SMART WSN BASED ON MACHINE LEARNING FOR MONITORING WORK ENVIRONMENTS

Yan Ferreira da Silva[1], Victor Guimarães Furtado[1] and João Viana da Fonseca Neto[3]
[1]Postgraduate Program in Electrical Engineering,
Federal University of Maranhão, São Luís, Brazil
[2] Department of Electrical Engineering,
Federal University of Maranhão, São Luís, Brazil
yan@nca.ufma.com, victor.gf@discente.ufma.com, jviana@dee.ufma.com

ABSTRACT

Thermal comfort, luminosity, and air quality are factors that directly impact the health, well-being, and cognitive performance of occupants in an indoor environment. It is crucial that ergonomic parameters such as temperature, humidity, light levels, and carbon dioxide concentration in these spaces adhere to criteria established by Brazilian standards. Addressing this issue, this study presents a methodology for developing a Wireless Sensor Network (WSN) with the objective of intelligently monitoring and classifying the environmental quality of study spaces. The WSN nodes comprise signal acquisition sensors, a microcontroller for processing, classification, and communication, and a multiplexer serving as an analog input expander for the microcontroller. The software components include signal processing, communication and classification algorithms that use machine learning approaches. To enable remote monitoring, the collected signals and classifications are transmitted and stored in a cloud infrastructure that uses Internet of Things (IoT) and cloud computing techniques.

KEYWORDS: *Wireless Sensor Network, Machine Learning, IoT, Sensors, Environmental quality.*

I. INTRODUCTION

Monitoring parameters of indoor environments has become a major concern, as the quality of these places is directly linked to the health and quality of life of the occupants [1]. The amount of time that people spend in environments such as classrooms, auditoriums, offices and laboratories makes the quality of these environments an even greater concern [2]. Thermal comfort, air quality, sound and visual noise are environmental factors that have direct effects on occupants' stay and work performance [3].

It is essential that regulatory bodies establish criteria for achieving a healthy internal environment. Brazilian standards from ANVISA, ABNT and MTPS determine acceptable levels of parameters in internal work environments [4]. These standards establish levels for quantities such as temperature, humidity, light, carbon dioxide, among others.

The advancement and popularization of residential and building automation has led to the expansion of the implementation of intelligent systems with the aim of offering comfort to private homes or commercial buildings, through the combination of control, monitoring and wired or wireless communication elements. Monitoring technologies are essential in this type of application [5].

Among the main monitoring systems, the Wireless Sensor Network (WSN) stands out. These networks are made up of sensor nodes that monitor phenomena of interest, are characterized as ad-hoc (do not require prior configuration) and communicate the collected signals to the central processing station, called a base station or gateway. As the name suggests, these networks use wireless communication channels, which allows greater flexibility in node allocation. Research in WSN was initially motivated by military applications and still has wide application in this area, however the development of this technology has provided and expanded its use in several areas such as health, environmental monitoring, among others [6].

Knowing the importance of comfortable indoor environments and the monitoring capacity of WSN, this work aims to design, develop and implement a WSN and an intelligent classifier based on machine learning for remote monitoring of temperature, humidity, dioxide concentration carbon (CO_2) and luminosity. The environment chosen for the tests is the Process Control Laboratory (LCP) of the Federal University of Maranhão (UFMA), in addition to a proposal for an intelligent classification method for environmental quality. WSN sends data to a cloud called ThingSpeak® using Internet of Things (IoT) techniques and the collected data is used to classify the environment according to Brazilian standards.

The article is organized into Sections. In Section II the development project of the WSN to be implemented is presented, in this same section it includes the description of the WSN concepts, architecture of the node's embedded system, communication structure and distribution of the WSN, the methodology for developing the intelligent classifieds based on decision tree. A brief state of the art bringing together the most current works related to the theme are presented in Section III. The results of hardware and software implementation and application of Brazilian Environmental Quality Standards as a quality criterion are presented in Section IV. The final considerations of the work are presented in the Conclusion Section of the work.

II. STATE OF ART

In the current panorama of research in information and communication technology, wireless sensor networks (WSN) and the Internet of Things (IoT) have stood out as areas of intense research and development. With the growing demand for smart, connected systems, the ability to efficiently monitor and control physical environments has become imperative. In this context, WSN and IoT play a crucial role by allowing direct and continuous measurements of essential environmental variables, such as thermal and lighting comfort. This text aims to explore the state of the art of these technologies, highlighting the most recent advances, challenges faced and potential applications involving WSN.

The development, mainly, of communication technologies, sensors and microcontrollers was essential for the creation of new detection and communication systems, including wireless sensor networks. These networks have military, industrial, residential, health, etc. applications. In [4], a WSN is presented to measure the magnitudes of an internal environment and develop a methodology using fuzzy logic to monitor the quality of the environment. In the proposed network, each sensor node is equipped with several sensors (temperature, humidity, light, carbon dioxide, noise and dust). The developed system has online monitoring interfaces in the form of virtual meters based on the methodology developed with reference to the Brazilian standards of ANVISA and NR17.

The work developed by [7] presents the development of a data acquisition module deployed in a building to detect, monitor and record data related to occupant comfort, such as temperature, humidity, lighting and air quality. The data collected is evaluated to achieve the best balance between user comfort and the amount of energy required to achieve this goal. The module presented consists of NodeMCU as a development board and DHT11 as a temperature and humidity sensor.

In [8] the development of a web environment monitoring system using a WSN is presented. The sensor nodes transmit the collected data of air and soil temperature, and air and soil humidity to the cloud-based database via a Web API request. The measured values can be monitored by the user remotely using the Web application via the Internet. If the ambient conditions exceed the values configured in the application, the user will receive a warning email to improve the ambient conditions.

In Sun [9], a WSN is developed to monitor the environmental status of a plantation. Network experiments were carried out in the laboratory and in the network deployment environment using the MRP protocol (MESH Routing Protocol) to evaluate network performance at different scales and different deployment modes. The system measures the temperature and humidity of the tea plantation and transmits it remotely to the base station.

An ambient air quality monitoring system based on WSN and IoT is presented in [10]. The system has a series of sensors that make it possible to control thermal comfort and the quality of internal lighting. A web application was developed to provide data analysis, system control and alert mechanisms to help prevent the triggering of respiratory problems.

In a similar way, [11] developed a Web system for monitoring air quality in environments based on WSN. The system was developed to monitor environmental air quality parameters, such as polluting gases, airborne particles, temperature and humidity. It has a computer as a base station that will record the data collected using a server program that can also be accessed via the Web.

In [12] proposes an indoor air quality (IAQ) monitoring system based on WSN and IoT using MQTT (Message Query Telemetry Transport). The monitored parameters are temperature, humidity, CO2 and dust. Sensor calibration was used to determine the error of each sensor and the three sensor nodes that make up the network were subjected to performance and reliability tests.

III. WSN Development Project

The development of intelligent WSN initially requires an analysis of the implementation environment: the LCP - process control laboratory.

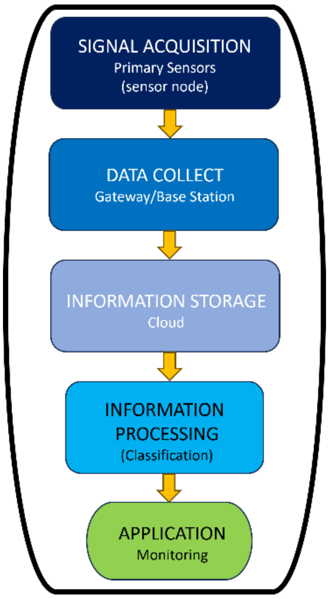

Figure 1. Block diagram of the system steps.

Having knowledge of the activities carried out, the routine of the occupants and the physical characteristics of the location, an online monitoring system based on WSN and environmental quality classification is proposed, with criteria of temperature, humidity, luminosity and carbon dioxide concentration rate adopted according to standards. Brazilians for indoor environments. Figure 1 presents the block diagram with the functional steps of the system.

When analysing the characteristics of the LCP, it was verified that the area is physically divided into three regions, with methodological objectives, the zones were called s1, s2 and s3 as shown in Figure 2.

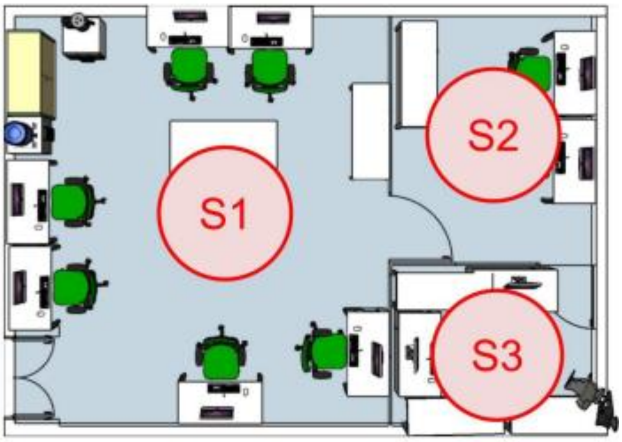

Figure 2. Division of the laboratory into zones [4].

Regions s1, s2, and s3 have, respectively, areas of $30.8m^2$, $10.9m^2$ and $7.2m^2$, an approximate area of $49m^2$ for the LCP.

3.1. Sensor node embedded system architecture

The developed sensor node features AOSONG®'s DHT11 as a temperature and humidity sensor, a 5mm LDR (Light Dependent Resistor) for luminosity and HANWEI's MQ-135 for carbon dioxide. The microcontroller used is the ESP8266 present on the ESP8266 NodeMCU ESP-12 open-source development platform from Espressif Systems. The NodeMCU has computational capacity and compatibility for the use of sensors, low cost, low energy consumption and communication support that includes a radio transceiver and antenna for communication via the IEEE 802.11 b/g/n (Wi-Fi) protocol.

3.2. Gateway

The WSN gateway function is performed by a microcontroller of the same type as those used in sensor nodes, due to its Wi-Fi support and compatibility for communicating with the nodes and sending data to the Internet. Configuring this device as an Access Point Station allows it to function as a network client and at the same time as an access point, a configuration necessary for it to function as a WSN gateway.

3.3. Sensor node coverage

The sensing coverage or sensing range of the proposed project node is defined with the binary disk method, which compares the radial range of all sensors in the node and adopts the smallest as the sensing range of the node.

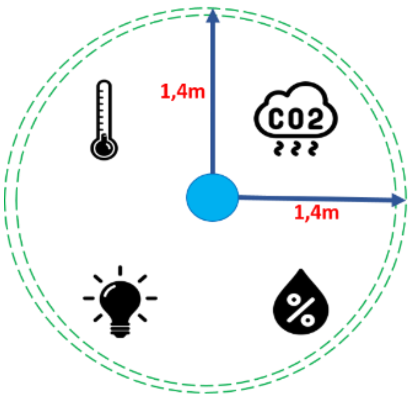

Figure 3. Sensor node coverage.

The DHT11 is the sensor that has the smallest radial range when capturing humidity, which is adopted as sensor node coverage: 1.4 m circumference radius.

3.4. Defining the number of nodes

Adopting the criteria: larger sensing area, smaller area of intersection between node coverages, smaller area of coverage holes and smaller number of nodes. The definition of the number of nodes is made by dividing the area to be instrumented by the coverage area of the sensor node is given by

$$\frac{49m^2}{\pi \times (1.4m)^2} = 7.95 \ \ nodes. \qquad (1)$$

The calculation results in a non-integer value, so an approximation to 8 is performed. An approximation downward would cause a considerable area of coverage holes.

3.5. Spatial distribution

In the proposed model, the radio and communication characteristics of the microcontroller used, in terms of range, exceed the node coverage and the physical dimensions of the environment, therefore, regardless of the number of nodes and their distribution, node-gateway and gateway- access point (router) is not an obstacle to WSN implementation.

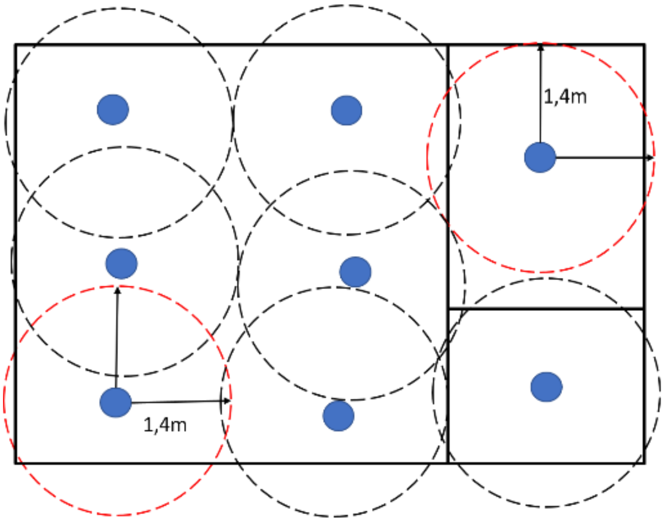

Figure 4. Representation of the spatial distribution of WSN.

The spatial distribution problem of the proposed network, then, is limited only to the detection coverage. Respecting the established criteria, the physical subdivisions of the environment and the binary disk model, the nodes are distributed in such a way as to comprise the work zones, regions in which the LCP's occupants/researchers most stay and carry out their activities. In this way, 6 nodes are allocated in zone s1, and the other two zones receive 1 node each, in a centralized manner, as Figure 4 shows.

3.6. WSN topology

The physical dimensions of the monitored environment and the communication range between sensor nodes and gateway, make the choice of topology independent of the spatial distribution. Thus, the star topology is the most suitable for the proposed objective, as it presents the lowest consumption among the topologies. In Figure 5 you can see a representation of the network in terms of topology.

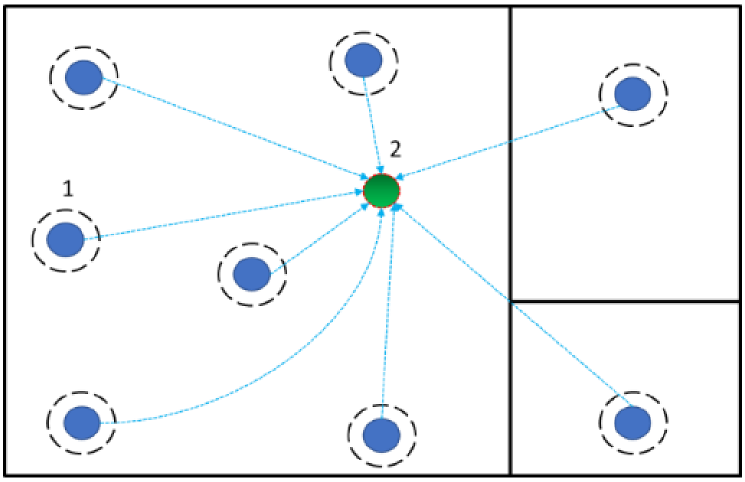

Figure 5. Representation of the WSN communication architecture: (1) sensor nodes; (2) gateway.

The Figure 5 also presents a representation of the signal flow between nodes and gateway, which consists of the internal communication stage of the network.

3.7. WSN communication

Communication is divided into internal and external stages. The internal stage is the communication between us and the gateway, while the external stage is the sending of signals, by the gateway, to be stored in a cloud, where they can be accessed and monitored remotely.

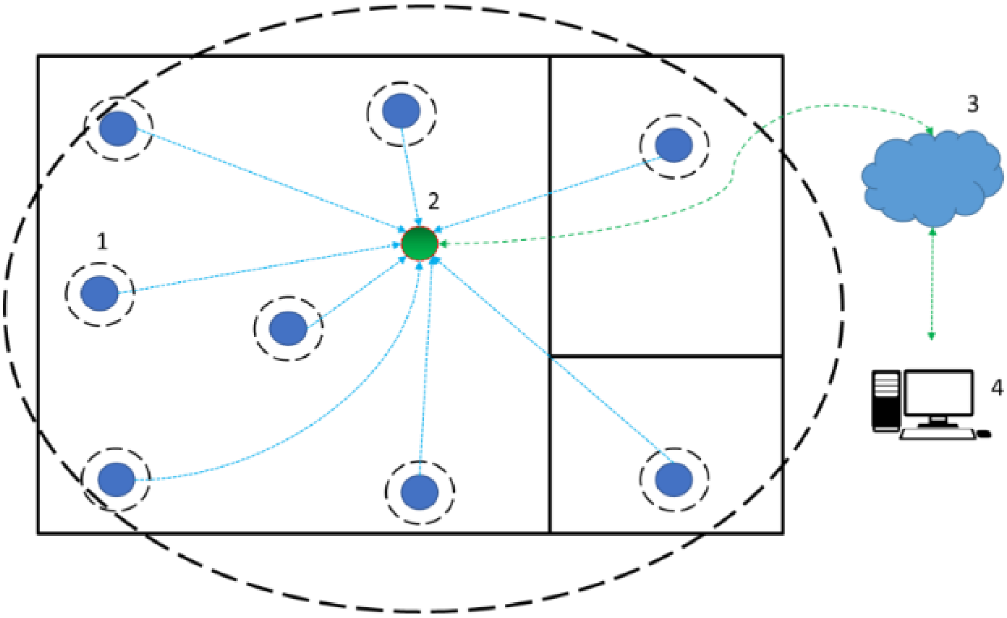

Figure 6. WSN internal and external communication stages: (1) sensor nodes; (2) gateway and its communication range; (3) data storage cloud; (4) device for monitoring.

The microcontroller used as a gateway is configured as a station and an access point at the same time. It generates a Wi-Fi network and connects to the Internet through the Wi-Fi network of the router present in the LCP. The microcontroller of the sensor nodes is configured as a station and connected as a client to the Wi-Fi network generated by the gateway.

3.8. Communication protocol

Both communication steps use the TCP/IP protocol with some differences. The first stage has the IEEE802.11b (Wi-Fi) protocol as the link layer, the IPv4 protocol as the network layer and the UDP protocol as the transport layer. Sending data using the UDP protocol guarantees low latency for sending data. The second stage differs from the previous one, as it has the TCP protocol as the transport layer and the MQTT protocol as the application layer.

The MQTT (Message Queue Telemetry Transport) protocol is a communication protocol between machines (Machine to Machine – M2M) based on the TCP/IP protocol, with a publish/subscribe model and widely used in IoT. MQTT has Broker (Cloud) storage that enables online monitoring and prevents data loss when there is a loss of connection or some other type of failure. For this application, the signals collected and pre-processed in sensor nodes are transformed into data and sent to the gateway, where they are converted into JSON (JavaScript Object Notation) and sent to a Broker, an IoT platform, to be stored and monitored. through the Internet.

3.9. Brazilian Environmental Quality Standards

NR17-Ergonomics establishes that indoor workplaces where activities that require intellectual demand and constant concentration are carried out must have an effective temperature between 18°C and 25°C [13]. ANVISA Resolution 09 of 2003 establishes that in artificially air-conditioned environments for public and collective use, the maximum recommended value to avoid chemical contamination is 1000 ppm of Carbon dioxide (CO2), this value is an indicator of external air renewal. This resolution also establishes the relative humidity operating range as between 40% and 65% [14]. NBR ISSO/CIE 8995-1:2013 determines that the minimum lighting level criterion for indoor work environments such as educational buildings – application rooms and laboratories must be 500 lux [15]. NBR 5413:1992 establishes that the maximum lighting limit for indoor work environments that have activities with normal visual requirements, average machinery work or offices is 1000 lux [16].

3.10. Intelligent Classifier

For the sensor node's embedded system, the intelligent classifier is developed via decision tree approach. A decision tree-based algorithm is a machine learning model that represents decisions and their possible consequences in a tree-like structure [17]. Each internal node in the tree represents a test on an attribute, while the leaf nodes represent predicted classes or outcomes. The objective is to divide the data into increasingly homogeneous subsets, making decisions based on the characteristics of the signals [18]. Considering the structure of a decision tree, as parameter criteria, the values established [19] in Brazilian environmental quality standards, presented in the previous topic. Its objective is to analyse whether the region covered by the node is within the criteria at the time of collection. Figure 7 presents the structure of the intelligent decision tree-based algorithm that represents this step.

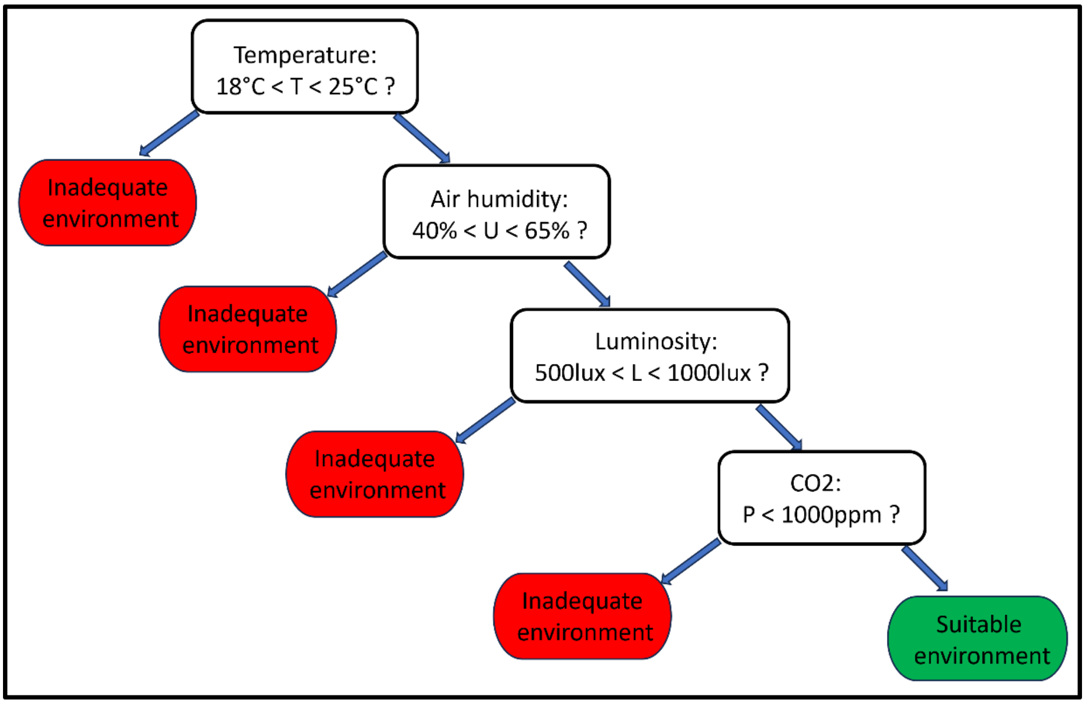

Figure 7. Machine learning algorithm structure (decision tree) of the first stage of the classifier.

The intelligent classifier checks, respectively, whether the temperature, humidity, luminosity and carbon dioxide concentration are within the established criteria. The environment is classified as inadequate if at least one of the quantities is outside the established criteria.

The structure of the proposed machine learning-based algorithm has a variable corresponding to each parameter. If the parameter meets the criteria, its variable receives '1', if it does not, it receives '0'. At the end of the data acquisition, an average of variables, called the classifier value, is given by

$$Cl = \frac{A+B+C+D}{4}, \qquad (2)$$

where A is the variable corresponding to temperature, B to humidity, C to luminosity and D to carbon dioxide. Values calculated at each sensor node are sent to the cloud to be monitored and stored. The second stage of the intelligent classifier consists of a global average of all nodes regardless of the region, in this case, the nodes have equal weight, calculated in MATLAB®, Based on the values from the first step of the time interval classifier, the day is divided into 5 intervals of 4 hours each. The acceptable range for working in the environment is between 0.8 and 1, although the environment is considered inadequate when at least one of the variables is outside the range, the final average is considered 20% tolerance.

IV. EXPERIMENTAL RESULTS

4.1. Implementation of sensor nodes

The Figure 8 A) shows the structure of the node, developed using the Fritzing® CAD software. The microcontroller used presents an obstacle in the development of the circuit as it has only one GPIO that works as an analog input, and the LDR and MQ-135 provide an analog signal. The problem was solved with a 4052 multiplexer, its function is to momentarily expand the number of analog inputs on the microcontroller to 2 inputs. Using two output channels, the multiplexer switches between the two channels, connecting the NodeMCU analog pin alternately to these two sensors at 1-second intervals.

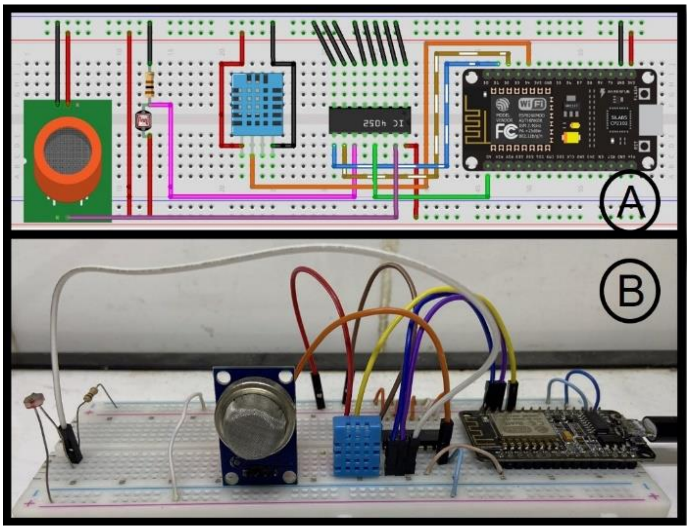

Figure 8. A) Embedded system design of the sensor node in Fritzing, B) Prototyped physical system.

The Figure 8 B) presents the prototyping of the sensor node following the model presented in Figure 8 A). The calibration of the sensors is done through the measurement method using specific measuring equipment. The same assembly model was adopted for the other nodes, as shown in Figure 9.

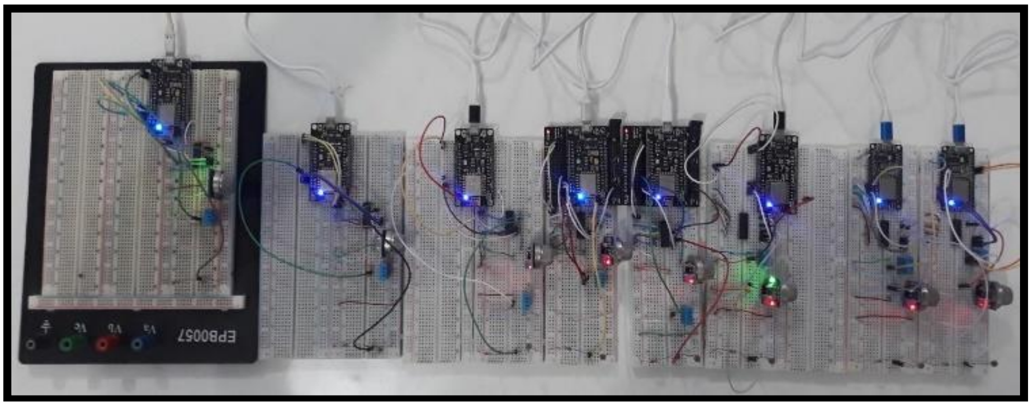

Figure 9. Eight assembled WSN sensor nodes.

The sensor nodes presented in Figure 9 are in ascending order from right to left. Nodes 1 and 2 were assembled using a NodeMCU V2 while the others NodeMCU LolinV3, nodes 4 and 5 were assembled using an expansion shield for the NodeMCU V3, for the applications of this work none of these divergences present relevant implications in the assembly circuit of the sensor nodes.

4.2. Storage and monitoring

The storage and monitoring cloud used is ThingSpeak®, an IoT analytical platform that allows you to aggregate, visualize, monitor and analyse data flows in the cloud. The stored data can also be extracted in table format, for example XML, a format interpreted by various data analysis software [20].

4.3. Laboratory test results

After individual and general functioning and communication tests, the sensor nodes were positioned as shown in Figure 4 and the WSN was enabled for full operation. To represent and analyse WSN's daily data acquisition, the graphics presented refer to a complete day, November 17, 2022.

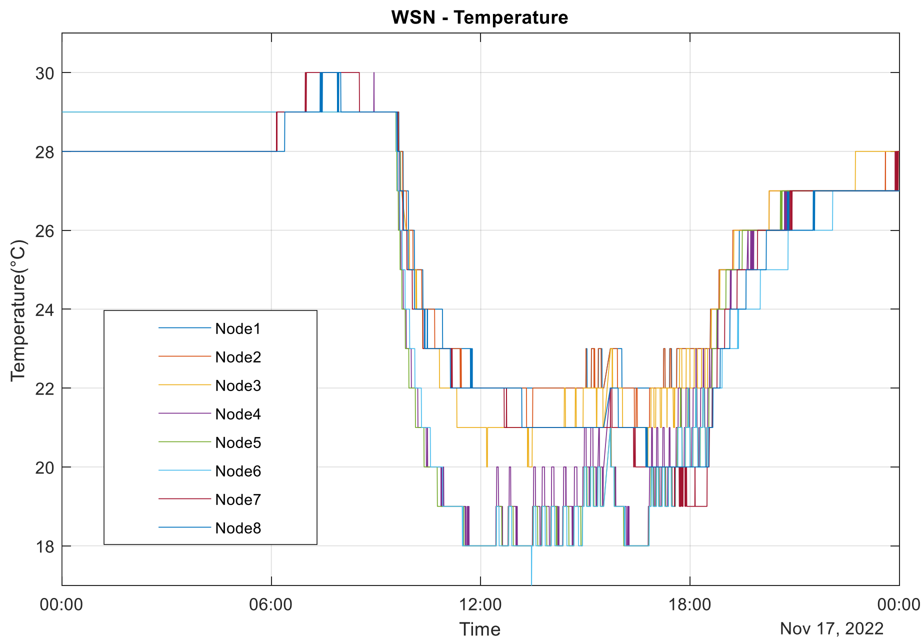

Figure 10. WSN temperature graphic.

Observing Figure 10, it is possible to notice that from 10:00 onwards, temperatures begin to drop due to the start of air conditioning, resulting from the arrival of an occupant at the laboratory. There is stabilization from 12:00 until 18:00, with temperatures between 18°C and 23°C. Nodes 4, 5 and 6 were those with the lowest temperature, as they are positioned relatively in front of the air conditioning in region s1. From 6:00 pm onwards, it is possible to observe that there was a gradual increase in temperature until it stabilized, this increase occurred due to the air conditioning turning off, marking the end of that day's activities. For most of the time there were occupants, the laboratory temperature, regardless of the region, was within the criteria established for obtaining thermal comfort.

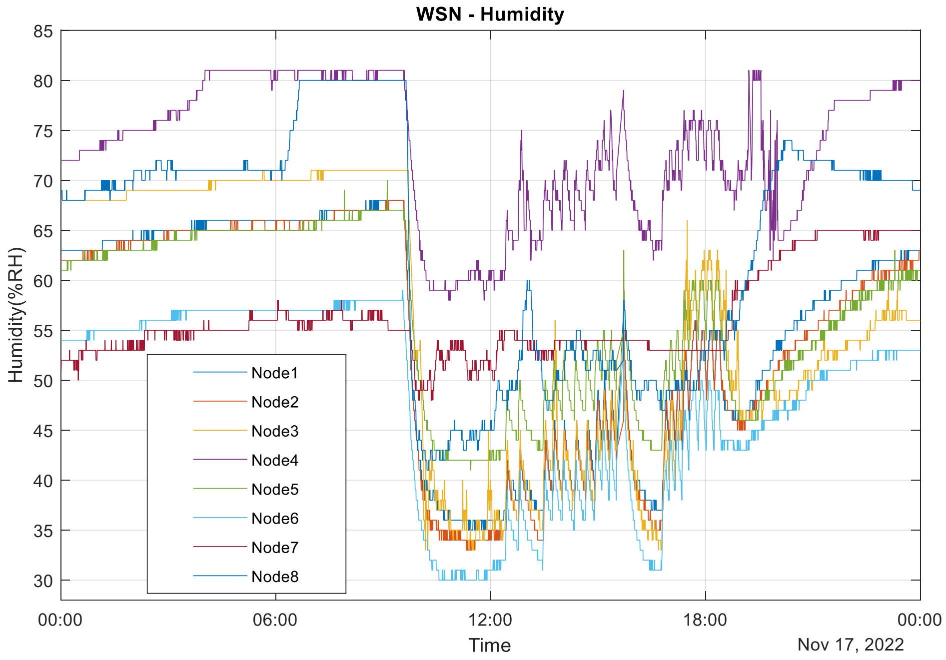

Figure 11. WSN humidity graphic.

The Figure 11 shows the WSN humidity graphic, it is important to note that until 10:00 the ambient humidity values have a common rising behavior and from the arrival of the occupant a gradual drop, having been caused by the beginning of the operation of air conditioners, which remove humidity from the air. Between 10:00 and around 18:00, only nodes 7 and 8 were within the criteria. After 6:00 pm, due to the air conditioning being turned off, there was an increasing increase in humidity values, with the exception of node 8 which showed an oscillation towards a drop.

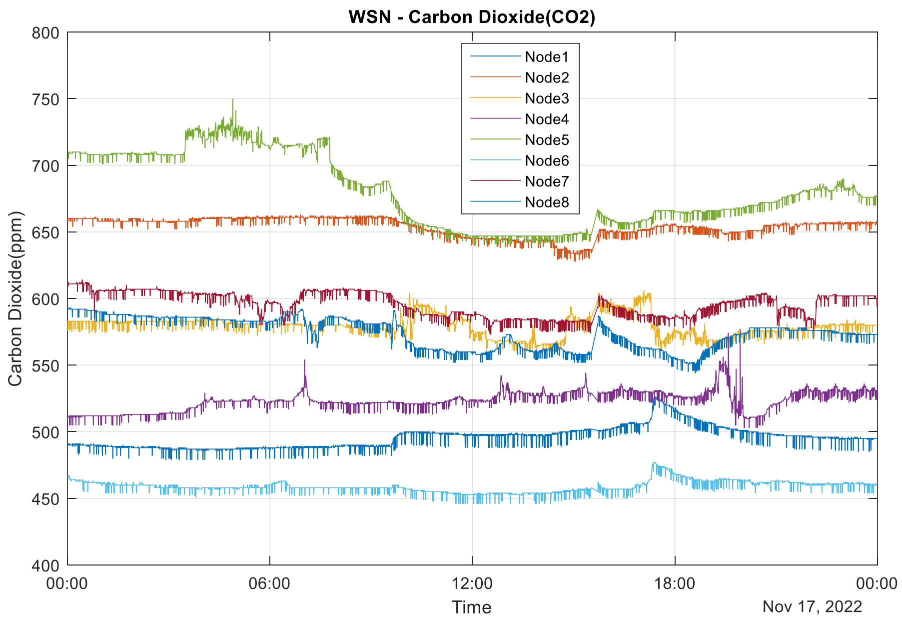

Figure 12. WSN carbon dioxide concentration graphic.

Regarding the concentration of carbon dioxide, analysing Figure 12, it is possible to state that throughout the day the laboratory was within the criteria. The measured values are in the range between

450 and 750 ppm, and have a characteristic and stable behavior, this is probably due to: no welding activities, only 3 occupants in the laboratory and a good air exchange with the external environment.

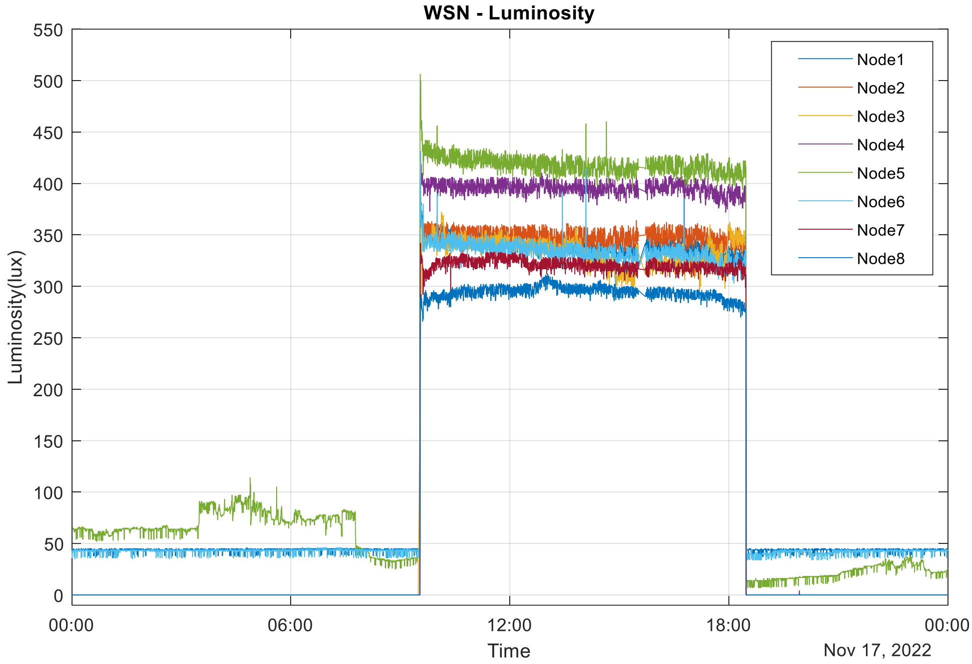

Figure 13. WSN luminosity graphic.

Analysing the luminosity graphic, shown in Figure 13, it is possible to notice that when the lights were off, most nodes had 0 lux, with the exception of nodes 1, 6 and 5 which had higher values, this was probably due to some small source of light or noise from the sensor. At around 10:00, the lights were turned on and a peak was noticeable and then stabilization, this is a characteristic behavior of the LDR. From 10:00 until around 18:30, there is great stability in luminosity, but below the criteria. The analysis indicates that the laboratory does not have adequate lighting. Figure 14 shows the classifier values.

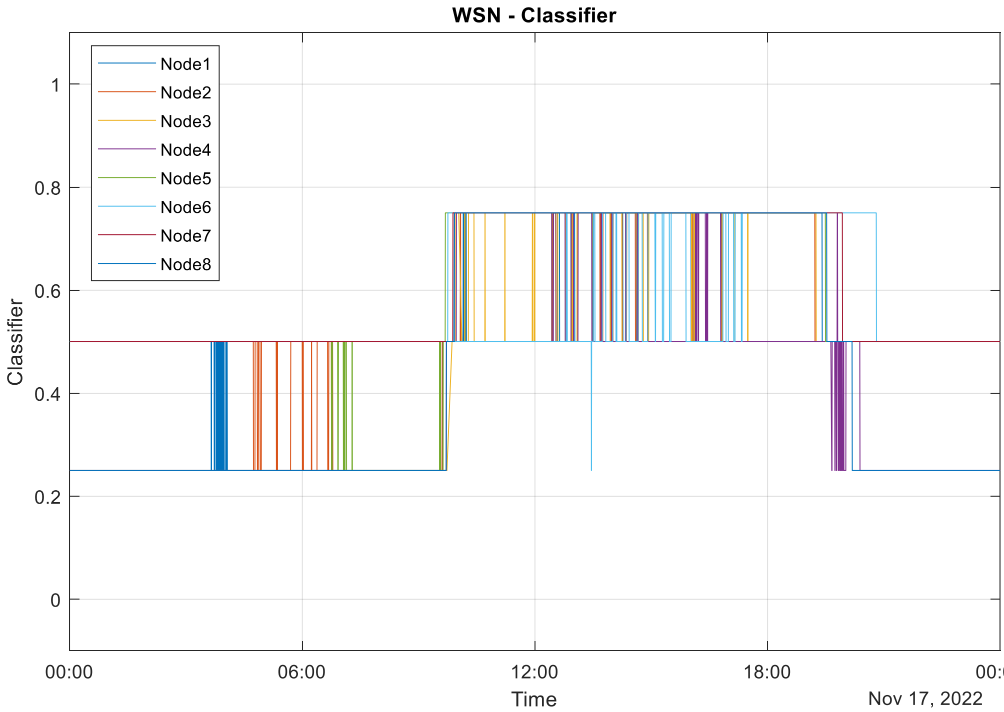

Figure 14. Graph of WSN machine learning-based intelligent classifier.

The intelligent classifier did not present the maximum value in any of the sensor nodes, as the lighting criterion was not met at any time. The classifier also did not obtain a value of 0, because at no time was the environment outside the carbon dioxide criteria. When there were occupants, its value was generally 0.75. During the period in which there were occupants, the classifier values varied between 0.75 and 0.5, reaching 0.25 only at one time by sensor node 6. Table 1 presents the values calculated from the second stage of classification.

Tabel 1. Classifier global mean values

Day range	Classifier Value
00:00 – 08:00	0.3782
08:00 – 12:00	0.4973
12:00 – 14:00	0.5534
14:00 – 18:00	0.6849
18:00 – 23:59	0.5172

Analyzing Table 1, it is possible to observe that the time interval in which the laboratory has the most variables within the criterion is between 2:00 pm and 6:00 pm, but none reached even 0.75. The first and last interval are times when there are no occupants during the entire interval in the laboratory and on the day analyzed, there were no occupants for most of the second interval.

V. CONCLUSION

This work presented the development of an intelligent WSN combined with a machine learning algorithm capable of monitoring and classifying the quality of indoor environments, in addition to sending and storing data in the cloud. The efficiency of WSN was tested in several situations and presented satisfactory results for the proposed objectives. The use of ThingSpeak® for the application was satisfactory for the applications and its response time and it works as a supervisor, this allowed the observation of variables online. The smart WSN model was developed for a research laboratory, but it can be applied to other types of internal environments such as hospitals, classrooms and auditoriums with appropriate adaptations.

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