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CO2 and CH4 emission meter in hydroelectric plants on aquatic surface

The recent intensification of human activities has led to a significant increase in the emission of certain gases, called greenhouse gases (GHG), such as carbon dioxide (CO2) and methane (CH4). The Earth's climate changes together through United Nations Organizations (ONU) to create strategies to reduce the impacts of gases in the Earth's atmosphere. Of all the GHG generation activities, the energy sector is the one that most contributes to global warming, the reservoirs of hydroelectric plants are potential emitters of greenhouse gases. Considering the importance of developing new policies to slow global warming, the proposer work will help to compare the studies carried out on automated gas emission measurement tool, which allows the identification of an estimated amount of pollution in reservoirs that a hydroelectric plant is capable of to produce and emit to the atmosphere. Currently, this measurement is performed using stationary sensors manually positioned whit the aid of boats. The robotic model allows data collection through gas sensors and moves around the water surface by means of engines and guided by GPS. The prototype was applying to a reservoir at the Mourão Hydroelectric Plant in the city of Campo Mourão, Paraná, Brazil, for accurate and reliable data, it was necessary to consider parameter that influence gas measurements, such as humidity, temperature, and climate. The data collected may contribute to future studies for the development of methods for recovering water conditions, through preservation actions.

Keywords: Greenhouse Effect; Global Warming; Reservoirs.

Medidor de emissão de CO2 e CH4 em plantas hidroelétricas na superfície aquática

A recente intensificação das atividades humanas tem levado a um aumento significativo na emissão de alguns gases, chamados de gases de efeito estufa (GEE), como o dióxido de carbono (CO2) e o metano (CH4). O clima da Terra muda em conjunto por meio das Organizações das Nações Unidas (ONU) para criar estratégias para reduzir os impactos dos gases na atmosfera terrestre. De todas as atividades de geração de GEE, o setor de energia é o que mais contribui para o aquecimento global, os reservatórios das usinas hidrelétricas são potenciais emissores de gases de efeito estufa. Considerando a importância do desenvolvimento de novas políticas para desacelerar o aquecimento global, o trabalho do proponente ajudará a comparar os estudos realizados na ferramenta de medição automatizada de emissões de gases, que permite identificar uma quantidade estimada de poluição em reservatórios que uma hidrelétrica é capaz de atingir. produzir e emitir para a atmosfera. Atualmente, essa medição é realizada por meio de sensores estacionários posicionados manualmente com o auxílio de barcos. O modelo robótico permite a coleta de dados por meio de sensores de gás e se movimenta na superfície da água por meio de motores e guiado por GPS. O protótipo foi aplicado a um reservatório da Usina Hidrelétrica Mourão, na cidade de Campo Mourão, Paraná, Brasil, para dados precisos e confiáveis, era necessário considerar parâmetros que influenciam as medições de gases, como umidade, temperatura e clima. Os dados coletados podem contribuir para estudos futuros para o desenvolvimento de métodos de recuperação das condições hídricas, por meio de ações de preservação.

Palavras-chave: Efeito estufa; Aquecimento global; Reservatórios.

Topic: **Desenvolvimento, Sustentabilidade e Meio Ambiente**

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INTRODUCTION

In global warming, heat retention is done through the presence of gases in the atmosphere, called greenhouse gases (GHG), they allow the passage of solar radiation, which according to Schuchter (2010) are essential to maintain the average temperature from the earth. These gases are carbon dioxide (CO_2) and methane (CH_4), other gases such as ozone, chlorofluorocarbons, composed of bromine and iodine also affect the greenhouse effect, however, these other gases are in low concentration.

The Earth's climate change caused by the excess of greenhouse gases, has caused the world communities to come together through United Nations (UN) Organizations to create strategies to reduce the impacts on the environment.

In 1979, the first World Climate Conference was held, which pointed to the need for cooperation among nations to develop a global strategy for understanding the functioning and rational use of the climate system (WMO, 1979). There was an evolution in the meetings and ten years later, the Intergovernmental Panel on Climate Change was created, in which governments had a clear vision of what is happening with the global climate. In 1992, the UN brought countries together to stabilize greenhouse gas emissions into the atmosphere so that it would not interfere with the climate system in a dangerous way. From this meeting, the Kyoto Protocol was established, which brought real commitments and established the reduction of greenhouse gas emissions (UN, 1998).

According to the Kyoto Protocol, in a period from 2008 to 2012, it considered that 1 t of CH_4 corresponds to 21 t of CO_2, on global warming in 100 years. More recent studies of the protocol increased the proportion from 21 t to 34 t, including effects of aerosol gas. The amount of methane is less than carbon dioxide in the water, but it is the most worrying. Only a part of carbon dioxide has an impact on the greenhouse effect, as a percentage of it is lost through absorption.

In 2017, COP21 (21st United Nations Conferences on Climate Change) was held, in which a new agreement was adopted to replace the Kyoto Protocol, since it would have its due date in 2020. The new protocol the replacement agreement is called the Paris Agreement. The new agreement has the objective and commitment to maintain an increase in the average temperature of the earth at less than 2º C.

To achieve the objective of the Paris Agreement, each country has committed itself to creating its own commitments. Brazil has pledged to reduce the emission of greenhouse gases by 37% compared to the 2005 data, by 2025. To do so, the country will have to increase the share of sustainable bioenergy by 18%, reforest 12 million hectares of forests. and achieving a 45% share in renewable energy (BRAZIL, 2017). The most recent united nations conference was held in 2019 in Madrid, Spain, named COP25. The meeting focused on the carbon market. During the meeting, several reports were presented regarding the emission of greenhouse gases. One of them was published by the World Meteorological Organization (2019), reporting a new record in emissions of gases in the atmosphere, accounting for 407.8 parts per million in 2018.

In 2018, the climate observatory, SEEG, published a document for the analysis of GHG emissions in Brazil. The report explains that the energy sector - including production and consumption of fuels and electricity - represents the third largest source of gross GHG emissions in Brazil, with 19% of the total in 2016 (423.4 million tons of CO_2 emissions), behind only agriculture and land use change. This is the sector where emissions grew the most in the period evaluated, an increase of almost four times between 1970 and 2016.

There are three factors that are responsible for the production of greenhouse gases in hydroelectric plants: 1. Decomposition of pre-existing vegetation, of trees affected by the flooding of areas used for the construction of the reservoir; 2. The action of primary algae that emit CO_2 in plant lakes; 3. The accumulation of organic nutrients in dams brought in by rivers and rains.

The organic matter that is converted to methane comes from sources in two groups: the initial stocks such as the leaves of the trees in the flooded area and the carbon in the flooded soil, and the renewable stocks, such as the macrophytes that grow in the water and the herbs that grow in the depletion zone, that is, the large mud that forms annually when the water level is lowered in the reservoir. Vegetation in the drawdown zone is rooted to the bottom, where, as the water level rises, it decomposes in the oxygen-free zone and generates methane. When plants grow, they take carbon from the air in the form of CO_2 by photosynthesis, and when they die inundated, they return this carbon in the form of CH_4. As it is an emission that is repeated every year in a sustainable way, the hydroelectric plant works as a “methane factory” (FEARNSIDE, 2008).

Another type of contribution to global warming comes from the flooded forest. The carbon stock leads to the emission of CO_2 by the decomposition of dead trees. This emission is added to the great production of methane by the decomposition of the leaves that fall from these trees below the water.

In September 2015, the UN in celebration of its seventieth anniversary decided with the heads of state and government to create the Sustainable Development Goals (SDGs). The SDGs are an agenda made up of 17 objectives and 169 goals to be achieved by 2030. For this purpose, global actions in several areas are foreseen, being divided into four dimensions: social, environmental, economic and institutional.

Some phenomena drive the emission of gases and the amount of CO_2 emitted in the year 2020 can reach 417.4 ppm, an increase of 2.75 ppm in relation to previous years (KAHN, 2020). The importance of measuring greenhouse gases gains even more importance given recent studies on climate change, to develop new policies to reduce environmental impact and slow down global warming.

GHG flows into the atmosphere through the reservoir surface can be measured/estimated using the following techniques: (I) flow measurement through the air-water interface; (II) measuring the concentration of gases in the water and applying empirical equations; (III) based on turbulent covariance theory (LAMBERT et al., 2005). Direct measurements are carried out using funnels for collecting bubbles, installed below the surface of the water, and diffusion chambers, installed on the surface of the water, in which the emitted gases are stored (MANNICH, 2013).

According to Anderson (2005) the method of measuring the field through cameras is quite simple. But there is no technical standard that specifies how these chambers should be manufactured, nor a technical standard on sampling methodology. It is important to use in the manufacture of the chamber a material that does not adsorb the gas of interest and is not affected by the diffusion of the environment. The air inside static chambers must be well mixed to avoid empty areas, particularly in rectangular chambers.

Floating chambers are closed chambers, connected to a float, in which gases accumulate and have variable geometry. The operational methodology consists of placing the open part of the chamber, which has an open and a closed part, on the surface of the water, allowing surface emissions to accumulate inside the chamber or reduced. The estimation of gas concentration is performed by collecting samples from the internal atmosphere. The variation in concentrations over time provides an accumulated curve from which the flux can be deduced. Commonly, this methodological process is represented by a linear variation, whose slope is the estimate of the emission rate in the evaluated time interval (SBRISSIA, 2008; LAMBERT et al., 2005; IHA, 2010; MANNICH, 2013).

It is important that the chambers have an extension of the walls below the water line to prevent the turbulence created by the movements of the chamber over the water, although anchored to the bottom, affecting the transfer of gases. In addition, an opening for regulating the pressure is necessary, as the increase in pressure increases the solubility of the gas, reducing the flow. The radiation effects must be overcome by manufacturing the chamber with reflective material, to keep the internal temperature in balance with the environment. The gases are collected in syringes and analyzed by gas chromatography in the laboratory (LAMBERT et al., 2005; IHA, 2010; MANNICH, 2013).

This type of chamber is not recommended for use in shallow bodies of water, as they may run aground or present problems when a measurement at a fixed point is desired.

However, the chambers (Figure 1) have the advantage of allowing the analysis of flows on a local scale, but they can influence the surface under study. Effects are complex and depend on the environment placed. The superficial chambers can overestimate the actual flow, increasing the rates of surface renewal due to the deformation they cause and the disordered movements. They also increase turbulence in the sublayer. Sbrissia (2008) explains that the chambers can underestimate the flow by protecting the surface of the water from capillary waves, from the humidity of the waves and protecting the surface from the wind and, thus, reducing the speed of friction. In addition, as the air concentration increases in the chamber, the potential concentration or gradient that makes the flow decreases. This leads to a lower estimate of the flow that would occur under natural conditions.

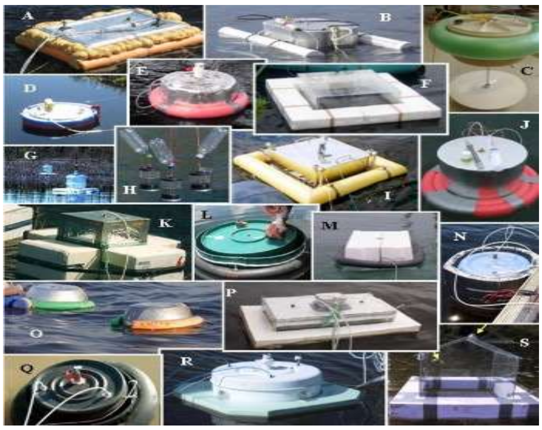


Figure 1: Types of floating chambers around the world. Source: Mannich (2013) IHA (2010) (B, M), Esmanhoto E (C), Teodoru et al. (2012) (E, R), Huttunem et al. (2005) (F, I), Louis (2000) (G), Santos (2017) (H, J), Lima (2008) IBT (K), Abril et al. (2005) (Q), Harby A (S).

MATERIALS AND METHODS

The work was carried out at the Usina Mourão reservoir, located in the city of Campo Mourão, Paraná, Brazil, and was divided into three stages. The first stage consisted of assembling the prototype that was placed on the aquatic surface of the reservoir. With the prototype assembled, tests were started on each sensor that makes up the robot, the components were tested individually before the definitive assembly of the model.

The second stage consisted of testing at the study site, the prototype was placed on the water surface of the reservoir to find out how it moved in relation to water, and the collection of collected data. The last step was the identification of the collections, to verify the effectiveness and veracity of the data that the robot was able to collect. The data were compared with similar tests for error identification and data calibration.

Electronic model for measuring CO_2 and CH_4 gases

The electronic model consists of a tire air chamber, which allows the robot to float and move over the water, and in the center there is a container responsible for storing the gases that are being emitted by the water as shown in Figure 2 (A), the which will be collected by a gas sensor MHZ -19 (Figure 2 (B)) that collects CO_2, with a detection range of 0 to 2,000 ppm, and the sensor MQ-2 that collects CH_4 informed in Figure 2 (C), its detection level ranges from 0 to 10,000 ppm. Then, with the help of propellers printed on a 3D printer (Figure 2 (D)) and two DG01D-A130 GEAR MOTOR motors are controlled by the Arduino module, the robot can move according to the coordinates defined by the researcher using a GPS (Figure 2 (E)). The model also has a compass to help locate the GPS, so that the robot knows if the coordinate indicated on the GPS is correct in view of the north and south location (Figure 2 (F)). As an energy source, the robot uses a photovoltaic plate and a set of batteries (Figure 2 (G)). Another important aspect is the BMP280 sensor that collects the temperature, altitude and pressure of the analyzed environment (Figure 2 (H)), this sensor has a measurement range of 300 to 1,100 hPa. The data about the robot's path and the data collected by the sensors are stored on a memory card (SANTOS et al., 2017).

The Arduino UNO board was installed to manage all the data collected by the MHZ-19 and MQ-2 sensors and to command the movement of the robot, making it autonomous. The programming used is relatively simple. The current version of the software controls both the propellers and the engines, as well as the sensor that was programmed in a specific application for development with this platform, the Arduino IDE where there are the necessary commands so that the robot can perform the tasks and complete them with success. The prototype has a height of 22 cm, a length of 68 cm and a width of 50 cm. It has small dimensions and is easy to move from one place to another with little current.

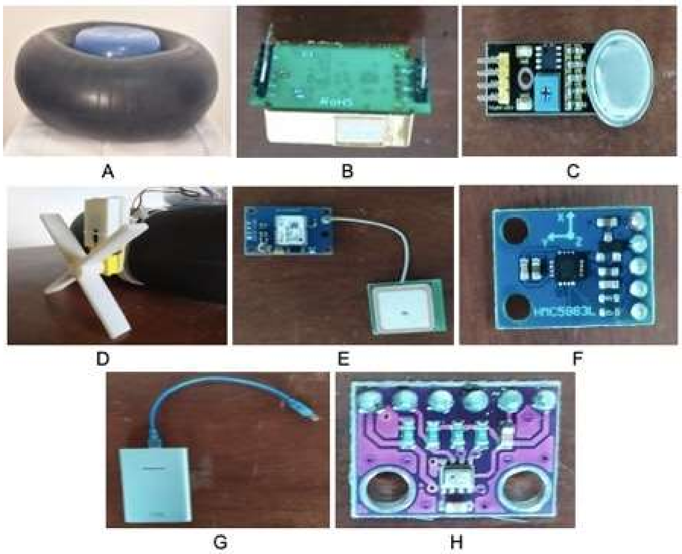


Figure 2: (A) Tire air chamber and gas storage container; (B) MHZ-19 sensor; (C) MQ-2 sensor; (D) Engines and propellers; (E) GPS module; (F) Compass; (G) PowerBank; (H) Pressure, altitude and temperature sensor (BMP280).

Component testings

For each sensor component of the robot, tests were carried out separately to verify that all were functioning as expected to proceed to the final assembly of the robot. Start the experimental test with the MHZ-19 sensor, to check the data count. For the test, a simple experiment was used in which a solution of bicarbonate, water and vinegar was created. The solution can produce a reasonable amount of carbon dioxide, which made it possible to certify the CO_2 sensor.

For the solution, 50 mL of water, a shallow spoon of sodium bicarbonate and 25 mL of vinegar were used. In a glass container with a volume of 500 mL, water and bicarbonate were mixed, then the container was covered with a lid with a larger diameter and with three circular openings so that the BMP280 sensor, which measures altitude pressure and height, and the MHZ-19 sensor, which measures CO_2 gas, came into contact with the solution to collect the data, the last opening served to pour the vinegar into the container, so that the solution entered the working system together with the sensor reading.

For data collection, three tests were performed with the same amount of solution, for the first test, 30 seconds were waited for data collection, for the second test, 60 seconds were waited, and for the last collection, if 120 seconds. With the same test, it was possible to calibrate the sensors. The MQ-2 sensor can detect a variety of flammable gases such as liquefied petroleum gas (LPG), methane, propane, butane, hydrogen, alcohol and natural gas. This type of sensor is widely used for fire and smoke notification alarms.

As the sensor can detect several gases, the test that was used to verify that the sensor was operating correctly was the cooking gas test. For the test, a 13 kg gas cylinder was used, a stove with automatic ignition, with a gas system connected to the cylinder, a metal container with a lid, resistant to fire and the MQ-2 sensor.

First the valve of the gas cylinder was opened to allow the gas to pass, then the stove with automatic ignition was turned on, the metal container with a lid was placed on top of the fire flame to start the production of gas and smoke, the MQ-2 sensor was fixed to the lid itself to check and calibrate the data collected from the gases that were inside the container.

Water surface application

The test routine of the gas meter used in this study was based on field tests that allow the elaboration of a routine of use. The meter, after assembly, was applied to an aquatic surface to analyze the data provided.

At first, after assembling the electronic model, it was exposed to an aquatic surface influenced by nature to test each component of the model, namely: engine, propellers and sensors. Furthermore, it was evaluated how the robot behaves in an aquatic environment, which underwent changes in its assembly throughout the study.

Then, the tests in an aquatic environment began. For this, the reservoir of the Mourão Hydroelectric Plant was part of the object of study. The reservoir was chosen because it is one of the environments with the highest number of greenhouse gas emissions according to research reported in the theoretical framework. Due to the high pollution index, it was determined that the tests would be carried out in the reservoir.

Characterization of the study area

Following Encarte III - Management Plan - Lago Azul State Park (2005), the plant was installed in the city of Campo Mourão and Luiziana, Paraná, Brazil, located on the Third Paraná plateau, has its geographical center at 52 ° 20 ' Longitude W-GR and 24 ° 04 'South Latitude, with administrative headquarters at BR-487, leaving Campo Mourão towards Luiziana, the plant has been in operation since 1964. It has a sufficient capacity to serve approximately 25 thousand consumers, with approximately 8,500 kilowatts.

The insert also states that as the Rio Mourão System is a tributary of the left bank of the Rio Ivaí (357 km), it has 3 high jumps, namely: (I) São João Complex, with 5.3 m difference in level and flow of 60 m^3/sec; (II) Natal with 5.9 m of unevenness and 15 m^3/sec of average flow; (III) Set with 146.6 m of unevenness and 3 m^3/sec of average flow, where the Hydroelectric Power Plant Mourão I is installed.

The Mourão - Lago Azul Hydroelectric Plant Reservoir has a flooded area of 1273.6557 ha and upstream the basin is covered in an approximate area of 581 km^2 with a perimeter of 109.5 km. In Appendix B and Appendix C, it is possible to observe the location and detail of the hydrographic basin.

In August 1999, monitoring was carried out at points downstream and upstream of the reservoir, to assess the interventions resulting from the installation of the plant in water quality. According to IBAMA - Encarte III (2005), the results obtained showed that the waters of the Mourão River were in the range between 52 and 80 of the Water Quality Index - IQA, indicating that “they are good quality waters for the purpose of potable public water supply. In terms of bathing, the waters showed good quality. The invasion of the Permanent Preservation Area of riparian vegetation contributed to the contribution of alien substances to the waters of the Mourão River.

Twenty years after the first surveys carried out in 1999, Permanent Preservation areas are once again an obligation in the region of riparian vegetation, with a criminal nature if the area is degraded or invaded.

Reservoir application

To operate the meter in the field, the following routine was followed: The robot was kept with the opening directed towards the water to collect the gases, with the programming system protected from contact with the water; The exit, collection and return points were programmed; After the location of the points were determined and located by the robot, the data collection process began; The robot started the engines and with the help of the side propellers it can move from one point to another; When it reached the programmed point for collection, the robot turned off the engines to start data collection, and so proceeded to the other programmed point, until it returned to the starting point.

The campaigns were carried out from February to November 2020. Water samples were taken from various points to determine concentration profiles. The determination of the concentration of CO_2 and CH_4 was carried out through the measurement sensors, in which the data were stored on a memory card and read through a computer system.

The collection points were determined by the position of closest proximity to the public that uses the reservoir lake, to obtain the influence of the transition regions of environments and close to the banks and zones of stagnation, for data comparison.

As the robot has a GPS system for locomotion, the points were programmed through georeferencing. After collecting the gases and calibrating the data, a comparative analysis was performed between the values found at the various points collected and data taken from a satellite that quantifies the gases approximately, to certify the robot for use.

Data analysis

The data collected by the sensors included in the robot were stored on a memory card to facilitate data reading. The data was programmed in a relatively simple way, so that the storage was easy to understand.

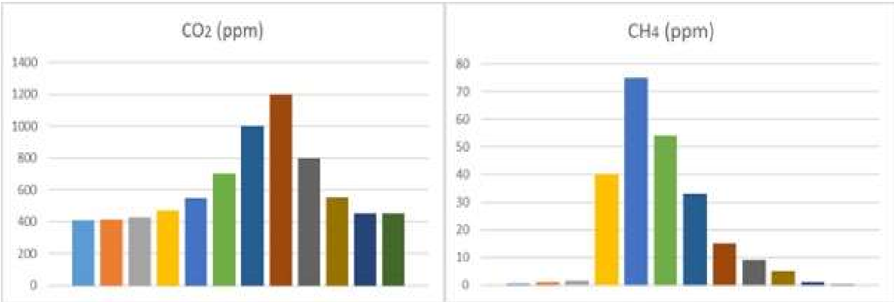
With the data in hand, it was possible to compare CO_2 and CH_4 gas emissions at the various points collected. The comparison analysis was made at the two measurement sites, the collections were carried out at points close to the recreation sites, where the human influence contributed to the increase of the emitted gases, and in places of stagnation, without human influence, and further away from the reservoir dam. Thus, being able to compare the data obtained in the two distinct points of the reservoir.

RESULTS AND DISCUSSION

Component testing

The three sensors, MHZ-19 to measure CO_2 emissions, MQ-2 to measure CH_4 emissions and the BMP 280 sensor to measure pressure, altitude and temperature were tested separately, but in the same environment. The tests were carried out inside a room without the influence of environmental weathering, following the applied methodology.

For the MHZ-19, a good performance was observed during the tests, below in Figure 3 (A), it is possible to observe the data collected in the test environment, twelve collections were made for each type of sensor, to obtain a standard curve in the analyzes. The MHZ-19 sensor provides the data in the unit of measurement ppm (parts per million). At the highest point of the Figure, in collection number 8, it was the peak of the collection, at which it reached the value of 1200 ppm. After reaching the peak, the solution started to lose gas, which explains the drop in the graph. During the tests it was observed that the starting point of the sensor is at 400, that is, when the sensor collects data in an external environment, the minimum value is 400 ppm, and when it is in an internal environment, the normal is to supply a minimum value of 700 ppm, therefore, when the sensor reaches the value close to 400 ppm, it means that the environment has a low CO_2 emission content.



A B

Figure 3: (A) MHZ-19 Sensor test; (B) MQ-2 Sensor test.

The MQ-2 sensor also performed well during the testing phase. Following the methodology, the sensor made 12 collections for data analysis. Figure 3 (B) shows the sensor's behavior. Through the graph, it was possible to verify that the sensor gradually increases the value, and after reaching the peak it decays sharply, having a behavior opposite to the data prior to the peak. The MQ-2 sensor, like the MHZ-19, provides data in the ppm unit, reaching its peak during testing at approximately 6 ppm.

Unlike the CO_2 sensor, the methane gas sensor starts at 0, so the values are lower than the values of the MHZ-19 sensor.

For the BMP280 sensor test, the values did not fluctuate, since the environment did not change or change location, which was satisfactory, since the values were maintained in the same measure. Table 1 shows the values presented by the sensor during the tests, eight collections were performed, according to the methodology.

Table 1: Sensor Test BMP280.

	PRESSURE hPa	ALTITUDE m	TEMPERATURE ºC
1	94924.37	547.07	27.45
2	94926.59	546.86	27.45
3	94927.44	546.95	27.46
4	94922.23	547.26	27.43
5	94925.75	546.67	27.46
6	94925.91	546.93	27.46
7	94927.09	547.11	27.46
8	94923.84	547.00	27.46

Water surface testing

After testing with each sensor, it was possible to make the final assembly of the robot, so that all components worked together to form the object of the work. In Figure 4 (A) it is possible to check the image of the robot assembled in perspective from above, with all its components, including float, engines, propellers, gas storage container, protection container for electronic components. In the container of electronic components there is a GPS, compass, memory card and powerbank, all of them interconnected through power cables to transmit the information programmed through the Arduino.

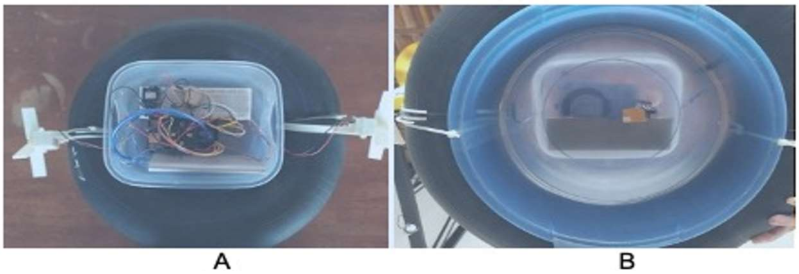


Figure 4: Robot, (A) Top perspective; (B) Perspective from below.

In Figure 4 (B), we have the view under the robot, being able to check the location of the sensors inside the gas storage container. It is in this space where the gases emitted from the reservoir water are stored and encountered the sensors to read the data.

First test

On November 8, 2019, the first test was carried out with the prototype in an aquatic environment, in the lake of Parque Municipal Joaquim Teodoro de Oliveira. During the test it was evaluated how the model behaved in front of an aquatic surface, as well as its propellers, engine and sensors. During the test it was possible to verify that the robot was able to move, but the wind was able to easily move the robot from position due to its light weight. Another observed fact was that the plants, both shallow and those that have roots, got tangled in the engines, which caused the engine to stop.

The CO_2 sensor and the BMP sensor, which measures temperature, altitude and pressure, were also tested and obtained good performance, however they were tested in a swimming pool inside an enclosed room. In Table 2 we can verify the data emitted by the sensors.

Table 2: CO_2 emission results, ambient temperature and altitude through the Arduino serial monitor.

Temp. (°C)	Approximate Altitude (m)	Pressure (hPa)	CO_2 Emission (ppm)
24	593.73	94394.02	256
24	593.65	94394.86	410
24	593.56	94397.39	410
24	593.61	94395.34	1584
24	593.52	94396.41	1387
24	593.68	94394.49	1338
24	593.59	94394.15	1322
24	593.71	94394.15	1287
24	593.71	94394.00	1244
24	593.73	94394.15	1221
24	593.71	94394.82	1172

24	593.75	94391.92	1125
24	593.91	94395.46	1103
24	593.60	94392.94	1058
24	593.61	94394.78	1009
24	593.68	94394.53	959
24	593.83	94392.86	896
24	593.73	94392.94	860
24	593.70	94394.36	840
24	593.56	94395.87	803
24	594.16	94389.06	774
24	593.67	94394.70	760

Rural zone

The first test of the robot on an aquatic surface in the reservoir of the Mourão Hydroelectric Power Plant - object of study - was carried out in a region of the lake away from human interference, the test was carried out to verify how the robot behaved in the aquatic environment to proceed with the collections. The test was carried out close to the edge at a distance of approximately 1.5 m inside the reservoir. Data from 3 points were collected, being the starting point (P00), point 1 (P01) and point 2 (P02). At points 1 and 2, 4 collections were made at each point. Each collection took about 1 second to collect the data, between the starting point and point 1 the robot took about 30 seconds to reach the programmed point, the same time was considered for the distance between point 1 and point 2 The Robot made the collection only when it arrived at the indicated points, during the journey from one point to the other the sensors were not connected. In Figure 5, it is possible to verify the robot's behavior at the three points in relation to CO_2 emission.

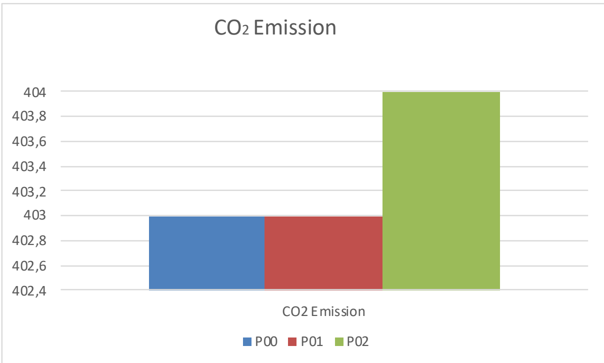


Figure 5: CO_2 emission.

In Figure 5, points P00, P01 and P02 were considered, the 4 data collections from points P01 and P02 remained at 403 ppm and 404 ppm, respectively. The CO_2 emission value for the study site was relatively low, compared to the expected data according to the bibliographic references. It is believed that how the place is removed from human interference, having a stagnation in water quality there, and the riparian forest around it, influenced the CO_2 emission filtering, decreasing the amount of pollution in the place.

Table 3 shows the data collected from the BMP280 sensor, collected while the MHZ-19 sensor made the collection. Through the table, it appears that the data did not oscillate, which represents a good workability of the BMP280 sensor on site.

Table 3: Sensor Data BMP280.

	PRESSURE hPa	ALTITUDE m	TEMPERATURE ºC
P00	94192.81	611.48	36.93
P01;1	94161.47	614.25	36.90
P01;2	94161.64	614.24	36.90
P01;3	94161.80	614.22	36.91
P01;4	94161.88	614.04	36.91
P02;1	94154.09	614.90	36.21
P02;2	94157.38	614.61	36.21
P02;3	94152.88	615.01	36.21
P02;4	94149.07	615.35	36.22

The second test was carried out with the robot already in motion, 5 collections were made, with a time distance of 1 second from one point to another. In this test, the robot did not stop at the determined points to make the collection as in the first test, as it moved around, it was doing the data collection. Figure 6 shows the behavior of the CO_2 emission at the points collected. According to the graph, the CO_2 emission value remained the same in the first three collections and only changed in the last collection. However, as the sensor emits a data of 400 ppm considering that it is the value of 0, the emission of carbon dioxide in the place is still relatively low to verify an emission of greenhouse effect.

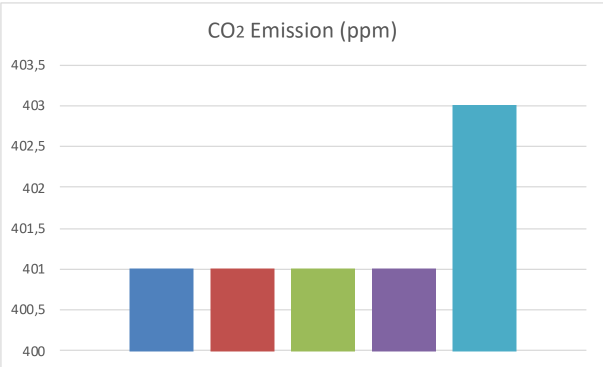


Figure 6: CO_2 emission.

Considering the data from the BMP280 sensor, there was no sudden change again. This is due to the calibration of the sensor and because they are environment data, since there was no change in the location. Table 4 shows the sensor data.

Table 4: Sensor BMP280.

	PRESSURE hPa	ALTITUDE m	TEMPERATURE ºC
P00	94117.56	618.13	32.09
P01	94116.53	618.22	32.11
P02	94117.25	618.16	32.13
P03	94115.19	618.34	32.13
P04	94114.93	618.10	32.14

Urbanized point

The second data collection site within the reservoir of the Mourão hydroelectric power plant was carried out in a region that has leisure and residential housing. It is the region of the lake with the greatest number of human influences, being characterized by the construction of land boundaries, buildings, warehouses, kiosks, among other interferences considered for leisure. The place is widely used by residents, in which they use the water from the reservoir to bathe.

According to residents of the region, some time ago the houses could be built close to the lake, without any master plan for the location. Currently, the management of the plant has a master plan for construction, maintaining a minimum distance from the lake to the property of approximately 20 meters. In addition, the warehouses must be made of wood and barrels for flotation, to avoid increasing the pollution of the lake with materials from the lake. civil construction such as concrete and steel. The administration also implemented the APP, a permanent preservation area, close to the lake, ensuring that residents do not use the area for construction or deforestation.

Before starting the tests with the robot on the water surface, a pre-test was carried out with the robot out of the water to check if the sensors were really working. For the MHZ-19 sensor, a series of breaths were carried out close to the sensor to detect the CO_2 that the human body emits when exhaling. For the MQ-2 sensor, a phosphor was lit close to the sensor to detect CH_4 data. In Figure 7 (A), it is possible to verify the data collected from the CO_2 pre-test. The graph shows the exact line of the increase in carbon dioxide when the sensor detects the gas.

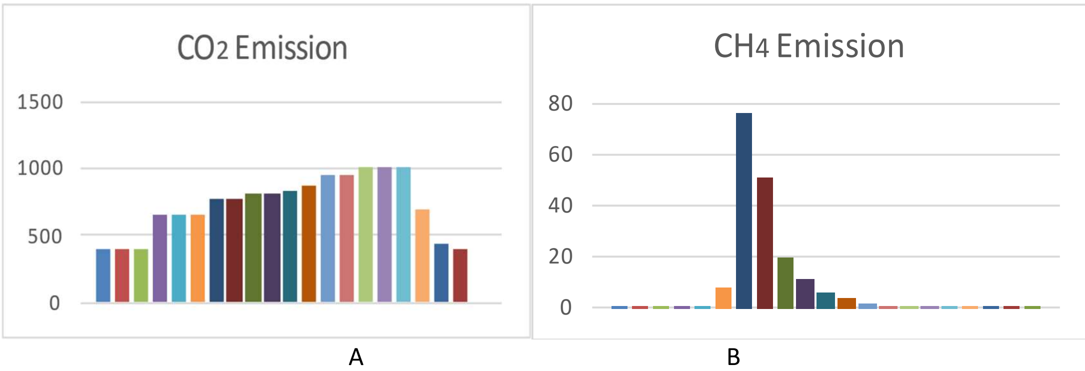


Figure 7: (A) CO_2 emission (pre-test); (B) CH_4 emission (pre-test).

In Figure 7 (B), there is an increase in CH_4 gas as soon as the sensor detects the gas emitted by the phosphor. An extremely important factor observed during the tests was that the MHZ-19 sensor takes more time to detect the gas, whereas the MQ-2 detects it immediately.

After the initial tests were completed, the robot went to the water surface. The data were collected from three different points, one point closer to the lake shore, another point further away and the last point was close to the pier. 75, 100 and 120 collections were performed respectively. As the sensors collect with 1 second interval, a high amount of data can be collected for the analysis curve.

Figure 8 shows the data collected from the MHZ-19 sensor for the three collection points. The data remained in the 400 ppm range, varying up to 404 ppm, which is considered low for the location. The MQ-2 sensor data, on the other hand, had no fluctuations, remaining at 0.01 ppm, which can be considered a negative range for methane gas pollution.

After data collection, it was verified that the sensors, both the MHZ-19 and the MQ-2 were connected via bluetooth and because of that the programming is different when the sensors are connected via cable by a computer. The sensors in the pre-test, carried out before the robot was inserted into the aquatic environment, were connected via a computer cable, which justifies the difference in data between the pre-test and the test in the lake.

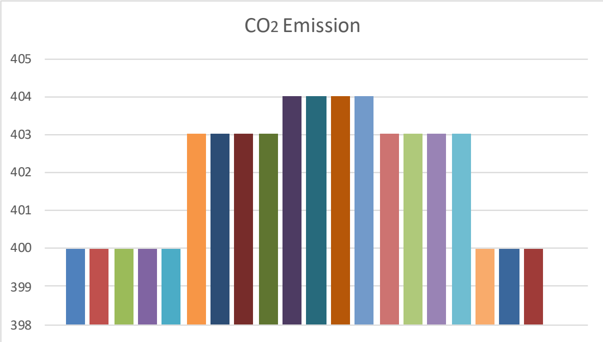


Figure 8: CO_2 emission.

The BMP280 sensor had a good performance, it is through it that it is possible to check if the sensors are in operation, as it emits temperature data. During the tests, the BMP280 sensor encountered water accidentally, but the data was not compromised and not even its functioning, the sensor continued to collect data, which can be concluded that it is waterproof. Table 5 shows the values collected by the sensor.

Table 5: Sensor data BMP280.

	PRESSURE hPa	ALTITUDE m	TEMPERATURE ºC
P01;1	94610.35	574.67	31.66
P01;2	94599.00	575.67	31.51
P01;3	94611.56	574.56	31.28
P01;4	94612.29	574.50	31.27
P01;5	94594.53	576.06	31.00
P01;6	94600.80	575.51	31.04
P01;7	94604.38	575.19	31.03
P01;8	94593.05	576.19	31.06
P02;1	94612.69	574.46	31.08
P02;2	94603.13	575.30	31.13
P02;3	94599.31	575.64	31.22
P02;4	94618.80	573.93	31.28
P02;5	94601.17	575.48	31.46
P02;6	94597.72	575.78	31.47
P02;7	94596.63	575.88	31.40
P02;8	94602.20	575.39	31.33
P03;1	94618.73	573.93	31.36
P03;2	94610.00	574.70	31.37
P03;3	94595.67	575.96	31.60
P03;4	94596.18	575.92	31.75
P03;5	94612.63	574.47	32.36
P03;6	94580.52	575.29	32.47
P03;7	94586.59	576.76	32.54
P03;8	94590.06	576.45	32.57

After verifying the error in the programming of the MHZ-19 and MQ-2 sensors in the connection via bluetooth, a new test was carried out with the sensors to verify the values.

Four tests were performed, considering 3 points with 50 collections each. The first test was to verify the workability of the sensors before inserting the robot into the water, for the methodology, the same process as the previous day's test was used, for the MHZ-19 several blows were performed to collect the CO_2 gas from human expiration. As for the MQ-2 sensor, we used the smoke from the lit phosphor to collect the methane data. In Figure 9 we have the data collected from the first test before the sensor goes to the aquatic surface.

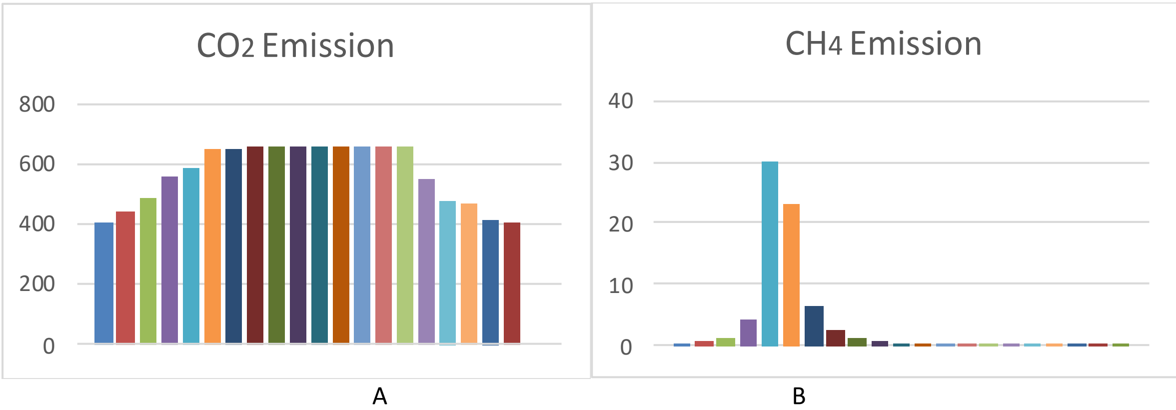


Figure 9: (A) CO_2 emission (B) CH_4 emission.

In Figure 9 (A), it is possible to verify the increase in the amount of CO_2 emission during the pre-test, the same happens in Figure 9 (B) with the amount of CH_4 emission. After the pre-test, the robot was inserted into the aquatic surface, three tests were carried out in the water, the first test was carried out close to the margin, the second test was carried out with a greater depth and the third test was carried out close to the margin, but horizontally, to check the influence of the subsoil on the collected data.

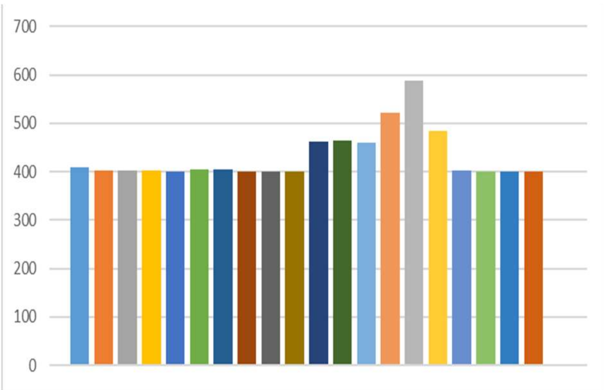


Figure 10: CO_2 emission.

For the first collection test, 50 samples were collected at 3 points, going from the point closest to the margin to the farthest point. Figure 10 explains how the MHZ-19 sensor behaved and its data collection. During the collection, it was identified that at a specific point in the lake, at a depth of 0.50 m, the sensor collected a variation in the CO_2 emission inside the reservoir, this variation occurred after the soil was moved to move the robot from one place to another. It was the point of greatest emission value. The biggest problem in the plant's lake is believed to be the soil, which probably has decomposition of organic matter and is releasing a certain amount of gas.

The data for the MQ-2 sensor, on the other hand, had no change, remained in the range of 0.01 to 0.08, which is considered a value almost equal to 0, that is, the sensor cannot detect CH_4 emission for the points collected. The pressure, altitude and temperature data can be seen in Table 6.

Table 6: Sensor data BMP280.

	PRESSURE hPa	ALTITUDE m	TEMPERATURE ºC
P01;1	94345.69	597.99	31.36
P01;2	94400.41	593.16	31.10

P01;3	94368.20	596.00	31.02
P01;4	94371.09	595.75	31.01
P01;5	94371.77	595.69	30.97
P01;6	94372.79	595.60	30.97
P01;7	94370.50	595.80	30.91
P01;8	94369.64	595.88	30.92
P02;1	94359.77	596.75	31.01
P02;2	94369.61	595.88	31.06
P02;3	94363.88	595.39	31.16
P02;4	94363.78	596.39	31.26
P02;5	94322.73	600.01	31.26
P02;6	94368.75	595.95	31.23
P02;7	94383.20	594.68	31.24
P02;8	94355.50	597.12	31.22
P03;1	94399.34	593.26	31.24
P03;2	94369.93	595.85	31.19
P03;3	94349.13	597.68	31.19
P03;4	94368.02	593.02	31.19
P03;5	94370.08	595.84	31.18
P03;6	94367.55	596.06	31.23
P03;7	94375.68	595.34	31.27
P03;8	94366.92	596.12	31.27

Figure 11: Robot performing data collection.

The second test, carried out at a depth of 1.00 m, the sensor values did not change, the MHZ-19 sensor remained at 400 to 403 ppm, while the MQ-2 sensor did not exceed the 0.03 ppm margin. The collected values are relatively low compared to the expected according to the bibliographic reference. During the test, the same methodology of the previous test was used so that the soil emitted bubbles to the surface for the sensor to perform the collection, but the gas force was not enough to reach the sensors, due to the height of the depth.

In the third test, the robot was placed to collect the gases in a horizontal line in the river (Figure 11), remaining at a height of 0.50 m in depth, the same height at which the sensor managed to collect a variation in emission of carbon dioxide gas, but the results were not satisfactory, the collected data remained in the same range as the second collection, for both the MHZ-19 and MQ-2 sensors.

CONCLUSIONS

In the first test of the robot carried out in the lake of Parque Municipal Joaquim Teodoro de Oliveira, it was possible to detect that the robot could easily be driven by the wind, moving it from one position to another. In addition, the design of the propellers contributed to the shallow plants getting tangled in the engine, causing it to stop. In the following tests, according to all the results exposed in this work, it was possible to identify that the developed methodology model had a good performance to evaluate the levels of carbon dioxide and methane gas in the aquatic surface of the reservoir of the Mourão Hydroelectric Plant. The reservoir under study had a low level of greenhouse gas emissions. In the two locations of the experiment, the values were close, with no difference between the emission levels of the urban area and the rural area within the limits of the Mourão Hydroelectric Plant. The low level of emission is due to the permanent protection areas (PPA), an area that has become mandatory on the banks of the lake, to avoid deforestation due to urbanization of the place and still assist in the fauna and flora of the area, thus helping in the absorption of greenhouse gases through the green area maintained. During field campaigns, gas emission events were observed through bubbles, when the subsoil was stirred, there is probably sedimentation of organic matter in the place, which may have originated from the bottom discharge of the existing dam. If there were no dam, this sedimentation along the river would probably cause more distributed emissions. Through the measurements, it was verified that when closer to the lake shore, the gas emitted by the aquatic subsoil gets faster to the sensors to make the collection. The deeper the depth of the reservoir, the lower the emission value of the gases, it is believed that the lack of pressure and speed of the gas to reach the surface, made the collection by the sensors difficult. It is worth mentioning that the collections took place during the hottest months of the year, the temperature ranged from 28 to 32º C, in addition, the water levels in the reservoir were below the average level expected for the months in question due to the lack of rain. Considering all the data collected, the robot had a good performance related to data collection in the plant's reservoir, only the prototype data was considered, it is necessary to use another meter already existing in the research market, qualified and certified, that performs the measurement of greenhouse gases for certification of robot data. In addition, parameters such as oxygen dissolved in water and biochemical oxygen demand were not considered, which would assist in determining the present pollution. With this, it was felt the need to incorporate the sensors inside the water surface for a better parameter of the data with comparison effect, since the sensors are not waterproof and collected the data of the gases that the water emitted to atmosphere. The recommendations for future studies described show that the study of measuring greenhouse gases in reservoirs of hydroelectric plants is a complex activity, which requires different areas of knowledge and constant study.

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