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PRESENTATION

A relação entre o ser humano e o meio ambiente tem se tornado um dos temas mais relevantes e urgentes da atualidade. Diante dos desafios globais relacionados às mudanças climáticas, à preservação dos recursos naturais e ao desenvolvimento sustentável, torna-se essencial compreender os princípios que regem os sistemas ambientais e suas interações com a sociedade.

Environmental Science Fundamentals é uma leitura altamente recomendada para estudantes, professores e profissionais das áreas ambientais, biológicas, geográficas e afins. A obra oferece uma base sólida para quem busca entender os fundamentos da ciência ambiental e desenvolver uma atuação mais consciente, crítica e comprometida com a sustentabilidade.

Com linguagem acessível e abordagem abrangente, este livro representa um importante ponto de partida — ou aprofundamento — para todos que desejam contribuir de forma responsável para o equilíbrio entre progresso humano e preservação ambiental.

SUMMARY

CHAPTER 1

LoRa NETWORK-BASED IOT NODE FOR INDOOR ENVIRONMENT MONITORING

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RESUMO: O conceito de Internet of Things (IoT), apenas pela sua designação, apresenta-se como uma rede de objetos físicos, que estão incorporados numa vasta espécie de sensores, software e qualquer outro tipo de tecnologias, com o propósito de conectar e trocar informação com outros dispositivos e sistemas através da Internet. Tal como o conhecemos, o IoT está presente num vasto leque de dispositivos que vão desde simples objetos domésticos a ferramentas complexas espalhadas por todos os setores da indústria. O meio de comunicação utilizado nos dispositivos IoT assenta na tecnologia Long Range (LoRa). Esta tecnologia destaca-se pela sua capacidade de operar com consumos energéticos baixos, sendo este fator vital para a utilização de dispositivos IoT dado que estes funcionam a bateria. No presente trabalho, abordar-se-á o desenvolvimento de um sistema de monitorização de espaços interiores tendo por base um Nó-IoT composto por sensores suportado pela rede LoRa. Por forma a atingir os objetivos é feito um estudo sobre aprofundado da tecnologia utilizada em redes LoRa. Seguidamente, é apresentada a arquitetura do sistema e posteriormente são apresentados os diversos testes realizados em espaços interiores para aferir tanto o funcionamento dos sensores como da rede em si. No decorrer do trabalho foram realizados inúmeros testes por períodos alargados que serão devidamente detalhados ao longo do documento. Estes são utilizados para conferir estabilidade do sistema de monitorização e aferir o estado ambiental do espaço onde este esteja instalado.

ABSTRACT: The concept of the Internet of Things (IoT), just by its name, presents itself as a network of physical objects, which are incorporated into a vast array of sensors, software, and any other type of technology, with the purpose of connecting and exchanging information with other devices and systems via the Internet. As we know it, the IoT is present in a wide range of devices ranging from simple household objects to complex tools spread across all sectors of industry. The means of communication used in IoT devices is based on Long Range (LoRa) technology. This technology stands out for its ability to operate with low energy consumption, which is vital for the use of IoT devices since they run on batteries. This paper will look at the development of an indoor space monitoring system based on an IoT Node made up of sensors supported by the LoRa network. To achieve the objectives, an in-depth study of the technology used in LoRa networks is carried out, followed by a presentation of the system's architecture and then the various tests carried out in indoor spaces to assess the functioning of both the sensors and the network itself. During the work, numerous tests were carried out over extended periods, which will be duly detailed throughout the document. These are used to ensure the stability of the monitoring system and gauge the environmental status of the space where it is installed.

1. INTRODUTION

Since the 1990s, the IoT has been present in our daily lives, and there are articles pointing to the presence of IoT devices - around 22 billion by 2025 [1] - which, in a way, confirms the exponential technological development that has been observed in recent decades. In addition to the interest in developing new IoT devices and their enormous versatility of use, there is a need to automate, control and simplify processes in different economic sectors. Today, it has been proven that practically everything produced in industry (except for a few sectors) uses an IoT device to make processes more efficient, economical and with substantially lower energy consumption, and the main aim in introducing these devices is to keep them running constantly, thus alleviating high energy burdens, and speeding up mass production. The growth of the IoT for sensing, monitoring and other applications brings with it a high demand for autonomous devices with low power, but also for extremely affordable Systems on Chip (SoC) [2] that combine a radio chip with the baseband signal and digital processing.

In this paper, we study the use of the LoRa technology in a sensory system for monitoring indoor spaces and present the development of a project that consists of a IoT system which is uses a wireless point-to-point communication to monitor several environmental characteristics such as humidity, temperature, sound level and concentration of Carbon dioxide (CO_2). Firstly, we begin by looking at the state of the art (section 2) and some related work that serves as a contribution to this document. In section 3, we provide a general overview of the LoRa Network and its key features. In section 4, we present the system's architecture with all its main components from the sensors to the microcontroller, the LoRa modules and the monitoring system. In section 5, we show results and critical analyses. Finally, section 6 finalizes this paper with conclusions.

2. RELATED WORK

The state of the art for the IoT is marked by continued growth and innovation. IoT has transcended its early stages of basic connected devices and evolved into a sophisticated ecosystem of interconnected sensors, devices, and platforms. Edge computing is increasingly integrated to process data closer to the source, reducing

latency and enhancing real-time decision-making. AI and machine learning play a pivotal role, enabling predictive analytics and automation across various industries, from smart cities to healthcare and manufacturing. Security remains a paramount concern, driving advancements in IoT security protocols and practices. Standardization efforts are also gaining momentum to ensure interoperability and scalability. As IoT continues to expand its reach, it promises to revolutionize industries, improve efficiency, and enhance our daily lives in remarkable ways.

LoRa technology has currently become a recurring option when it comes to developing IoT solutions. This is due to its versatility and adaptability to the communication medium. Pires M. Luis wrote the article "Importance of the effects of propagation factor interference on LoRa radio interface collisions". In this article [3], the author discusses the importance of Spreading Factor (SF) interference and the effects of collisions on the LoRaWAN radio interface. To this end, the author carried out an in-depth study of the different types of wireless sensor network as theoretical support for the practical tests carried out to understand the problem and its impact. Numerous measurements were made between an LG02 gateway (two-channel LoRa gateway) and a LoRa device (LoRa Bee module v1.1) connected to an Arduino microcontroller. After meticulously analyzing the results, it was possible to conclude that Time on Air (ToA) increases as SF increases. In addition, the author concluded that with a high SF value a greater distance is obtained in urban and rural environments, but the transmission time increases considerably and therefore the number of collisions increases. In contrast, with low SF values, channel occupancy is lower, and collisions are reduced. These conclusions are important because the project uses a point-to-point LoRa configuration and therefore enriches the theoretical basis described in this article.

Another focus of the project that gave rise to this article is the environmental factor associated with its main objective. Air quality is a topic that has always been in the media, but in recent years humanity has faced an unprecedented war that has changed the way human beings live. S. Vaheed, P. Nayak, P. S. Rajput, T. U. Snehit, Y. S. Kiran and L. Kumar took the initiative to write the article "Building IoT-Assisted Indoor Air Quality Pollution Monitoring System". In this article [4] the authors focused on air pollution, especially in buildings, where ventilation or lack of it can cause serious health problems for the people inside. Thus, air pollution can cause suffocation,

Chronic Obstructive Pulmonary Disease (COPD), lung cancer, infections and more. For this reason, there is a need to monitor indoor air quality for the safety of human life, and indoor air pollution is even more dangerous than outdoor air pollution. The research work carried out by the authors was to design a new system based on IoT technology that monitors indoor air quality and provides an online portal for visualizing the data. This system consists of several gas sensors that help read seven of the most polluting pollutants such as CO_2 (Carbon Dioxide), CO (Carbon Monoxide), O_3 (Ozone), NO_2 (Nitrogen Dioxide), Volatile Organic Compounds (VOC) and Particulate Matter, along with humidity and temperature. Based on an Air Quality Index (AQI), which acts as a sensitizing concept for the public on issues of well-being and health, the intelligent system developed by the authors made it possible to calculate this index using real-time data provided by the IoT devices present. This article is particularly interesting from the perspective of this paper's project, as it addresses the purpose of the paper, which is to monitor almost all the most polluting gases as well as temperature and humidity, producing suggestive alerts for users.

3. LORA NETWORK

LoRa is a low power wide area network (LPWAN) technology owned by Semtech [5] based on chirp spread spectrum (CSS) modulation. In digital communications, CSS is a spectral spreading technique that uses broadband linear frequency modulated chirp pulses to encode information [5]. Chirp pulses are sinusoidal signals whose frequency varies monotonously, i.e., the frequency increases and decreases with time. If the frequency is decreasing, this signal is called down-chirp and if the frequency is increasing, it is called up-chirp. This technique allows a balance between sensitivity and transmission rates with a bandwidth of 125 kHz, 250 kHz, or 500 kHz. Apart from this, the frequencies used may vary depending on the region, as they are unlicensed, those being: 433 MHz and 868 MHz for Europe [2]. LoRa is highly efficient in terms of power usage, wireless data transfer and license-free sub-gigahertz radio frequency bands, which is why it is often used in IoT systems.

LoRa is often used with the LoRaWan protocol. This protocol enables an expansion of the network with the use of terminal nodes which capture environmental

data, the terminal nodes communicate with the LoRaWan gateways which in turn forward the data to a central node that processes the received data.

LoRaWan is a communication protocol that uses packet forwarding as the method of data transfer. This protocol allows communication at a very long range, it has a high capacity for multiple sensors on the network and provides data security with its point-to-point cryptography.

LoRa can also be used on a point-to-point communication. This type of communication only needs two transceivers configured with the same frequency, bandwidth, SF and coding rate (CR). The use of SF provides an extended battery life of all the connected nodes. SF is thus defined as the representation of the number of modulation bits, with one or more data bits representing a symbol, in this context 2SF represents the possible values (equivalent to several SF bits, in binary). In addition to the above, the SF can, in a way, translate the duration of a chirp, i.e., the higher the SF, the longer the chirp and consequently the more bits will be transmitted per chirp. The range of SF values vary between 7 and 12, considering the environmental conditions the lower the SF the higher the number of chirps are sent per second [5][6]. In addition, LoRa modulation also includes a variable error correction scheme which, once applied, aims to substantially improve the robustness of the transmitted signal. It uses the Forward Error Correction (FEC) technique that enables error correction on the receiver by inserting redundant parity bits for each useful bit. There is therefore a need to define the concept of the CR, which is the proportion of useful bits and redundancy. This coding rate can/should be adjusted considering the conditions of the transmission channel to be used. The CR typically is set to 4/5, 4/6 or 4/8 [6] [7], meaning that for every four useful bits there are one, two or four parity bits. If the interference is too great, increasing the CR can help to reduce the amount of channel errors. However, the greater the CR value, the longer the transmission duration [2]. Thus, the bit rate (Rb) can be described by the expression (3.1):

$$R_b = SF * \frac{BW}{2^{SF}} * CR \quad (3.1)$$

It is well known that to implement any network (of any kind) it is necessary to consider various factors and the trade-offs that exist between them, such as baud rate, distance, energy consumption, bandwidth, and transmission channel.

4. SYSTEM ARCHITECTURE

The system's architecture is divided into two blocks: the transmitter block and the receiver block.

The transmitter block contains the DHT11v2 sensor [8] responsible for measuring temperature in degrees Celsius (℃) and humidity in Relative Humidity (%RH); the MG811 sensor [9] which measures CO2 concentration in parts per million (ppm); the LMV324 sensor [10] capable of measuring sound level in decibel (dB or dBA); an Arduino UNO board [11] with an ATMega328 microcontroller [12] based on Alf and Vegard's Reduced Instruction Set Computer (AVR) Computer Unit (CPU) architecture and finally a Grove LoRa - 868 MHz module [13] based on the Semtech SX1276 chip [14] (5 V or 3. 3 V supply voltage, 100 mW transmission power, 300 kbps communication speed, RX current at 10.3 mA and sensitivity up to -148 dBm). This module can transmit up to 27 dBm with a range of 10 km in Line-of-Sight (LoS) conditions and has a Universal Asynchronous Receiver Transmitter (UART) interface for easy communication with the microcontroller. It offers a frequency range of 433, 868 and 915 MHz, with 868 MHz frequency and 5 V supply voltage being used in this project. All the sensors and the LoRa module are directly connected to the Arduino Uno, where set of specific functions was developed (using the proprietary software Arduino IDE) to obtain the correct measurements from the sensors and to control/customise the LoRa parameters. This is also where the data frame was constructed, which is made up of a set of data provided by the sensors.

The receiver block contains: a Raspberry Pi3 (RP3) board [15] made up of a BCM2837 microprocessor based on the Advanced Reduced Instruction Set Computer (RISC) Machine (ARM) architecture [15] [16]; an SX1276 LoRa module operating at 868 MHz (compatible with the module in the transmitter block) with a Serial Peripheral Interface (SPI) and powered by 3.3 V supply voltage, and finally a small display. Here, functions were developed to control/customize the LoRa module and process the data sent by the transmitter. This processing involves not only reading/decoding the data frame but also manipulating it to display the sensory measurements (instantaneous values and average values). Figure 1 shows the electrical schematics for the transmitter as well as the receiver and Figure 2 shows both the transmitter block and the receiver after assembling.

Figure 1. Electrical schematics of the transmitter and receiver blocks

Source: Author
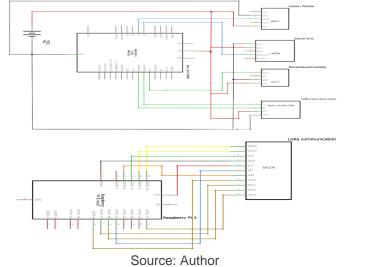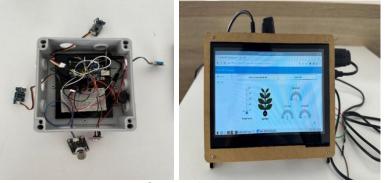
Figure 2. Final looks of the transmitter and receiver blocks

Source: Author

5. TESTS & RESULTS

This fifth section aims to describe the tests carried out on the system and present the results obtained. Firstly, the methodology used to acquire and process the data provided by the sensors will be discussed. This is followed by extensive testing of the sensors to check their validity and accuracy. Finally, the results of the data integration in the RP3 environment and its sampling in the application developed in Node-RED [17] will be demonstrated.

5.1 METHODOLOGY

As already stated, the project has been divided into two main blocks. In the transmitter block and putting into context what is typically used in many telecommunications systems, the data is collected by the microcontroller in instantaneous form. Sequentially, the data is sent to the LoRa module which has the task of transporting these instantaneous values to the receiver via radio communication. This approach aims to balance the computational effort and, therefore, although the Arduino Uno board can carry out all kinds of operations, whether more complex or simpler, the receiver will have a higher computational efficiency because all the RP3 hardware components perform very well, and the processing capacity is high.

The receiver block is responsible for the data processing and displaying. After receiving the instantaneous data, the RP3's function is to run a set of algorithms developed to calculate the averages with 30 samples associated with the values received. In addition to this function, it is here that these already processed values are sampled in a Node-RED application, where they are displayed on a dashboard. The average values will be displayed in real time using line graphs where we can visualize the variation in temperature, humidity, sound level and CO_2 concentration over time. In addition, there will be a main page where we can see the instantaneous values produced by the sensors and quickly understand the state of the environment in which the system has been implemented, i.e., you can easily see what the noise level is, what the temperature and humidity are, what the CO_2 concentration is and, via text, briefly inform the user of the environmental conditions of that location.

5.2 TESTS

The LoRa data frame used in the radio communication is displayed on Figure 3Figure.

Figure 3. Data frame used in LoRa communication

As we can see from the figure, the data frame contains: a preamble with a size of 12.25 symbols; a Header and Header Cyclic Redundancy Check (CRC) with a combined size of 4 bytes and a Payload of 19 or 20 bytes depending on the data sent by the sensors. It can therefore be concluded that the data frame used in point-to-point LoRa communication has a dimension of 20 bytes. If we add the variable size of the preamble, i.e., it depends on the SF to be used for the radio channel and as an example, if the SF is set to 8 chips the total size of the data frame described above will be 32 bytes.

The results presented here already include the parameterizations made to guarantee stable and reliable radio communication. The parameters used are summarised in Table 1.
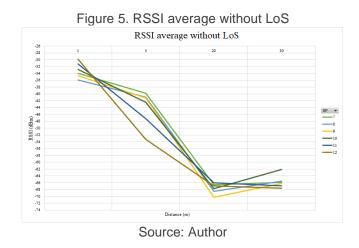
Table 1. Radio parameters for LoRa communication

SF	8
Frequency	868 MHz
Data frame	20 bytes
CR	4/5
BW	125 kHz
Transmission power	5 dBm

One of the tests made, during the development of the project, was the variation of the SF and distance between transmitter and receiver and how it affected RSSI (Received Signal Strength Indicator) with LoS on Figure 4 and without LoS on Figure 5.

Figure 4. RSSI average with LoS

Figure 5. RSSI average without LoS

Source: Author

With LoS the RSSI was higher with lower SF values with 1 meter of distance. The same trend repeats until the 30-meter mark where the signal with SF of 12 has a much higher RSSI than the rest. With higher SF values the signal becomes much easier to detect as spreads the whole signal in frequency which results on average in lower interference, a signal with lower interference gets detected much easier and that results in higher RSSI.

Without LoS the RSSI values were on average lower than the values of the test with LoS, the signal lost strength because it needed to penetrate the obstacle to reach the receiver. The RSSI was higher with higher SF values with 1 meter of distance. With 5 meters of distance the RSSI was lowest for a SF of 12 and highest for a SF of 7. With 20 meters of distance the values of RSSI are very close between all the values of SF. At the 30 meters mark there is an increase of RSSI for the higher SF values being the SF of 10 the best. The values obtained show that on average the higher SF values tend to have higher SF values, which can be explained by the lower interference that signals with higher SF tend to receive. That lower interference results in easier detection by the receiver.

Having configured the SF to 8 through the tests carried out, it was necessary to configure the bandwidth as this parameter has a direct impact on the bit rate, range, network capacity and radio interference mitigation. To obtain a satisfactory value for the bandwidth required for the system to work properly, some tests were carried out in a closed environment. These tests consisted of varying the bandwidth for fixed distances with a SF=8. By doing this, it is possible to measure the arrival time of the data being sent. The delay configured for the transmission of sensor measurements was removed so that the system's performance is more noticeable without any restrictions.

The transmitter was placed about 5 m away from the receiver and the bandwidth was set in the range [7.8 kHz; 500 kHz] and the results were as follows:

- BW 500 kHz - The data frame arrived at the receiver without any errors and with a sampling time of ≈240 ms.
- BW 250 kHz - Very similar results to those obtained in the 500 kHz, with only a slight increase in sampling time to ≈270 ms.
- BW 125 kHz - Few changes, just a rise in the sampling time to ≈330 ms.
- BW 62.5 kHz - In this configuration we can see that the sampling time has almost doubled, to ≈440 ms. However, the data frame remained intact.
- BW 41.7 kHz - Slight increase in sampling time to ≈550 ms and intact frame.
- BW 32.5 kHz - Increase in sampling time to ≈660 ms and intact frame.
- BW 20.8 kHz - A drastic variation in sampling time was observed and the data frame was completely lost. In this configuration, the time went up to ≈26 s on the first send and ≈73 s on the second. The entire data frame was received with errors, no useful information was visible and the RSSI dropped considerably to -88 dBm. It can be assumed with some certainty that this value is the maximum bandwidth limit that can be used in this system.

Having verified the behaviour of radio communication with a BW of 20.8 kHz, it was concluded that all values above this limit could be used in the system that was developed, so that, only as isolated tests, it was not even possible to measure the sampling time for values below 20.8 kHz, leaving the feeling that communication was lost in these configurations.

It was therefore concluded that although there is some flexibility in terms of bandwidth, the most suitable value to guarantee a satisfactory binary output is 125 kHz. Referring now to equation (3.1), the bit rate was calculated as per below:

$$R_b = 8 \cdot \frac{125\,k}{2^8} \cdot \frac{4}{5} = 3.125\ kbps$$

It should also be noted, despite the BW parameterization having been completed and that with a bandwidth of 125 kHz and an SF = 8, the transmission power can be set to its minimum value. In this case, this value is 5 dBm, thus guaranteeing

stable and robust radio communication and at the same time reducing the energy consumption of the transceiver in the transmitter block.

5.3 SENSOR RESULTS

As part of the project, the results obtained from the actual measurements taken by the sensors and their operation in the system are presented shortly. When testing the sensors, it was taken into consideration that to obtain the most accurate values, the sensors need to be in constant operation for some time. The sensors were therefore kept connected and collecting data for around 3 hours. Before presenting the figures related to the results obtained, it is important to note that the response time associated with the DHT11 sensor is limited to 2 seconds, according to the supplier therefore all the measurements were taken every 10 seconds, thus allowing for a considerable margin. There is also the need or not to calibrate the sensors, which in this case only applies to the MG811 sensor due to its physical nature, i.e., no other sensor needs to be calibrated. Figure 6 and Figure 7 show the results of the sensor DHT11.
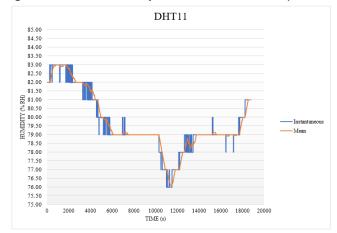
Figure 6. DHT11 humidity results, with ± 5 %RH precision
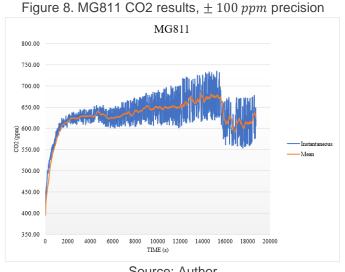

Source: Author

Figure 7. DHT11 temperature results, with $\pm 2\,°C$ precision

Source: Author

After looking at the graphs above, although the DHT11 sensor is simple and easy to use, it shows somewhat disparate values over time. Its measurement accuracy is considered and there is a somewhat abrupt variation in humidity measurements, as we know humidity in a closed room does not change as dynamically as the sensor makes it seem. On the other hand, although this model of DHT is the weakest in terms of performance, the temperature measurements appear to be more in line with reality, as the measured value stabilizes over time. In short, this sensor presents somewhat anomalous measurement data, but looking at its monetary value and the purpose of the project, the DHT11 turns out to be a choice that meets the main objective and so its performance is considered satisfactory.

Figure 8 shows the results of the MG811 sensor.

Figure 8. MG811 CO2 results, $\pm\,100\,ppm$ precision

Source: Author

From the results observed in the figure above, it can be concluded that this CO_2 concentration sensor takes readings with a considerable level of precision, presenting values that mirror its economic value. The MG811, despite needing time to warm up to work properly, manages to produce results that are very close to reality and since there are not many systems that use this metric as a basis for operation, it is believed that this is one of the most relevant sensors for this project. The possibility of measuring the concentration of CO_2 in a potentially dangerous place for human health with the precision of the MG811 is undoubtedly a strength of what has been developed. The sensor doesn't show any anomalous measurements over several hours of testing. Figure 9Figure shows the results of the LMV324 sensor.
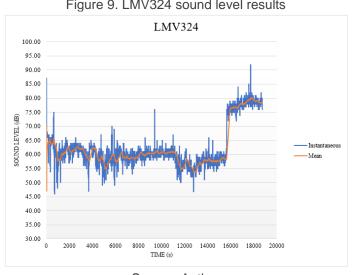
Figure 9. LMV324 sound level results

Source: Author

From the figure of the measurements taken by the LMV324, one thing that is clearly visible that is the relatively high noise levels. As we can see, the values are around 65 dB and 80 dB, meaning that we appear to be in the presence of an extremely noisy environment. However, we considered after research that these values may indicate another side of the sound level measured. Thus, the measures are mostly in the moderate-to-moderate high noise level for a long period of time, as there was some noise from loud conversations at the time of the tests. The sudden rise to values around 80 dB could be caused by several factors external to the sensor, however it is important to note that the LMV324 is a sensor with extremely high measurement sensitivity and a small vibration or contact with it can cause extreme and anomalous readings. Taking

all these factors into account, this sensor performs acceptably for the project ideology and although there were other options, the LMV324 was chosen because it also has a considerably low economic value.

5.4 MONITORING SYSTEM

In this project, the monitoring system includes a RP3 (responsible for processing and analysing the data) and a LoRa transceiver (responsible for collecting the data). In this relatively simplistic monitoring system, there is a 7-inch touchscreen display with a resolution of 1024x600, connected via HDMI to the RP3 and used to display the data to be monitored. The LoRa transceiver is directly connected to the RP3 via the General-Purpose Input/Output (GPIO) pins.

The RP3 is equipped with a proprietary and globally used Operating System (OS) called Raspbian [18] which is free and open source based on the Debian Linux. On the project, we used Debian version 11 with kernel 6.1.21-v7+. This OS is ideal because it has all the tools needed for the project's main objective: monitoring air quality levels in indoor areas. This monitoring makes a key contribution to the project, and its development was based on Node-RED.

Node-RED is a graphical programming tool that allows users to easily create and deploy IoT applications. It is an open-source graphical environment, based on flows. Flows are created by dragging and dropping nodes from a predefined palette and establishing links between them. Each node represents a different function, such as data input, processing, or output. Nodes can be configured to perform specific tasks, such as reading data from sensors, processing that data, and displaying the results on a server or dashboard. Node-RED version 3.0.2 was used in this project. The graphic aspect developed in Node-RED will depend on the specific objectives of the project and the blocks used. In our case, a dashboard consisting of real-time line graphs was used, with the aim of sampling the measurements taken by the sensors and presenting these values on the display in a customized window.

The flow developed is based on four large blocks of well-defined functions with their own algorithms. FigureFigure 10 shows the basic structure of the flow developed for sampling the results.
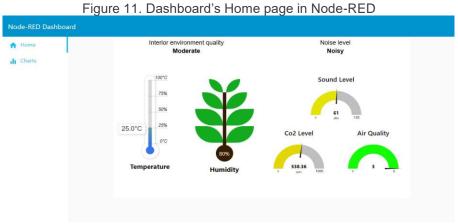
Figure 10. Flow structure developed in Node-RED

Source: Author

We can see from the figure that there is a division of the values produced by the sensors. These values are displayed on the dashboard so that the instantaneous values can be seen on one page and the average values on another. There are two pages in the application, the "Home" page, and "Charts" page.

The Home page shows brief and more relevant information about the environmental characteristics. The goal of this main page is to provide the user with a very simple and clear picture of the indoor environment. The values associated with each environmental characteristic are of the instantaneous type so that we can see any abrupt changes in them in real time. FigureFigure 11 shows the dashboard's Home page and its content.

Figure 11. Dashboard's Home page in Node-RED

Source: Author

At the top of the page, we can see some suggestive messages for a quick interpretation of the values presented by the dynamic graphs. Regarding the messages related to the quality of the environment in general, these are slightly more complex to present because all the temperature/humidity, CO_2 level and air quality sensors have
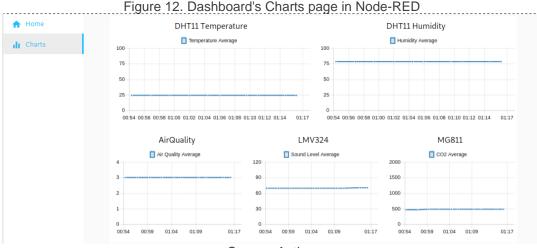
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been considered. To this end, the messages are presented dynamically according to the following assumptions:

- The messages associated with the air quality status are "Very Good", "Good", "Moderate", "Unhealthy", "Very Unhealthy" and "Hazardous".

Just as the air quality messages are displayed dynamically, the same logic was implemented for the sound level, thus giving a more intuitive meaning to the measurements taken by the LMV324. The following has been considered:

- The messages associated with the sound level are: "Very quiet", "Quiet", "Moderate", "Moderate High", "Noisy" and "Very noisy".

In addition to the main "Home" page, the "Charts" page was also developed. This page is intended to inform the user of the history associated with sensory measurements. FigureFigure 12 presents the Charts page and its appearance.

Figure 12. Dashboard's Charts page in Node-RED

Source: Author

If we look at the figure above, we can identify each of the sensors implemented in the transmitter block and the measurements they take. The values sampled in each line graph are average values, thus fulfilling the assumptions described in previous chapters. This approach adds value to the results obtained because it is only by sampling average values that we can get a sense of how the sensors are working and how the environment is. Another important factor to mention is that only through average values can we get a real sense of the measurements, since instantaneous values often show extreme values that don't match the real state of the space where the system is implemented.

It should also be noted that, due to a limitation of the Node-RED tool, it is not possible to add explanatory labels to the vertical axis of each of the graphs. Also, it's not possible to set a customized spacing on this axis, which to some extent makes it appear that the measurements being processed are constant when this is not the case. The simple fact that it is not possible, for example, to add a spacing of 0.1 between each value on the vertical axis for the DHT11 sensor measurements, makes incorrect measurements appear. However, we can always use the cursor to check which value is at which point on each graph.

6. CONCLUSION

The aim of this project was to develop an IoT monitoring system within the LoRa network with wireless point-to-point communication to monitor environmental characteristics in an interior space such as humidity, temperature, sound level and CO_2 level. Throughout the project, important results were achieved that contributed to the expansion of IoT as a technological area and to the development of monitoring systems in general.

The results obtained demonstrate the reliability and effectiveness of using LoRa technology in projects of this nature, presenting it as one of the best options currently available in the wireless communication spectrum given its easy implementation, configuration, and operating cost (both in terms of equipment and energy consumption). The IoT Node developed using different types of sensors was able to collect important and generally accurate data, such as temperature and humidity, CO_2 concentration, sound levels and air quality.

The contributions of this project are relevant to the technological advancement of IoT and environmental monitoring systems. In a world where there are countless technological possibilities for wireless communication, the importance of using the LoRa network is reinforced, as it is the most viable alternative in all spectrums and is fully compatible with an IoT architecture in the image of what has been developed, with no major computational or functional challenges in its implementation. Besides that, the availability of real-time data and its transport capacity has revealed its full potential as a technology that was totally unknown to the authors of this project.

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