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IoT sensory platform for monitoring temperature, relative humidity of the air and CO2 in situ

This article addresses the development of a sensory platform capable of measuring temperature, relative humidity, and carbon dioxide. The system is based on concepts of an IoT (Internet of Things) platform using the ESP8266 microcontroller connected to DHT21 and CSS811 sensors, the power system has lithium batteries. An App (Application) in Blynk technology was used to display the collected information and georeferenced the data, which in turn are stored in a digital cloud. Two experiments were carried out to determine the environmental quality in a forest and urban area within Belém, showing the quality of the developed system and the influence that trees have on air quality in relation to carbon dioxide and thermal comfort. Furthermore, a reformulation of the urban public transportation system must be employed, enabling it to be used in an efficient and less polluting way, since transportation is the leading emitter of pollutants that contribute to the greenhouse effect and aggravates factors related to public health. The description of the developed device allows its reproducibility and has as main differentials: optimized power system, possibility of integration with renewable energies, low cost platform; connection with several sensors; easy programming and operation; internet access and, last but not least, low cost.

Keywords: Application; Carbon Dioxide; Digital Cloud; Thermal Comfort.

Plataforma sensorial IoT para monitoramento de temperatura, umidade relativa do ar e CO2 in situ

Este artigo aborda o desenvolvimento de uma plataforma sensorial capaz de medir temperatura, umidade relativa e dióxido de carbono. O sistema é baseado em conceitos de uma plataforma IoT (Internet das coisas) utilizando o microcontrolador ESP8266 conectado aos sensores DHT21 e CSS811, o sistema de potência conta com baterias de lítio. Um App (Aplicativo) em tecnologia Blynk foi utilizado para exibir as informações coletadas e georreferenciar os dados, que por sua vez são armazenados em uma nuvem digital. Dois experimentos foram realizados a fim de determinar a qualidade ambiental em uma área de florestal e área urbana dentro de Belém, mostrando a qualidade do sistema desenvolvido e a influência que as árvores detêm sobre a qualidade do ar em relação ao dióxido de carbono e conforto térmico. Além disso, uma reformulação do sistema de transporte público urbano deve ser empregada, permitindo que ele seja utilizado de forma eficiente e menos poluente, uma vez que o transporte é o principal emissor de poluentes que contribuem para o efeito estufa e agravam os fatores relacionados à saúde pública. A descrição do dispositivo desenvolvido permite sua reprodutibilidade e tem como principais diferenciais: sistema de potência otimizado, possibilidade de integração com energias renováveis, plataforma de baixo custo; conexão com vários sensores; fácil programação e operação; acesso à internet e, por último, mas não menos importante, baixo custo.

Palavras-chave: Aplicativo; Dióxido de Carbono; Nuvem Digital; Conforto Térmico.

Topic: **Tecnologia, Modelagem e Geoprocessamento**

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INTRODUCTION

It is possible to observe that over the last few years, several studies have been elaborated on the quality and pollution of the air, revealing the dangers that the populations, especially in large urban centers, are exposed to daily. Among the several evils that can be mentioned related to air pollution we have: premature deaths, skin diseases, cardiovascular diseases, lung diseases, strokes, dementia, problems related to cognitive development, among others (DAPPER et al., 2016).

Actions to combat air pollution have proven effective in reducing hospitalizations and deaths caused by exposure to polluted air, according to actions taken in the EUA and Europe. However, in Brazil, there is no strict control for the prevention of diseases, since the issue of air quality is a matter of public health, in addition to the fact that access to air quality data is scarce, also important for the monitoring of cities, becoming a challenge to be overcome (GOUVEIA et al., 2003).

In the context of large cities, an environmental variable widely discussed lately is carbon dioxide (CO2); this chemical element is not considered a pollutant, however, when there are concentrations in the air above what nature can use in the natural carbon cycle, it involves several environmental problems and human beings. The biggest of the evils is the greenhouse effect on a global scale and the human being the exposure to high concentrations can cause drowsiness, headache, loss of consciousness and even death (SEINFELD et al., 2006; LEIRÃO et al., 2018; BUJDEI et al., 2011).

The atmosphere has CO2 in its composition naturally. However, anthropogenic emissions have raised concentrations year after year. In direct and indirect forms, the main sources of emissions are fossil fuel-powered means of transportation, industries, thermoelectric power plants, and forest burning (SILVA et al., 2017).

Consequently, daily life in large cities exposes people to risks that often go unnoticed, because the air quality, in general, is invisible and requires equipment for real-time monitoring. Usually, this equipment for environmental monitoring is expensive, making it impossible to obtain information with an adequate spatial resolution for large cities (ARROYO et al., 2020).

Thus, the introduction of low-cost and low energy consumption technologies, which can be used in environments in order to provide information to the population about air quality and atmospheric comfort, variables of extreme importance. Although these systems do not provide data with the accuracy required in officially enabled systems, they favor a substantial increase in the spatial sampling mesh, returning useful information to the general population. That is, low-cost technologies do not replace reference systems in monitoring, but complement them with important information, given the scarcity of such data (ARROYO et al., 2020; LUNG et al., 2018).

In this context, the study's objective is to develop a sensory platform capable of performing CO2, temperature, and relative humidity measurements in situ; the system relies on an ESP8266 microcontroller connected to the NodeMCU prototyping board. This board performs all the logic processing parts programmed in C computer language (ZAMBRANO et al., 2019).

The data acquisition will be done through the electrochemical CO2 sensor model CCS811 and the temperature and relative humidity sensor DHT21. The data obtained by the sensors are processed in the NodeMCU board and sent via Wi-Fi to a digital cloud, which in turn is connected to a multiplatform application developed in Blynk technology. When displayed in the application, all data are georeferenced in the WGS84 Datum.

Building this kind of application allows the creation of a wireless sensor network, called IoT (Internet of Things). The IoT combines objects such as sensors, wireless, human beings, using different modes of communication, but with a certain interoperability and that is a network that can be deployed in various spaces, acting in emergency situations and in everyday life (LARA et al., 2021).

Thus, the proposed system integrates current electronic and computing concepts allied to the scarcity of environmental data regarding air quality in urban and rural environments and forests, and can be a very useful tool in environmental quality alert.

MATERIALS AND METHODS

The study was conducted in the city of Belém - Pará Lat. -1°27'18", Long. - 48°30'9"), located on the banks of the Guamá River and Guajará Bay, a region characterized by the Amazon biome. According to the Köppen classification the region is comprised by the climate type Af - tropical humid or super humid, without dry season (SANTOS, 2019).

High humidity and heat favor the formation of convective clouds, coupled with weather phenomena, breeze circulations, causing high annual precipitation rates, ranging from 3.000 to 4.000 mm (COSTA et al., 2018).

The construction of the IoT sensory platform occurred in two stages: Development of the Hardware containing all the electronics needed for the operation; Development of Software capable of processing data and performing all the necessary procedures for sending the data via Wi-Fi to a digital cloud.

Development hardware

The developed sensor platform has two sensors for data acquisition: CCS811 (CO2) and DHT21 (Temperature and Relative Air Humidity). The CCS811 is a device with I2C architecture, electrochemical, the operating principle of this sensor is through contact with ambient air that passes through a capillary diffusion barrier, diffuses through a hydrophobic barrier until it reaches a specific electrode for the analyzed element where chemical reactions occur. Which in turn create an electric current that can be converted into a concentration of CO2 in ppm through a ratio.

The entire process becomes more reliable with the presence of a reference electrode and a counter electrode, keeping the sensor potential stable and constant (YUNUSA et al., 2014).

The electrochemical sensors do not suffer interference from water vapor, since the region of Belém has high relative humidity throughout the year. Another feature is the low power consumption and small dimensions, making the CCS811 suitable for in situ measurements proposed in this study. First, however, it is necessary to perform compensation of the temperature effect on the CO2 sensor measurements (KOROTCENKOV, 2014; OLIVEIRA et al., 2016; LOWINSOHN et al., 2006).

DHT21 has a digital architecture and has a thermistor for temperature measurement with an accuracy of ± 0.5° C. Internally, the thermistors have a ceramic that changes the resistance to the passage of electric current according to the temperature of the environment. These sensors are widespread in industrial and automotive environments, because they have low cost, fast response, provide high accuracy, ideal for conducting environmental studies (GRALIK et al., 2019).

The signal containing the data with the sensor measurements are received through i2C communication (CCS811) and a digital port (DHT21) by the NodeMCU board that contains the ESP8266 microcontroller that has integrated IEEE 802.11 standard Wi-Fi. The programming was developed in C language in the IDE (Integrated Development Environment) Arduino, where it is possible to perform the processing and reliability analysis of the data obtained by the sensors (PERNAMA et al., 2021). After processing the data, the program returns the CO2 concentration in the environment in ppm, and the air temperature in °C. In (Figure 1) represents the developed circuit.

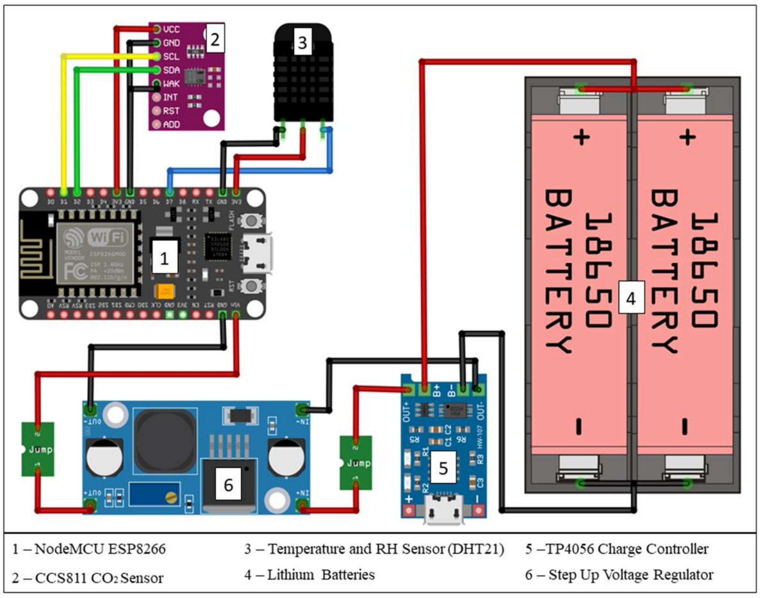

Figure 1: Electrical schematic of the sensory platform.

The power system was built from two 3.7 V, 2300 mAh li-ion batteries connected in parallel, a TP4056 charge controller to perform the charging of the batteries via micro-USB port, and a voltage elevator regulator with 98% efficiency. The calculation of the energy autonomy of the system was performed from the sum of the loads of the devices used, resulting in 333 mW (CHASE et al., 2018).

The maximum depth of discharge of the battery has been kept at 30% in order to maintain optimum life time, so there are 11.9 Wh available, resulting in a battery life of approximately 35 h. The sensors were used in a meteorological shelter to protect them from direct solar radiation, because under these conditions the reliability of the measurements of atmospheric variables such as temperature and relative humidity can be altered.

The electronic equipment used was arranged in an isolated phenolite plate with dimensions of

10x10cm, the interconnection between the devices was done through soldering and electric wires in the case of the lithium battery bank. This developed integrated board was coupled in a 25x20x8 cm hermetic box with IP65 protection degree (dust proof and protected against water jets) and produced in compatible material to favor the Wi-Fi signal propagation IEEE 802.11 standard. In Figure 2 we can see the developed prototype.

The platform produced had a total cost of R$ 315,00. However, with the circuit made and packaged, it was possible to develop the embedded programming in the ESP8266 microcontroller and the App for monitoring CO2, Temperature, Humidity, and GPS coordinate data.

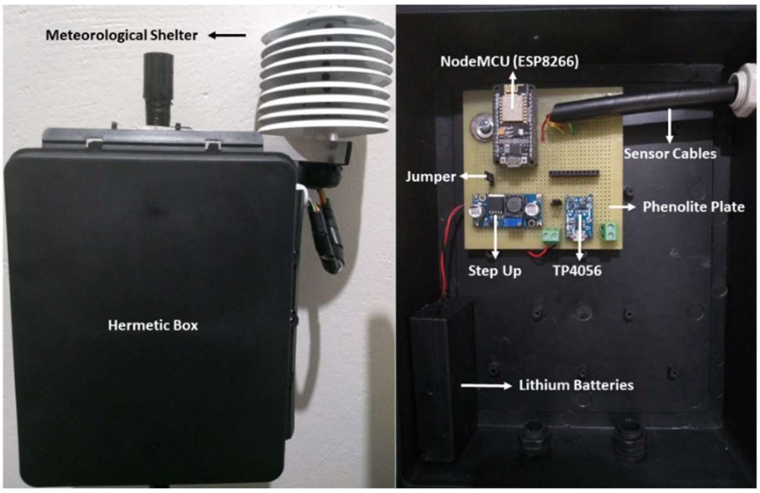

Figure 2: Sensory plataform developed.

Software and app development

The program embedded in the NodeMCU was developed based on the C/C++ computer languages in the Arduino IDE (Integrated Development Environment). The developed program processes the CO2 data from the CCS811 sensor through the communication ports with I2C protocol, and air temperature (DHT21) through the Wire communication bus, using the computational libraries of their manufacturers (NAHARRO et al., 2017; GUTIERREZ et al., 2006).

The NodeMCU is connected to the Internet through a Wi-Fi access point, and this connection allows the data collected by the sensors to be sent to the digital cloud Blynk. Sending this information is done securely using a randomly generated 32-character access key sent to the system administrator's email address, which can be included in the authenticity of the programming.

The data stored in the server are digitally arranged in an App developed in Blynk technology, which can be used in a multi-platform Android and iOS environment.

On the mobile device where the App works, data are requested from the cell phone's GPS (Global System Position) system via the Maps tool developed by Google® in order to save the CO_2 and air temperature data together with the geographic coordinates in the digital cloud. Thus, the sensor and the cell phone must be close at hand. The Figure 3 presents an overview of the sensory platform. The Figure 4 presents the flowchart containing the processes performed by the ESP8266 microcontroller.

After assembling and configuring the prototype it was possible to perform the experiment recording CO2 in ppm, temperature, and relative humidity in situ, which will be presented in the next section.

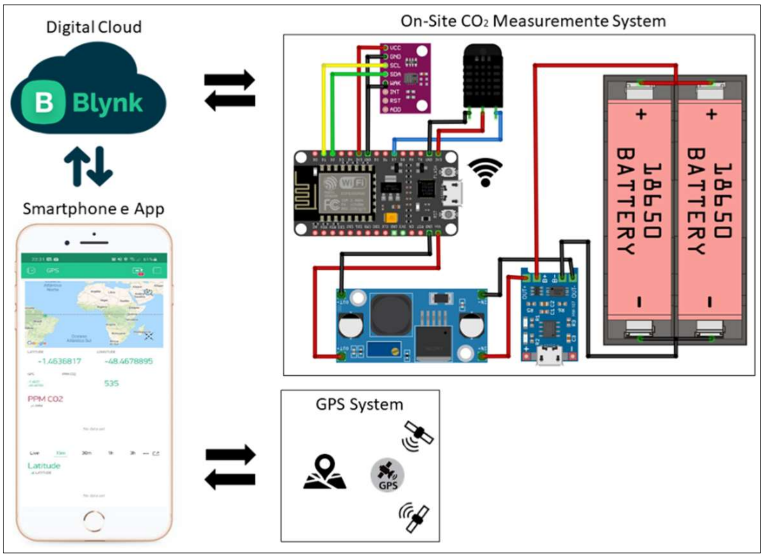

Figure 3: CO2, Temperature and Air Humidity Measurement System Overview.

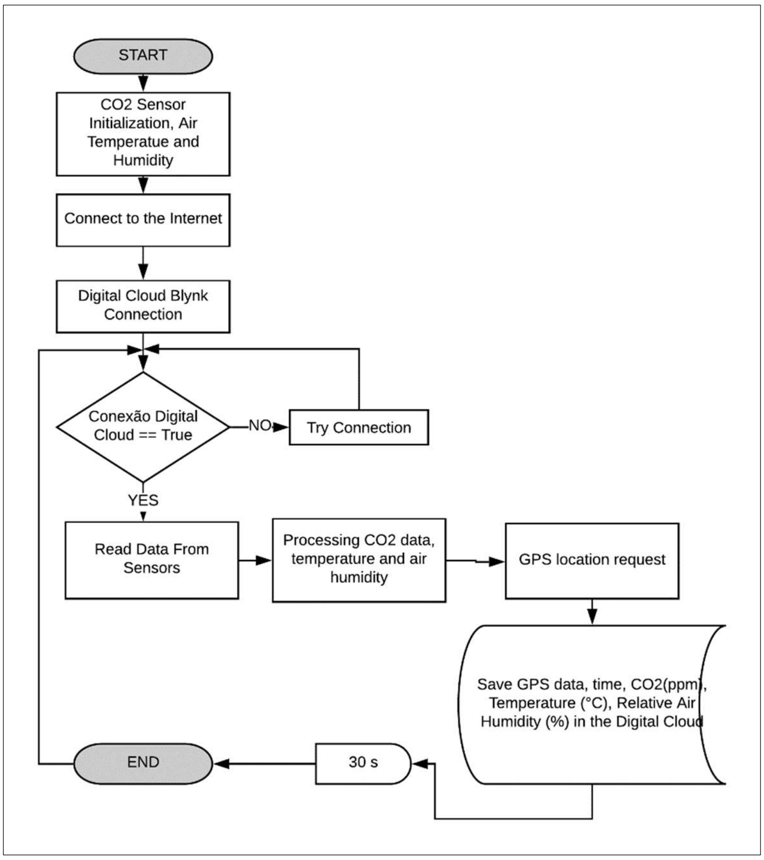

Figure 4: Program flowchart embedded in the ESP8266 microcontroller.

RESULTS

In order to study the performance of the system for measuring CO2, temperature and relative humidity two experiments were conducted: in a forest fragment located at the Universidade Federal Rural da Amazônia/Campus Belém – UFRA (north Latitude -1°27'29" and west Longitude - 48°26'13"), and another experiment at Avenue José Bonifácio (north Latitude - 1°27'49 and west Longitude - 48°28'7"). In (Figure 5) shows the map location of the points where the sensory platform performed the experiments.

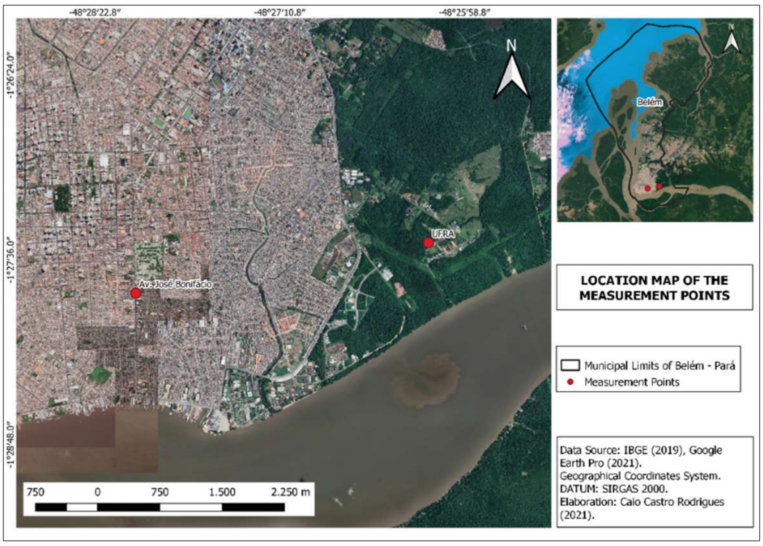

Figure 5: Localization map of the measurement points (UFRA area of campus and Avenue José Bonifácio).

The sites where the experiments took place were chosen due to distinct geographical characteristics, representing different environments in the capital of Pará, being: Forest fragment area (UFRA), an urbanized area with a high density of housing (Avenue José Bonifácio), and large circulation of people and vehicles.

The experiments aimed to collect data on air temperature and relative humidity, and with these data to return practical results, the Heat Index (HI) calculations were performed, and the CO2 concentration in the air was also determined.

HI equations

The Heat Index is a measure calculated from air temperature and relative humidity data related to thermal discomfort for humans (STEADMAN et al., 1979). To calculate the heat index, we used Steadman's (STEADMAN et al., 1979); this methodology performs calculations to find a temperature that provides health hazards (SILVA JÚNIOR et al., 2013). However, Rothfusz regressions are used refer to (1) (SILVA et al., 2014).

$$HI = -42{,}379 + 2{,}04901523 \times T + 10{,}14333127 \times RH - 0{,}22475541 \times T \times RH - 0{,}00683783 \times T^2 - 0{,}05481717 \times RH^2 + 0{,}00122874 \times T^2 \times RH + 0{,}0085282 \times T \times RH^2 - 0{,}00000199 \times T^2 \times RH^2 \qquad (1)$$

In the above formula, the *HI* refers to heat index; *T* refers to the air temperature measurement in Fahrenheit degrees (°F), and RH refers to the relative humidity of the air measured in percentage (%). In cases where the relative humidity is less than 13% and the air temperature is between 80 and 112° F the fitting refer to (2) is used, which subtracts from refer to (1).

$$ADJUST = \frac{13 - RH}{4} \times \sqrt{\frac{17 - ABS(T - 95)}{17}} \qquad (2)$$

Where: *ABS* is the absolute value. If the relative humidity is higher than 85% and the temperature is between 80 and 87 °F, a fitting refer to (3) is added refer to (1).

$$ADJUST = \frac{RH - 85}{10} \times \sqrt{\frac{87 - T}{5}} \qquad (3)$$

The Rothfusz equations do not return satisfactory results when HI < 80° F. For these cases, Steadman's equation is used refer to (4).

$$HI = 0{,}5 \times \{T + 61{,}0 + [(T - 68{,}0) \times 1{,}2] + (RH \times 0{,}094)\} \qquad (4)$$

Table 1 contains the reference values that should be observed concerning risks to human health according to the HI obtained through the calculations mentioned (Table 1).

Table 1: Reference values for heat Index.

Alert Level	HI (° C)	Symptoms
Extreme Danger	Higher than 54	Insolation, imminent risk of stroke.
Danger	Between 41.1 and 54	Cramps, heat stroke, physical exhaustion, possibility of stroke at high exposures with physical activity
Extreme Caution	Between 32.1 e 41	Possibility of cramps, physical exhaustion, sunstroke during long periods of exposure.
Caution	Between 27.1 e 32	Possible fatigue in case of prolonged exposure
No alert	Lower than 27	No problem

Experimental results

For the experiment, in situ, sensory platform was attached to a PVC rod so that the sensors were positioned at a height of approximately 1.5 meters. At UFRA Campus, the platform was positioned in a shaded region as Steadman et al. (1979) advises, in a forest fragment, where it was possible to perform the measurements. The measurements in situ was conducted on October 23, 2021, the hours of 9:00 am to 12:00 pm, and had a sampling frequency of 2 minutes, recording a total of 91 data.

At Avenue José Bonifácio the platform was positioned near the street on October 24, 2021 from 9:00 am to 12:00 pm. With the same sampling frequency as in the previous experiment. The Figure 6 shows the location where the measurements were taken.

Figure 6: Sensory Platform fixed, in a height of 1.5 meters from the floor.

A cell phone was used as an internet access point through the Wi-Fi router, and the data were saved in the digital cloud and arranged in the App. After performing the measurements, the data were exported in an Excel file, in order to verify the availability of the collected data and the reliability of the server in data packet losses (PINTO et al., 2021). Figure 7 shows the App screen containing the experiment information.

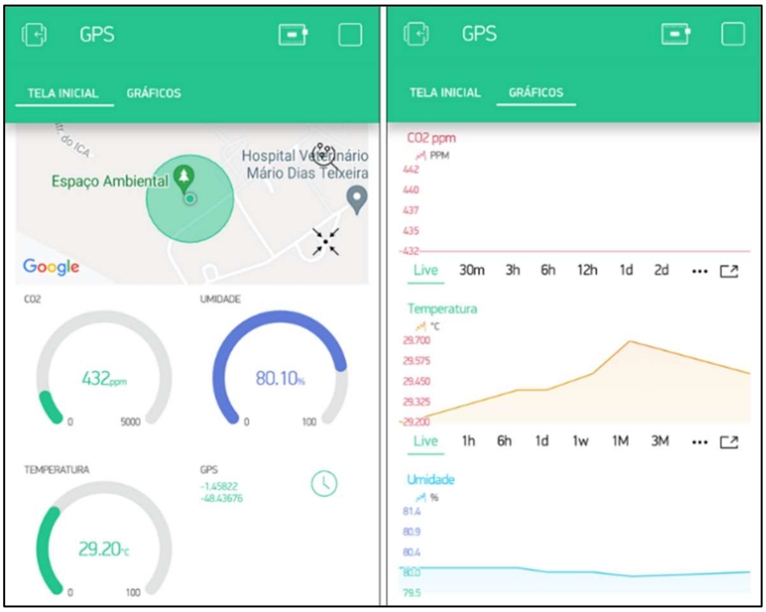

Figure 7: App screen containing the experiment information.

Tables 1 and 3 present the average values and complementary information of CO_2 concentrations, temperature, relative humidity, and HI according to the results observed during the experiments at UFRA (Table 2) and Avenue José Bonifácio (Table 3).

Table 2 : Values found during the UFRA experience.

Variable	Average	Standard deviation	Maximum	Minimum
CO_2 (ppm)	438.13	0.47	438	436
Air Temperature (° C)	29.01	0.47	29.75	27.68
HI (° C)	35.09	1.0	37.0	33.0
Relative Humidity (%)	81.36	3.0	90.94	77.27

ppm = unit parts per million; º C = degrees Celsius; HI = Heat Index.

Table 3: Values found at Avenue José Bonifácio.

Variable	Average	Standard deviation	Maximum	Minimum
CO_2 (ppm)	599.91	26.75	658	559
Air Temperature (° C)	31.06	0.56	32.00	29.37
HI (° C)	38.32	1.0	40.0	38.0
Relative Humidity (%)	75.65	2.98	80.58	67.28

According to the data obtained by the sensors, the values of air temperature, CI, and CO2 concentration were higher in the urban environment than in the forest fragment. Therefore, according to Mandú et al. (2019), there is the risk "Extreme Caution" in both cases, presenting the possibility of risks such as heat stroke and cramps. However, about thermal comfort, the forest environment presented better conditions overall. The two environments analyzed presented variations in relation to statistically proven means (Table 4).

Table 4: Variable comparison test level with 5% significance.

Variable	UFRA	Avenue José Bonifácio
CO_2 (ppm)	438.13^{A}	599.91^{B}
Air Temperature (° C)	29.01^{A}	31.06^{B}
Air Temperature (°F)	84.22^{A}	87.90^{B}
HI (° C)	35.09^{A}	38.32^{B}

Relative Humidity (%)	81.36[A]	75.65[B]

Equal letters in the row means that there is no statistical evidence to support the difference between the locations.

When we analyze the environment at the microclimate scale, forests have lower variations of meteorological variables compared to urban environments, and this effect is due to an ecosystem service provided by the canopy, causing a regulatory effect of the microclimate; this fact can be confirmed due to a lower temperature and higher humidity in the forest environment (GOTARDO et al., 2019).

This fact can be observed when comparing the graphs of the data obtained, since the experiment at the UFRA Campus presents variations between maximum and minimum temperatures that are smoother (Figure 8) when compared to the urban environment (Figure 9).

The variation in relative humidity is compatible with the results presented by Dantas et al. (2011), who performed measurements in a tropical forest and obtained values ranging from 90% to 77%. Corroborating the idea, the work of (MARTINI et al., 2015) reports drops in humidity values in urban environments, in agreement with the results presented in the experiments of this present study.

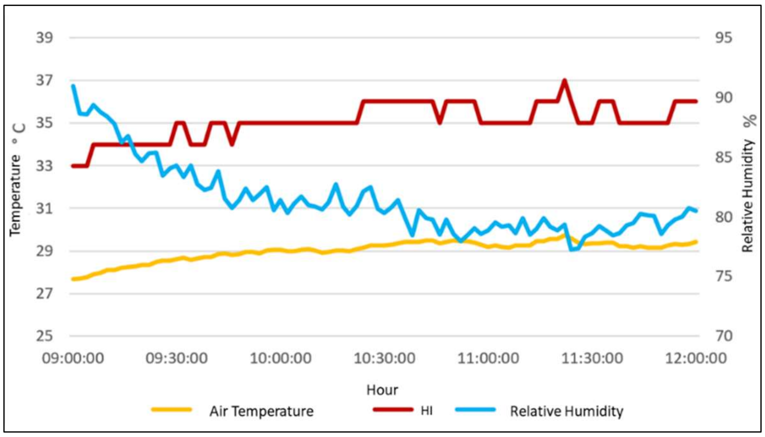

Figure 8: Graph of data from the experiment at UFRA.

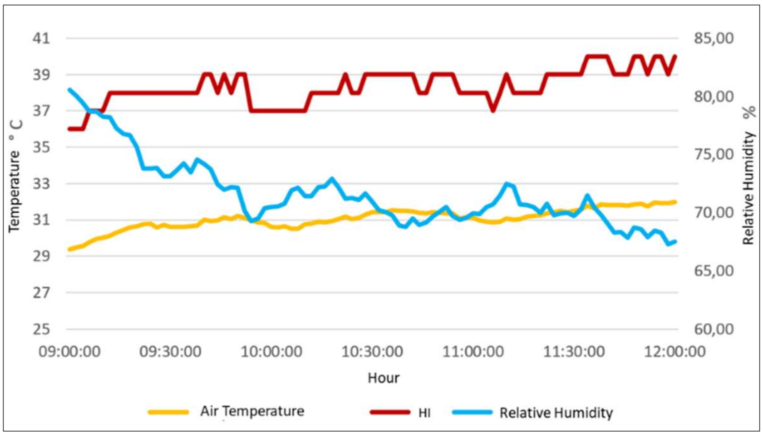

Figure 9: Graph of data from the experiment at Avenue José Bonifácio.

Regarding the concentration of CO2, the results showed values with little variation in the forest fragment due to less anthropic influence in this environment, presenting a cleaner air. However, Wanderley et al. (2019) emphasize that atmospheric variables can vary according to the conservation status of forests. In (Fig. 10) contains the graphs regarding the concentration of carbon dioxide.

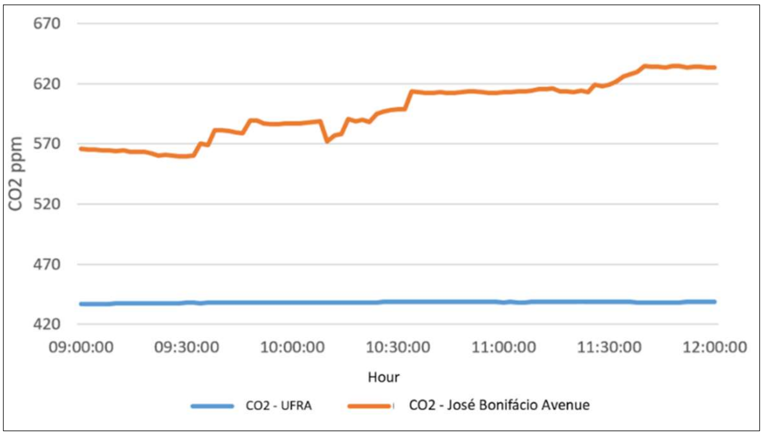

Figure 10: Comparison between CO2 concentrations the points UFRA and Avenue José Bonifácio.

Higher concentrations at Avenue José Bonifácio occurs mainly due to the very relevant increase in vehicle traffic and the density of buildings that hinder wind circulation, favoring the dispersion of the analyzed elemento (KOZERSKI et al., 2006).

The values found are below the level of 1.000 ppm, a concentration capable of causing symptoms such as headache, fatigue, irritation, among others (BUJDEI et al., 2011). However, from 600 ppm it is possible to activate breathing to active mode, which in turn causes a feeling of shortness of breath, causing the body to increase the respiratory rate (LEIRÃO et al., 2018).

Thus, it is clear that the platform developed meets the objectives that guided the development of this study, returning practical results in different environments, showing the versatility and quality of the data obtained.

DISCUSSION

The development of low-cost sensory platforms can return unofficial information that is important in exposing information that is indispensable in making decisions about public and environmental health policies.

The practical results of the study present the atmospheric and carbon dioxide dynamics in different environments, showing the ecosystem services that trees can promote. The thermal comfort was noticeably affected in urban environments, presenting higher values. However, what has been most commented on lately is carbon sequestration, in help to reduce the rates of carbon dioxide in the atmosphere to slow the greenhouse effect (ASSUMPÇÃO et al., 2019).

The increase in the rate of CO2 absorption is related to the planting of plant species that can assist in the process of carbon sequestration, as presented by Barbosa et al. (2021) in a study that quantifies the amount of carbon stored by wood species in reforestation.

However, Lima et al. (2020) state that the afforestation of medium and large trees in the city of Belém needs to have a focus on peripheral areas since these are areas that generally do not have a landscaping project with emphasis on planting species, as it requires resources and constant maintenance.

In this way, it can be seen that medium and large afforestation is related to real estate speculation in central areas and areas of greater buying power. This information brings cruciais insights into the issue of afforestation in Belém city; even though it is located in the Amazon, only 22.3% of the city's public roads are forested, according to recent data.

Public policies for the environment are paramount in promoting better thermal conditions on a microclimate scale and helping in carbon sequestration to avoid health problems and the greenhouse effect.

Furthermore, a reformulation of the urban public transportation system must be employed, enabling it to be used in an efficient and less polluting way, since transportation is the leading emitter of pollutants that contribute to the greenhouse effect and aggravates factors related to public health.

CONCLUSIONS

The work developed presents the construction of a sensorial platform capable of indicating important variables from the point of view of public and environmental health. The *in situ* sensory platform experimental results returned that could be explained and grounded according to what the literature addresses, highlighting the importance of forests in environmental quality.

Advances for in situ monitoring in regions of the Amazon, especially the thermal comfort, provides a significant development in the understanding of climate effects on animals and rural workers, which directly influences the production quality.

The description of the developed device allows its reproducibility and has as main differentials: optimized power system, possibility of integration with renewable energies, low cost platform; connection with several sensors; easy programming and operation; internet access and, last but not least, low cost. Thus, it is concluded that the development of the sensory platform met the objectives of the study.

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