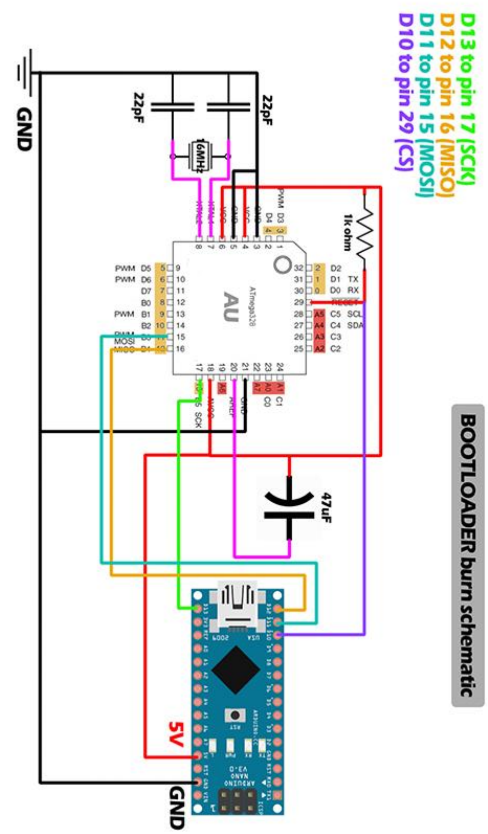

Fig. 15 View of the Communication Interface

After making the connections, we connect the Arduino nano board as ISP programmer and our sensor module, as shown in Figure 16:

Pin 15 (MOSI)……… D11
Pin 16 (MISO)……… D12
Pin 17 (SCK)………. D13
Pin 29 (RESET)…….. D10
VCC…………………. VDC (5V)
GND………………… GND

Fig. 16 Correct ISP pin locations on the gas sensor module

4. Results and Discussion

4.1. Results

- The tests were carried out at different potential points to measure the sensors.
- The analysis of the behavior of the sensors under different conditions was carried out.

4.1.1. Taking Measurements of the Prototype

Two types of tests were carried out, the first at 7 points with different characteristics in terms of possible GHG emissions; at each point, the measurement time was one hour and was intended to see if the measurements taken were by the types of points chosen; and, an additional test at a point that lasted 6 hours, to see the autonomy of the battery, see the stability of the emission of the measurements and the quality of the data emitted. Regarding the location information with the GPS, the data was similar to that taken with external equipment.

Point A

Where there was no representative vehicular movement by the time it was taken. Likewise, it is not a space where good air circulation is not evident, as shown in Figure 17.

Fig. 17 Location in a parking lot

Point B

The shots were taken in a corner with little air circulation and where there was a high level of traffic, as shown in Figure 18.

Fig. 18 Location at the intersection of avenues

Point C

The measurements were taken in a park with limited traffic circulation. At the time the measurement was taken, only 3 vehicles passed at a distance of 10 meters, and the area was well-ventilated and drafty, as shown in Figure 19.

Fig. 19 Location in a park

Point D

The point was located in a corner with medium traffic, with ventilation or drafts, and close to a faucet, as shown in Figure 20.

Point E

This measurement was made at a point that was 50 cm from the exhaust pipe of a car on fire to see an extreme point of GHG contamination, as shown in Figure 21.

Point F

This point was located on the fifth floor of a building, where there was good ventilation and air currents, away from public roads or transit spaces, as shown in Figure 22.

Fig. 20 Location in a high-traffic area

Fig. 21 Location directly behind a car

Fig. 22 Location on Building Roof

Fig. 23 Location Near the Sea

Point G

Measurement was taken near the sea, where there was no evidence of vehicle circulation, an open space, with ventilation and a current of the sea breeze, as shown in Figure 23.

4.1.2. Data Analysis

Methane

Regarding methane, a slight variation could be observed between the 7 points; making a visual analysis with the box plot, only two points (A and E) can be identified that do not have significant differences, as shown in Figure 24. Regarding the quality of the data, there is a dispersion of Standard deviation of 0.11 with an average measurement of 2.74 Volts; the red line shows a trend line with a moving average of value at 20 to smooth the variations of the measurements with an average of the last 20 measurements made, as shown in Figure 25.

CO (Carbon Monoxide)

In the case of CO, a greater variation is evident; it can be observed that points A and E have the highest measurement, while points C and G are related to the spaces where the measurements were made, as shown in Figure 26. Regarding the quality of the data, there is a dispersion of Standard deviation of 0.13 with an average measurement of 3.02 Volts; the red line shows a trend line with a moving average of value at 20 to smooth the variations of the measurements with an average of the last 20 measurements made, as shown in Figure 27.

Air Quality

In terms of air quality, it is not possible to identify which is the real measurement since there is a similarity in all the measurements, as shown in Figure 28. Data quality has a standard deviation spread of 0.13 with an average measurement of 2.54 Volts; the red line shows a trend line with a moving average value of 20 to smooth the variations of the measurements with an average of the last 20 measurements made. A more stable value is displayed, as shown in Figure 29.

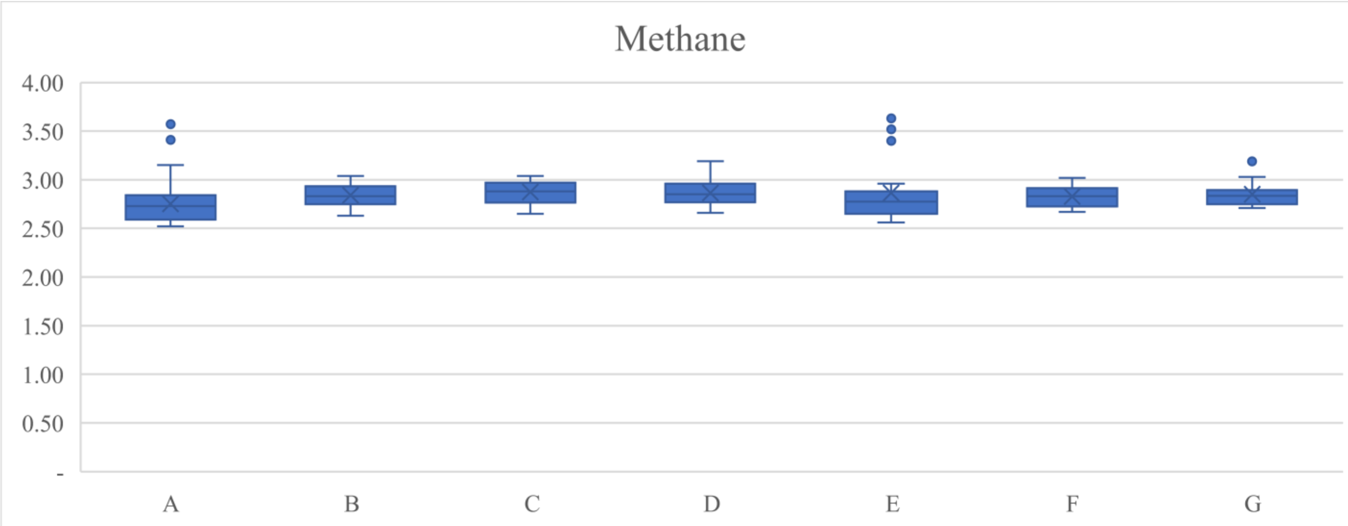

Fig. 24 Methane variation data capture

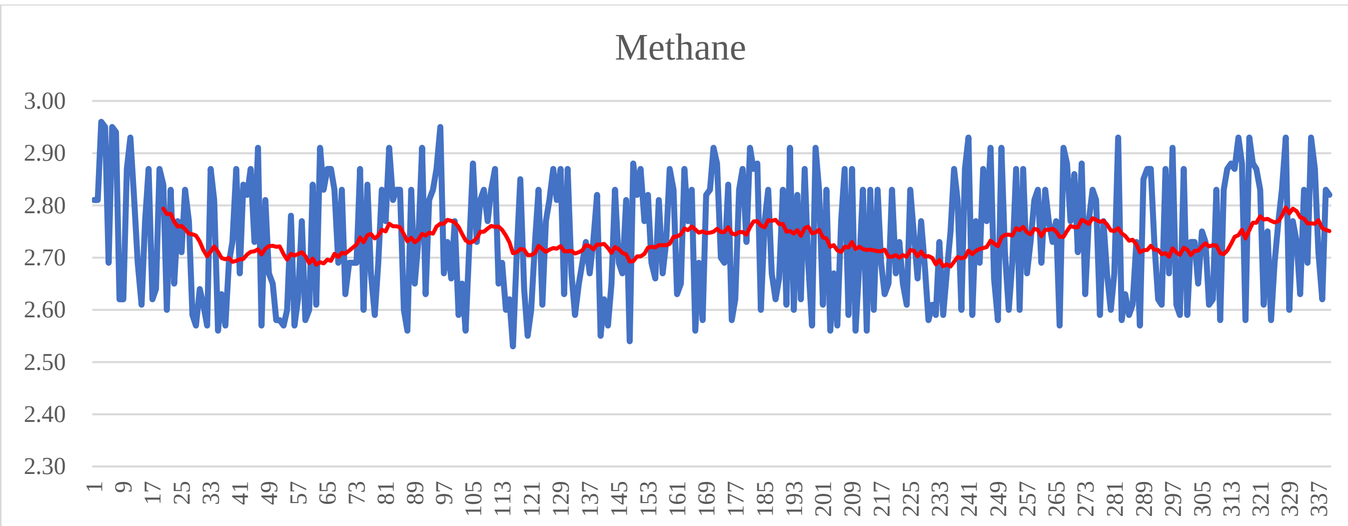

Fig. 25 Average Methane capture quality trend

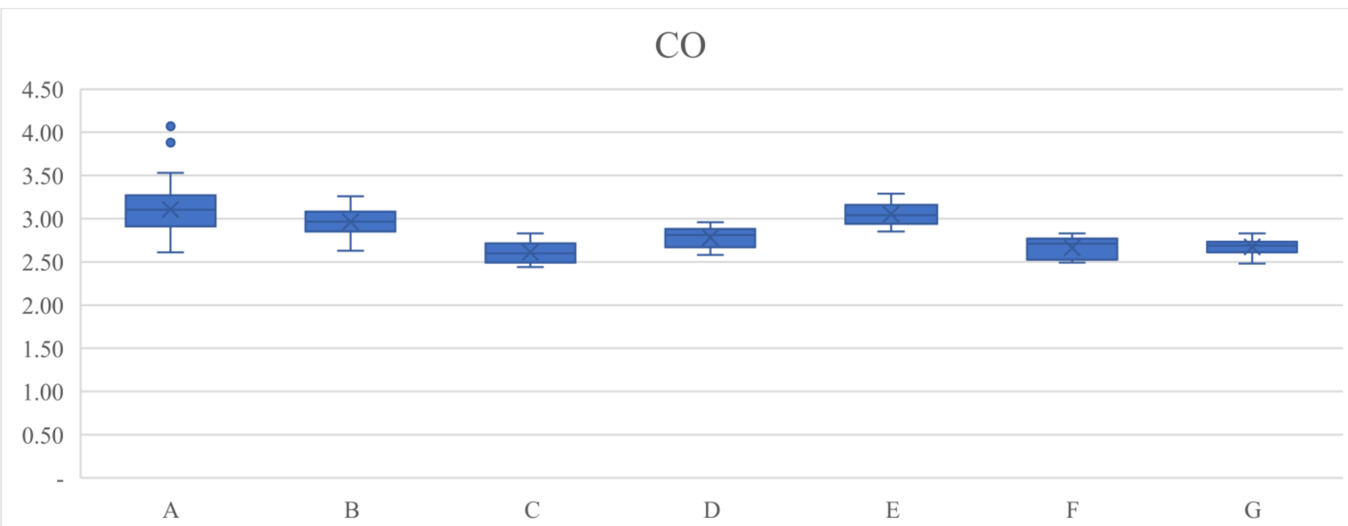

Fig. 26 CO variation data capture

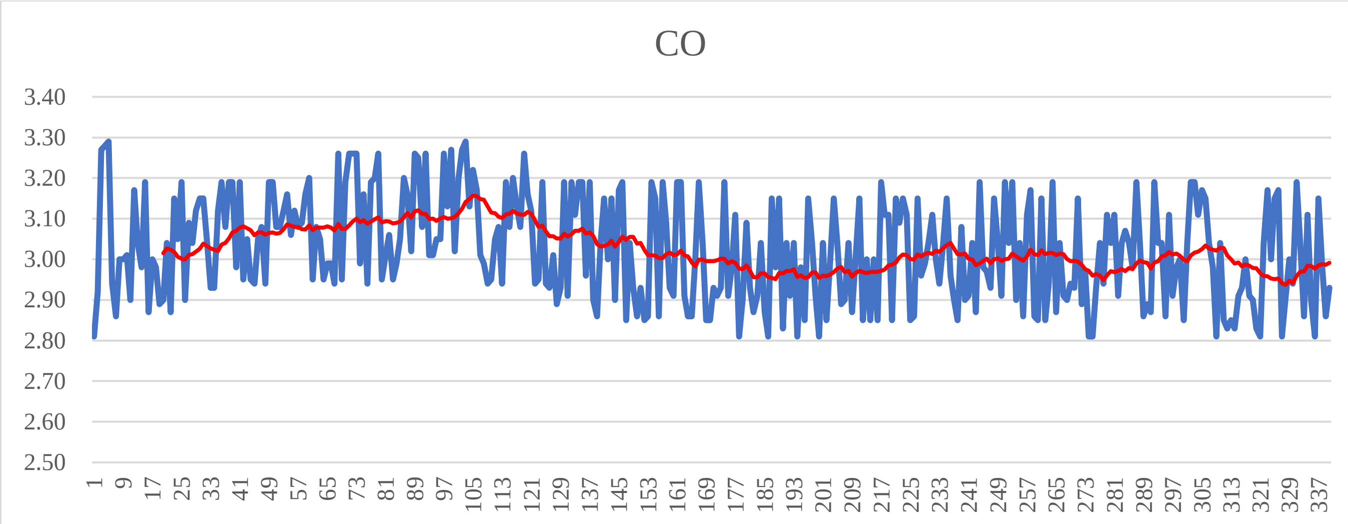

Fig. 27 Mean CO capture the quality trend.

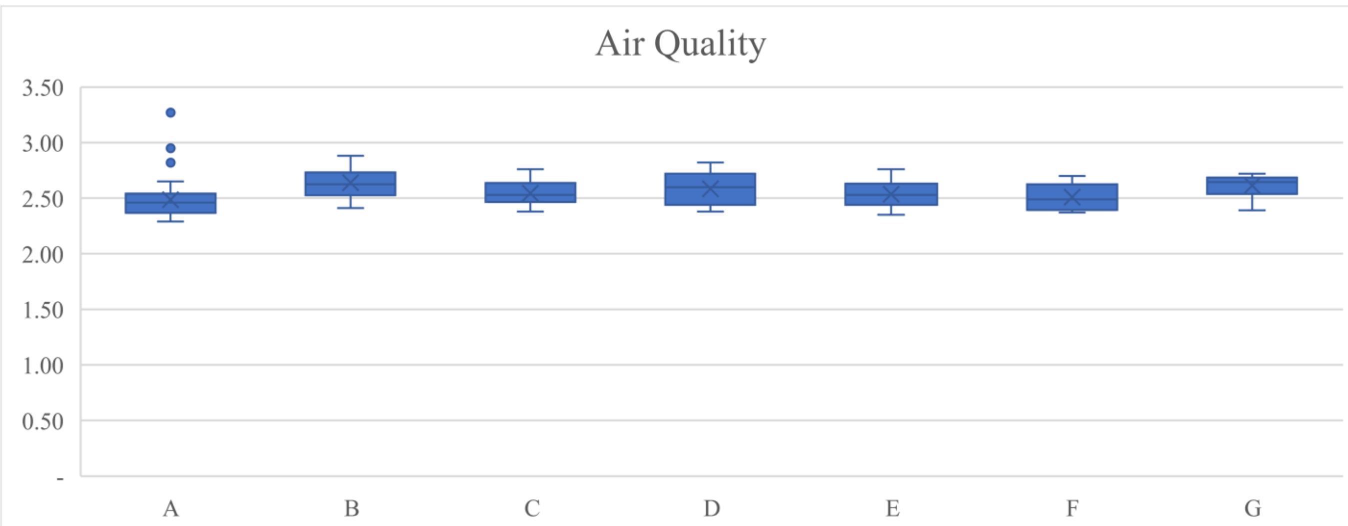

Fig. 28 Data Capture of Air Quality Variation

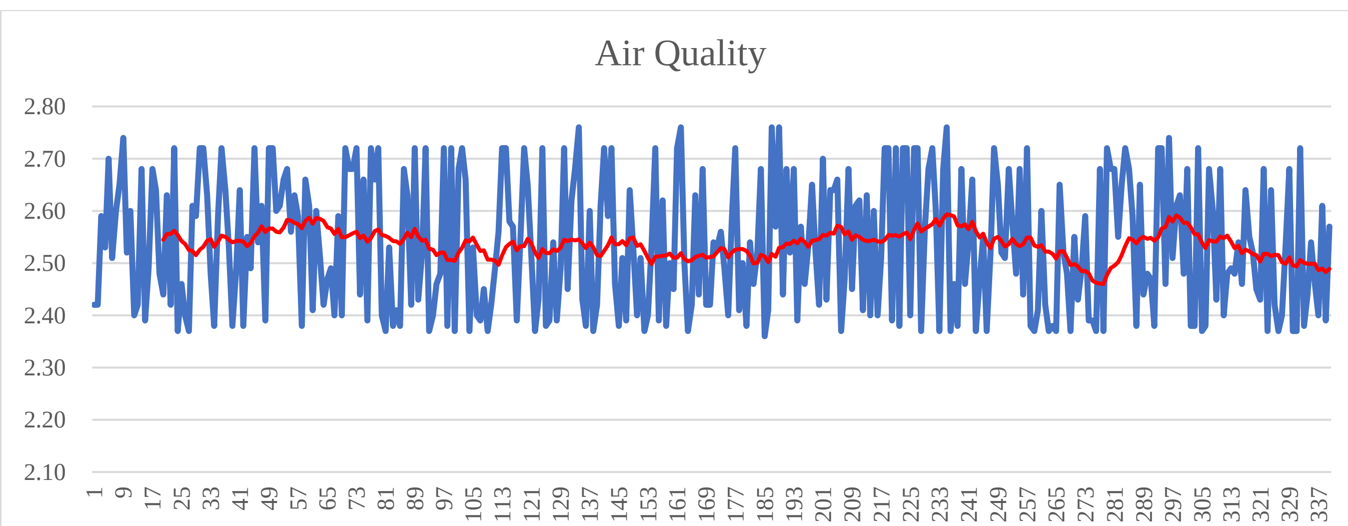

Fig. 29 Mean trend of Air Quality capture

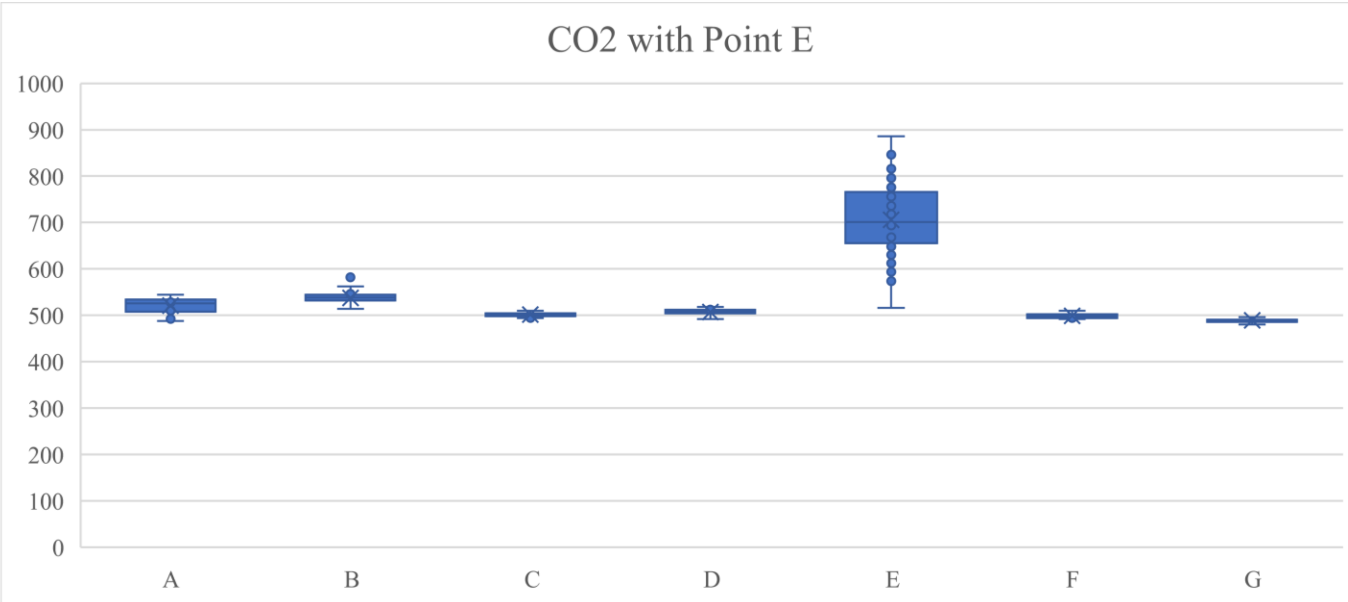

Fig. 30 CO2 variation data capture with Point E

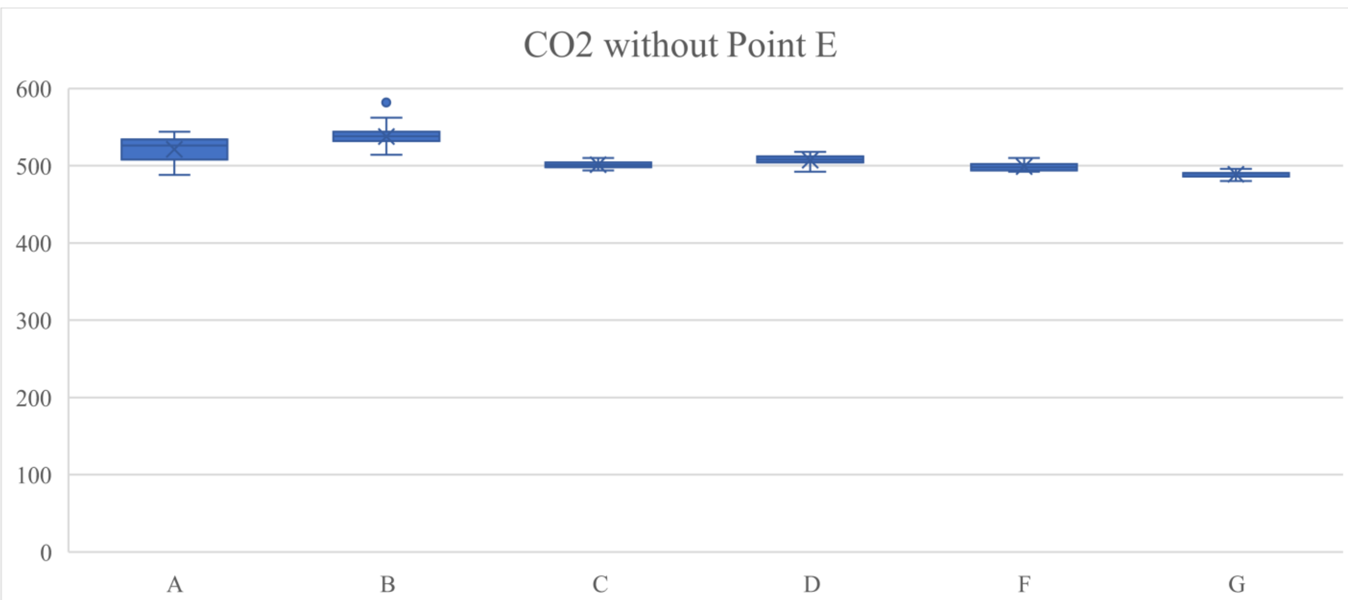

Fig. 31 CO2 variation data capture without Point E

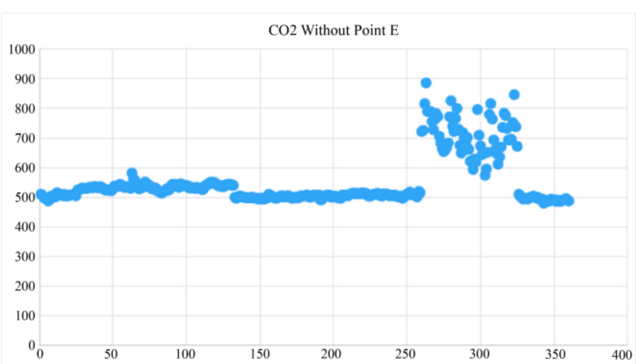

Fig. 32 Mean trend of CO2 capture quality with Point E

CO2 (Carbon Dioxide)

Regarding CO2, they have been taken under two conditions, the first in which measurements are taken in natural environments, and the second is with the condition of having the prototype close to the exhaust pipe of a car with the engine running, where can see the much higher sample, as shown in Figure 30.

Then the box diagrams without point E were analyzed, and the values corresponded to the places where the samples were shown, with the greatest contamination at point B and the least at point G; that is related to reality, as shown in Figure 31.

Regarding the data quality, the dispersion can be seen at point E, well above the other points and with an unstable measurement. This is due to the exhaust gases from the engine of the car with which the sample was taken, as shown in Figure 32.

To analyze the data dispersion quality, point E was removed, and it can be seen that there is a dispersion of 11.08 ppm for an average of 491.98 ppm. The data is stable; the red line shows a trend line with a moving average of value at 20 to smooth the variations of the measurements with an average of the last 20 measurements made, as shown in Figure 33.

4.1.3. Autonomy

An autonomy test was also carried out, so the equipment was activated at 08:00 pm with a new battery, and data could be collected for six hours; you can see the dispersion in the methane, CO, and air quality data. Regarding methane, there is a stable trend, with a moving average of 20 measurements; same for air quality; while for CO, there is a slight drop, as shown in Figure 34, Figure 35, and Figure 36.

In the autonomy test for CO2, a strong drop is evident during the early morning from approximately 515ppm, and it drops to 470ppm because the different elements that emit polluting gases are not operational at those hours, as shown in Figure 37.

Finally, a box diagram is shown where it can be seen that CO2 yields more stable data with less dispersion compared to the other gases, as shown in Figure 38.

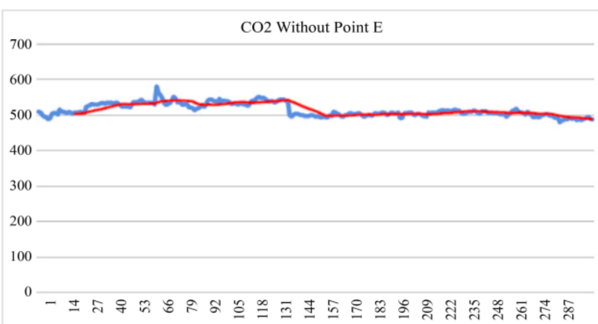

Fig. 33 Mean trend of CO2 capture quality without Point E

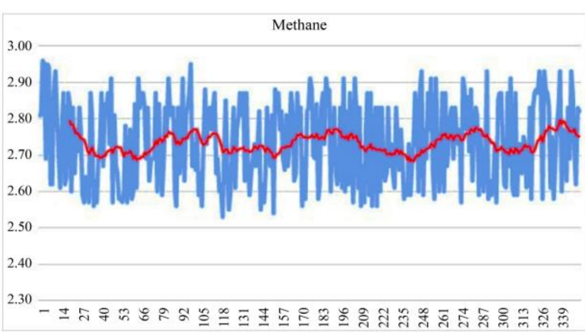

Fig. 34 Mean Methane Capture Quality Trend Invariant

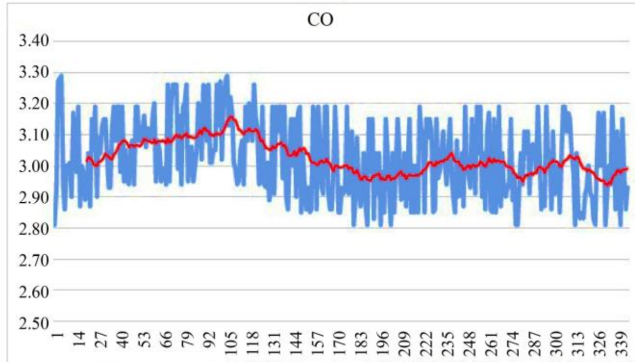

Fig. 35 Mean trend of CO captures quality Invariable

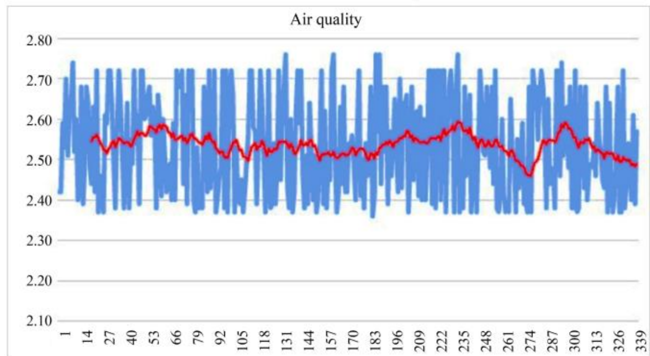

Fig. 36 Mean trend of Air Quality capture

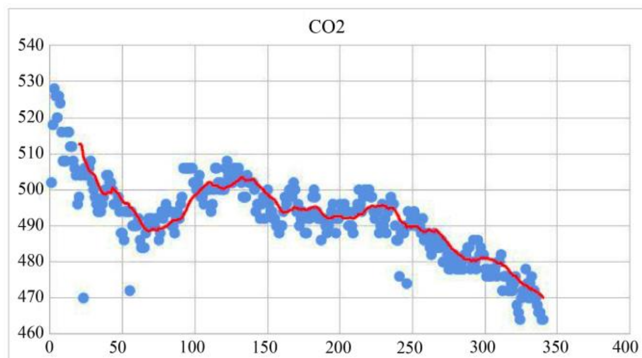

Fig. 37 Average trend of CO2 capture quality

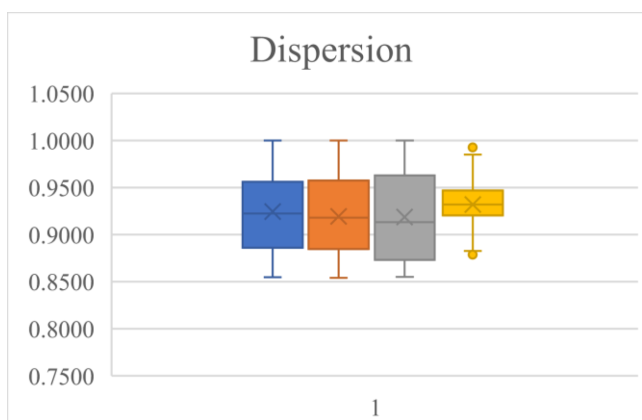

Fig. 38 Measurement of stable CO2 dispersion

4.2. Discussion

According to the results obtained, the design and implementation of the module for the measurement and monitoring of greenhouse gases of Methane, CO, Air quality, and CO2 were carried out, which allowed the measurements to be stored on a cloud platform so that they can be consulted and make a good decision. In the same way, the results of the research work [11] did a module with MQ-02, MQ-135, and TGS2602 gas measurement sensors and carried out tests in different areas of the city of Solapur, validating the correct reading of gas concentrations.

These results agree with [14], who developed a modular wireless system with MOS sensors calibrated for the detection of methane (MQ2, MQ4, and TGS2611) and carbon dioxide (MQ-135), with Arduino nano and XBee wireless transmission for sending the sensor measurement to the communications network. They obtained measurements of the different points of the city with high concentrations of gas due to traffic congestion and waste from the municipal market, validating the device's correct operation.

There are different Greenhouse Gases which are methane, carbon dioxide, carbon monoxide, and water vapor. These gases are the main triggers of global warming, as the changes are reflected today [1]. There are different measurement systems and sensors for each of the polluting gases; in the development of this research, the importance of knowing and distinguishing each of these pollutants is demonstrated to select the appropriate existing sensors and technologies for implementing the prototype market.

5. Conclusion

According to the results obtained from the measurement of 7 strategic places of GHG gas contamination of the City of Metropolitan Lima as areas with high vehicular congestion, in addition, for contrast, measurements were made in open areas where there is no vehicular traffic. It was possible to evaluate whether the module developed contributes to the measurement of polluting gases such as Methane, CO, Air Quality and CO2. In addition, with the incorporation of GPS into the module and the installation carried out in a vehicle, it was possible to more easily identify locations and potential contamination times according to the flow of traffic and activities carried out by people.

In the measurement results, CO2 stands out with the highest value of contamination compared to the other gases, having values close to 515ppm in areas and times of high traffic, and its counterpart in the early morning hours, approximately lower values around 470ppm.

This project allows the analysis of greenhouse gas emissions in areas of high traffic congestion for the case carried out in Lima, Peru, being also useful both for the industrial area and for the use of homes. According to the tests carried out with the prototype, monitoring was carried out through a web portal, and the gas emission levels were identified for adequate corrective and preventive decision-making.

The developed module allows us to favor the conservation of a better environment because it improves our climatic environment, allows people to carry out their activities in a safer and more controlled environment, and identifies the sources of contamination to take mitigation actions more accurately.

The construction of this prototype was developed with low-cost components and with accessibility to acquire them or find their replacement in case they suffer any damage or deterioration. In addition, it uses solar panels to power the module and GPS, being an ecological mobile alternative solution.

For further studies, a graphical interface can be incorporated into the web portal where it is possible to monitor through maps and alert sites with a high rate of GHG-polluting gases in real-time. In addition, for a better analysis of contamination of a variety of GHG gases, other sensors can be incorporated to measure nitrous oxide (N2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs and HCFCs), trifluoride of nitrogen (NF3), perfluorocarbon (PFC). Together with the municipalities, seek mechanisms for awareness, prevention, and control of zones at times when emissions with a high polluting index of GHG occur for the care of people's health and the environment in general.

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