INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

# Warehouse Monitoring, Data logging and Interface Implementation based on Internet of Things application

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Master in Industrial Engineering

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# Dedication

**To my dearest Parents**, I can never express the gratitude, pride and deep love I have for the sacrifices you have made for my success. Your prayers, encouragement and support have always been a great help to me.

***To my dear brothers***, for their love and affection. May God bless you and keep you in his peace

***To my dear friends***, your precious collaboration and friendly support have been a source of inspiration and encouragement to me. May God give you happiness and prosperity.

***To all the people who***, actively or not, participated and helped in the accomplishment of this work.

To all those who I love, I dedicate this work

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With the most sincere gratitude, I would like to thank my supervisors ***Prof. Dr. José Lima*** and ***Prof. Thadeu Brito***, for all their effort, their constant help and the trust they give me on a daily basis, without their active participation's and encouragements this work would not have been done. You have been an undeniable source of motivation and working with you has been a real pleasure.

I would like to express my deepest gratitude to the members of the scientific committee for their kindness in reading this study and their interest in reviewing this document and enriching it with their proposals.

Finally, may all the people, who contributed to the accomplishment of this project, find here the expression of my respectful gratitude and the testimony of my dedication...

# Abstract

Due to the high demand for wood around the world, wood warehouses are becoming increasingly popular. As a result, the large amount of stored wood requires special attention to maintain its quality, as well as, the protection of wood warehouses, which can now be accomplished thanks to the Internet of Things platforms and applications, therefore, this project aims to develop a system capable of real-time monitoring of the wood warehouse, based on the ATMEGA328P microcontroller, LoRa technology for data transmission, as well as, flame, gas, humidity, and temperature sensors, in order to prevent any disaster that could affect the warehouse operators, as well as, it can due to a significant losses of stored wood and its quality, Finally, to preserve the environment from the fire ignitions.

**Keywords:** Wood Warehouse, LoRa Technology, Flame Sensors, Gas Sensor, Humidity and Temperature Sensor, Internet of Things.

# Resumo

Devido à grande procura de madeira em todo o mundo, os armazéns de madeira estão a tornar-se cada vez mais populares. Como resultado, a grande quantidade de madeira armazenada requer uma atenção especial para manter a sua qualidade, bem como a protecção dos armazéns de madeira, o que agora pode ser conseguido graças às plataformas e aplicações da Internet das Coisas, portanto, Este projecto visa desenvolver um sistema capaz de monitorização em tempo real do armazém de madeira, baseado no microcontrolador ATMEGA328P, tecnologia LoRa para transmissão de dados, bem como sensores de chama, gás, humidade e temperatura, a fim de evitar qualquer catástrofe que possa afectar os operadores do armazém, bem como perdas significativas de madeira armazenada e da sua qualidade, finalmente, para preservar o ambiente do risco de incêndio.

**Palavras-chave:** Armazém de Madeira, Tecnologia LoRa, Sensores de Chama, Sensor de Gás, Sensor de Humidade e Temperatura, Internet das Coisas.

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# Acronyms

**ABP** Activation By Personalization.

**AppEUI** Application Extended Unique Identifier.

**Appkey** Application Key.

**AppSKey** Application Session Key.

**B2B** Business To Business.

**B2C** Business To Consumer.

**CeDRI** Centro de Investigação em Digitalização e Robótica Inteligente.

**Chirp** Compressed High Intensity Radar Pulse.

**CO2** Carbon Dioxide.

**CRC** Check Redundancy Cycle.

**DCS** Distributed Control System.

**DevAddr** Device Address.

**DevEUI** Device Extended Unique Identifier.

**DR** Data Rate.

**FDMA** Frequency Division Multiple Access.

**FSCM** Frequency Shift Chirp Modulation.

**IIoT** Industrial Internet of Things.

**IoT** Internet of Things.

**IPB** Instituto Politécnico de Bragança.

**ISM** Industrial, Scientific, and Medical.

**JoinEUI** Join Extended Unique Identifier.

**LoRa** Long Range Wide Area.

**LoRaWAN** Long Range Network Protocol.

**LPWAN** Low-power Wide Area Networks.

**MAC** Medium Access Control.

**MIC** Message Integrity Control.

**MQTT** MQ Telemetry Transport.

**NFPA** The National Fire Protection Associations.

**NwkAddr** Network Address.

**NwkID** Network Identifier.

**NwkSKey** Network Session Key.

**OTAA** Over The Air Activation.

**RFID** Radio Frequency Identification.

**RH** Relative Humidity.

**SF** Spreading Factor.

**TTN** The Things Network.

# Chapter 1

# Introduction

In the first row, this project aims to monitor in real time the data gathered from the sensor, as well as, to log the data using Internet of Things platforms in order to visualise the data behavior over a long period of time, so the procedure that was followed will be shown in detail in the rest of this work.

## 1.1 Theoretical Framework

The warehousing environment factors, primarily temperature, humidity, and flame presence, have a significant impact on the warehousing time and quality of the woods. Furthermore, environmental parameters such as air quality and carbon dioxide concentration, as well as the presence of fires, have a significant impact on the wood's warehousing period and quality. As a result, multi-parameter monitoring and analysis of the parameters are collected, as well as, a real-time monitoring, are critical in the wood warehousing environment. Currently, the method for monitoring the meteorological in wood warehousing relies primarily on temperature and humidity sensors, gas sensors, and, most importantly, flame sensors. Furthermore, they use a simple environmental monitoring system to capture local temperature and humidity, or a simple wired environment monitoring system to capture parameter information, but they are rarely able to do multi-parameter monitoring due to the lack of space. This thesis presents a LoRA-based warehousing monitoring and control system that works well in a wood warehousing environment. It can collect the main dominant factors variables that influence the quality of wood warehousing and perform data acquisition, display, storage, and transmission.

## 1.2 Objectives

Referring to Campbell Book [1], during the five-year period of 2009-2013, U.S. fire departments responded to an estimated average of 1,210 fires in warehouse properties per year (excluding refrigerated or cold storage). These fires caused an annual average of $155 million in direct property damage, three civilian deaths, and 19 civilian injuries. Nearly one-fifth of these fires were set intentionally. Electrical distribution or lighting equipment was involved in 18% of fires. Electrical failure or malfunction was the leading factor contributing to the ignition of warehouse fires, as well as in contributing to direct property damage and to civilian injuries. This project aims to develop a general system for monitoring warehouses, and it has done so by monitoring a variety of parameters such as temperature, humidity, atmospheric gases, and fire detection. These parameters serve as indicators for determining the warehouse's environment. thus, it will be able to save tonnes of wood goods by implementing such a system in warehouses. The proposed system is an implementable model that consists of four flame sensors, a gas sensor, and temperature and humidity sensor, all of which are connected to a microcontroller for data acquisition, as well as, LoRa sending protocol to an internet of things server and online platforms for data visualization. The proposed system is simple in design and can be implemented in any storage facility by simply changing the parameters of each module, as well as, the number of modules required, depending on the warehouse's space area. The system's overall architecture is divided into four sections: software monitoring, sensor acquisition, sending process, and data visualisations. The Figure 1.1 depicts the overall system for two Supervision Modules of a wood warehouse, as well as data transfer to the cloud application, all of which are wireless connected together with the LoRa Gateway. The number of the supervision modules can be more than 2.

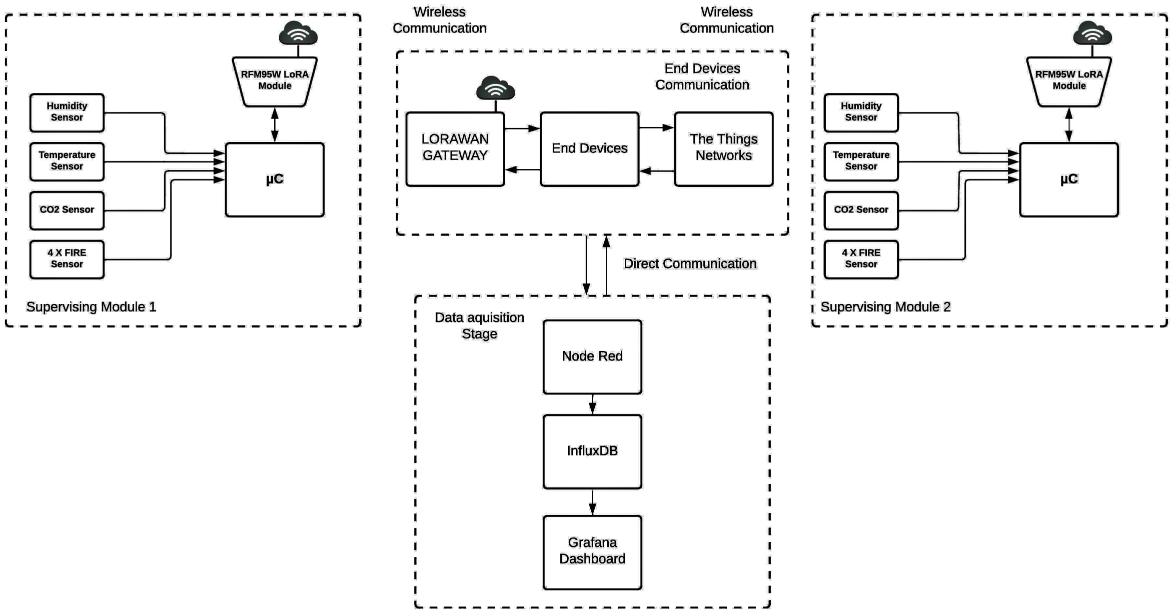



Figure 1.1: General Representation of the System.

## 1.3 Structure of the Document

This document is divided into 6 sections, using the following structure:

- **Chapter 2**: This chapter gives an overview of the warehouses types, factors affect them, as well as, an overview of the Internet of Things, its history and the wireless IoT connectivity technologies.

- **Chapter 3**: This chapter discusses the various wireless technologies in use around the world, moreover, differences between them, as well as the LoRa and LoRa Gateways technologies.

- **Chapter 4**: This chapter demonstrate all the equipment used.

- **Chapter 5**: This chapter explains the system design, technical analysis and the relationship between the various components

- **Chapter 6**: This chapter provides the results of the final test made in real case simulation, as well as, a discussion about the graph results.
- **Chapter 7**: This chapter summarizes the main points made in this document and outlines future work that will be done to improve it.

# Chapter 2

# State of the art

This chapter gives an overview of warehouses around the world and the different types of warehouses, as well as the factors that can affect them. It also gives an overview of the Internet of Things (IoT) and its history, as well as wireless IoT connectivity technologies.

## 2.1 Warehousing

Warehousing is the housing of quantities of finished products or goods in a specially constructed building. The duration of storage has no influence on the concept described. It can be short or long, depending on the product, commodity or raw material considered [2].

Storage, another similar concept, is defined as a warehouse practice. The shorter the storage time, the higher is the profitability of the stock. For simple reasons: less product obsolescence, less loss, less theft, less space rental costs, less storage area usage costs. Hence the notion of short term storage, just in time, before the product is put on the shelf [2].

### 2.1.1 Definition of Warehouse

A warehouse is a building that stores products for storage, packaging and preparation for shipment. Warehouses are central locations that handle both incoming and outgoing products. Maintaining a warehouse is crucial for any business that sells physical goods or receives products from a wholesale market. As a company's sales increase, so does the need for physical space to store and package items.

Depending on a company's needs or preferences, several service providers can handle separate warehouse-related tasks. There are different types of warehouses for different businesses, but each warehouse provides secure storage for products [3].

#### Bonded Warehouse

A bonded warehouse stores products before they are released for delivery to customers and before duties are paid by the importer of the product.

Bonded warehouses are useful for several reasons. Firstly, it's a simple way to expand warehousing operations and reach more efficiently new customers. Secondly, it is possible to get a bond for your products, which protects your profits from local taxes. Thirdly, bonded warehouses offer temperature-controlled rooms and storage options, ensuring that products doesn't spoil. Fourthly, the bonded warehouse that are contracted with, may offer its own logistics, thus, making shipping and delivery easier to manage [3].

#### Distribution Center

Many people confuse a warehouse with a distribution center and use the terms interchangeably. Whereas a warehouse might hold items for a long period of time, a distribution center holds products for a short period of time and sees a much higher velocity of products coming in and going out.

Distribution centers are very customer-centric and are typically located close to where the end user is, so they receive products quickly and in good shape. A distribution center may also offer value added services, such as cross docking, pick and pack services, or simple product mixing or packaging. Because a distribution center offers more services than a warehouse, they are also equipped with much more advanced technology to facilitate the processes happening within [4].

#### Smart Warehouse

To receive products, put them away, pick them for orders, ship them, and keep an accurate inventory count, a smart warehouse employs automation systems and interconnected technologies. Smart warehouses use technology to boost output, reduce errors, and reduce the number of people needed to run the operation [4].

### 2.1.2 Factors affecting the warehouse

There are several reasons or factors that can damage the products inside the storage space in the warehouse, which can lead to a significant loss for the owner. For this reason, it will be discussed in the following about the main factors that can cause this damage.

#### a. Humidity

Excessive humidity in warehouse areas can lead to mildew and mould growth on products, shelves, boxes and walls. Condensation causes rust and accelerates corrosion of metal parts. Increased insurance costs due to customer claims or returns. Optimal humidity levels in warehouses should be from 40-50 percent Relative Humidity (RH). Elevated humidity levels promote the growth of mould on stored items, corrosion, and rust, it creates condensation on walls, ceiling, and floors, which creates conditions suitable for pests. It can also lead to additional insurance costs for mould and mildew claims from customers [5].

During the heat of the day, humidity can be around 30 percent or lower, but that can be misleading, because during the night the humidity can reach 70-80 percent, therefore 24/7 monitoring is required [6].

**b. Temperature**

RH is directly related to the temperature of the air. If the temperature of the warehouse increases, the relative humidity will decrease and vice versa. RH doesn't reflect how much water vapour is actually in the air, but, it tells how close the air is to being saturated.

That is why ideally humidity and temperature should be monitored simultaneously to have the full spectrum of the environmental data [6].

**c. Carbon dioxide CO2**

Amongst others, logistic activities in global supply chains have become a major cause of industrial emissions and the progressing environmental pollution. Although a significant amount of logistic-related Carbon Dioxide (CO2) emissions is caused by storage and material handling processes in warehouses, prior research mostly focused on the transport elements. The environmental impact of warehousing has received only little attention by research so far. Operating large and highly technological warehouses, however, causes a significant amount of energy consumption due to lighting, heating, cooling and air condition as well as fixed and mobile material handling equipment which induces considerable CO2 emissions [7].

**d. Fire Damage**

The loss of assets also means loss of productivity as well as jobs. Many employees of the company that owns the warehouse may see their jobs suspended or even eliminated as the result of the fire. If the fire is severe enough, the company may have to undergo some major reorganization in order to be able to continue doing business. There are other consequences to warehouse fires, such as the damage to neighboring buildings. Warehouse fires can grow to considerable size if not quickly knocked back, and as such they can easily be carried by the wind into neighboring facilities, resulting in multiple fire damage cases. There are also environmental concerns as the result of excess fire, smoke, and soot damage to the surrounding areas, not to mention fire and other extinguishing material runoff that may affect the land surrounding the property. There also remains the problem of adequate insurance, whether the warehouse was properly covered against the threat of fire, not to mention making provision for workers or anyone else who may have been injured or killed as a result of the fire [8].

## 2.2 The Internet of Things

The IoT (Figure 2.1) describes physical objects (or groups of such objects) that are embedded with sensors, processing ability, software, and other technologies, and that connect and exchange data with other devices and systems over the internet or other communications networks.

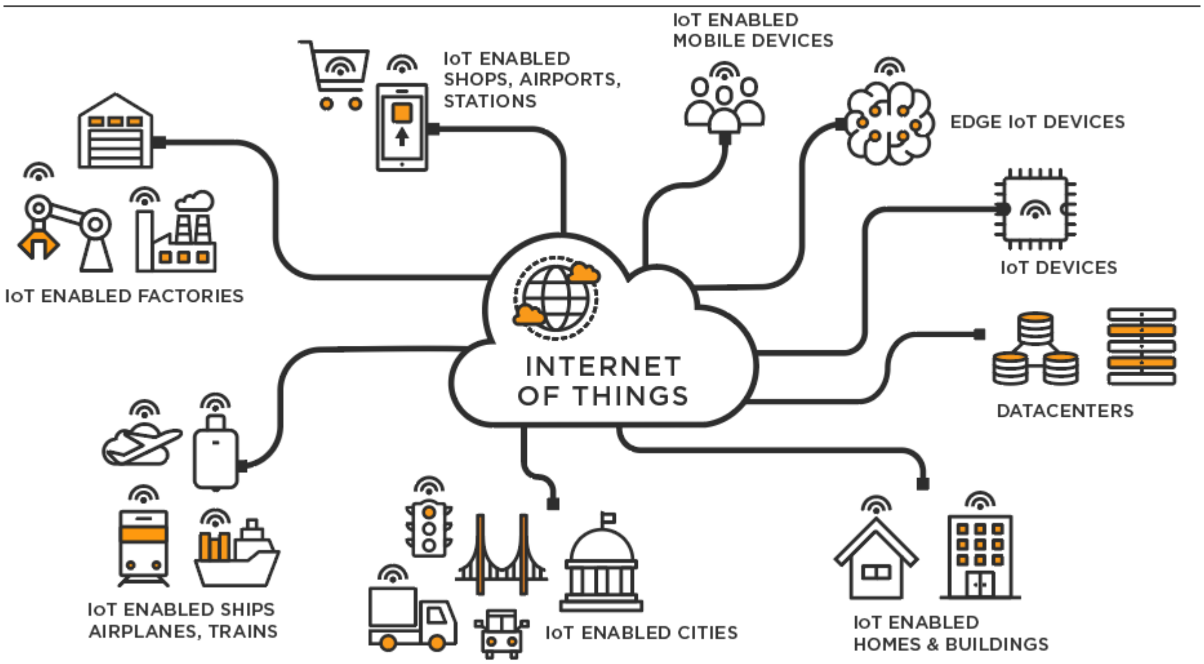



Figure 2.1: Internet of Things architecture [9].

### 2.2.1 History

The term Internet of Things is 16 years old. But the actual idea of connected devices had been around longer, at least since the '70s. Back then, the idea was often called "embedded internet" or "pervasive computing". But the actual term "IoT" was coined by Kevin Ashton in 1999 during his work at Procter & Gamble. Ashton who was working in supply chain optimization and wanted to attract senior management's attention to a new exciting technology called Radio Frequency Identification (RFID). Because the internet was the hottest new trend in 1999 and because it somehow made sense, he called his presentation "IoT".

### 2.2.2 Industrial Internet of Things

Industrial Internet of Things (IIoT) is a term that refers to interconnected sensors, instruments, and other devices that are networked with industrial applications on computers, such as manufacturing and energy management. Data gathering, exchange, and analysis are all possible with this connectivity, which could lead to increased production and efficiency, as well as, other economic benefits. The IIoT is an evolution of a Distributed Control System (DCS) that uses cloud computing to enhance and optimize process controls, allowing for a higher degree of automation [10].

IIoT technology is used to bring automated instrumentation, data collection and analysis, reporting and decision making to industrial operations. It enables this through an interconnected system of smart sensors, gateways, software platforms, and cloud servers. Sensors are deployed on machines where they capture data and send it to the gateway, which functions as a hub between the connected devices and applications and services running in the datacenter or the cloud. This data can then be accessed by workers via a computer or mobile device [10].

### 2.2.3 The difference between IIoT and IoT

In principle, IoT and IIoT work in the same way. They both connect devices to the internet and make them smarter. The difference is that IoT works to make consumers live more convenient and easier, where IIoT works to increase safety and efficiency on production facilities. IoT is Business To Consumer (B2C) and IIoT is Business To Business (B2B). For companies with multiple plants and production facilities the benefits of implementing IIoT solutions are huge. The ability to monitor and analyze data, conduct predictive maintenance on the entire supply chain and manage staff from the same system will drastically improve production efficiency and eradicate a lot of paperwork [11].

#### Consumer vs Industry

The first and foremost difference is the end-user of these two technologies. IoT is for retail consumers. Devices like smart bulbs, voice assistants, and smart vacuums are prime examples. IIoT, on the other hand, is for industries where the emphasis is on collecting data measurement for an intelligent ecosystem between the machinery [12].

#### The Focus of Development

IoT aims to provide the homeowner with a higher level of convenience. Having lights that automatically switch on and off, and air conditioners that turn off when nobody is at home are examples of how IoT helps the homeowner have a higher level of comfort while reducing running costs. IIoT is about making the industry more efficient by collecting relevant data metrics that are used to analyze and optimize its operations. The results are not just savings due to optimization but deeper insights into the machinery health that can be used to predict or prevent downtime [12].

#### End Devices

The end devices of IoT systems are smart devices that we use daily. These devices include smart assistants, smart thermostats, smartwatches, etc. Hence, these are devices that the consumer uses to enrich their lives. The end devices of IIoT are sensors, PLCs, and controllers that work in tandem with machinery to generate data on its operations. These are devices that cannot work directly but integrate with the existing mechanism. Smart machinery is another type of IIoT device that comes preinstalled with monitoring capabilities [12].

# Chapter 3

# Lora based wireless communication

In the IoT world, many protocols exist, one of which is Low bandwidth, high range, but overall low power protocols, thereby, LoRa technology may be a viable solution to the IoT concept's various issues, therefor, this chapter will focus on LoRa technology, how it is made, how it works, the modulation used to ensure high range data transferring, the sending and receiving formats that are used with this technology as well as LoRa gateways application keys, data range, the application layers that are used and the activation applications.

## 3.1 The IoT wireless protocols

Many protocols exist in the IoT world, including Bluetooth, Zigbee, WiFi, 2G, 3G, 4G, 5G, NFC, and so on. As shown in Figure 3.1, they are generally classified according to their bandwidth and range. The first benefit is increased range and bandwidth (better range and bandwidth) [13].

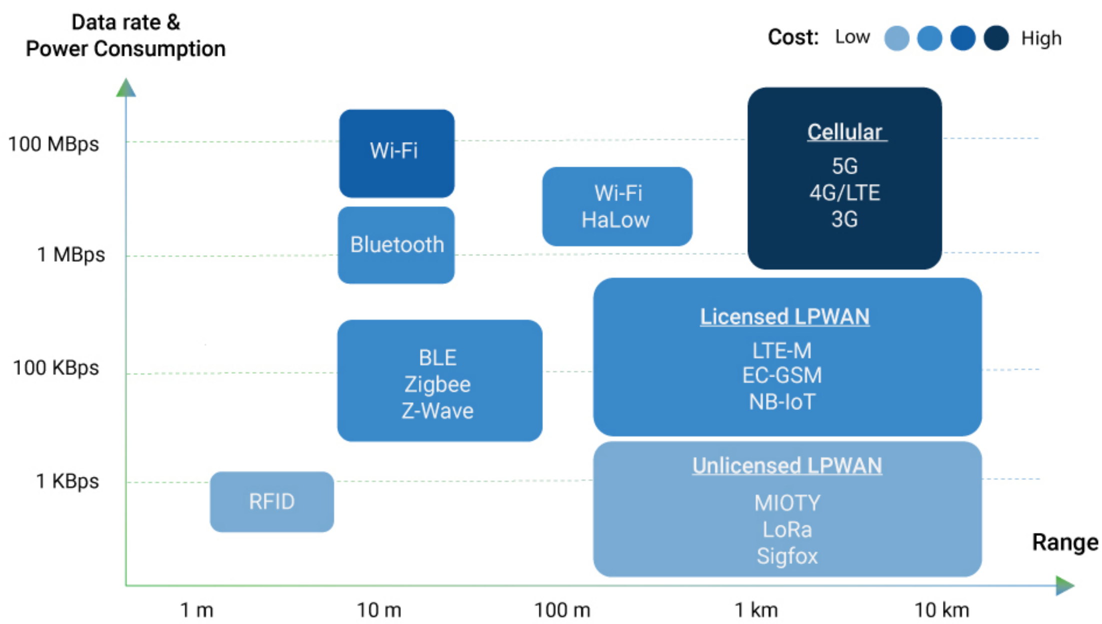



Figure 3.1: Protocols used in IoT [14].

Low bandwidth, high range, but overall low power protocols like NB-IoT, LTE, Sigfox, and LoRaWAN are considered extremely long range and extremely low power on the bottom right. Low-power Wide Area Networks (LPWAN) refers to all of these networks [15].

### 3.1.1 Frequency bands

In the world, some frequency bands are free to use. some of these free frequency are shown in Table 3.1. This means:

- No need to ask for authorization,
- Free of charge,
- It is now available only in three continents.

| **Band** | **Examples of protocols** |
|---|---|
| **13.56 MHz** | RFID, NFC |
| **433 MHz** | Walkie Talkie, Remote control, LoRa |
| **868 MHz** | Sigfox, LoRa |
| **2.4 GHz** | Wifi, Bluetooth, LoRa, Zigbee |
| **5 GHz** | Wifi |

Table 3.1: Free frequency bands.

## 3.2 Long Range Wide Area

Long Range Wide Area (LoRa) technology may be a viable solution to the IoT concept's various issues. The frequency band used for communication is the unlicensed Industrial, Scientific, and Medical (ISM) band. A star network topology is used by LoRa. As a result, each node can communicate directly with the Gateway module over a distance of several kilometers [16].

Figure 3.2: Long Range Wide Area logo [17].

### 3.2.1 Frequency Division Multiplexing

There are three bands of transmission frequencies that belong to the network around the world: the first is in the United States, the second in Europe, and the third in Asia, and each continent has a free band of frequency for all users [18]:

- United States : 915 MHz
- Europe : 868 MHz
- Asia : 430 MHz

Frequency Division Multiplexing Frequency channels are used by devices to separate their transmissions. This sharing mode is used by LoRa, in which the free 868 MHz band is split into several channels that can be used to transmit data. The Figure 3.3 clarify the Frequency Division Multiple Access (FDMA) [19].

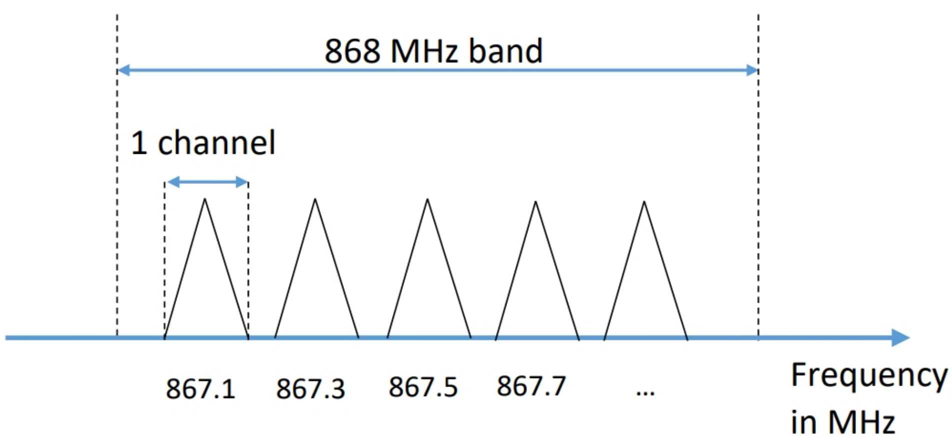



Figure 3.3: FDMA usage in LoRa [15].

### 3.2.2 Spread Spectrum

End-devices transmit at the same time, on the same channel, but with a specific signal structure (codes or symbols) that allows the receiver to recover the buried signal from the noise. This sharing mode is used by LoRa as shown in the Figure 3.4 [20].

The Table 3.2 demonstrates the four spreading codes and how three end-devices can simultaneously transmit the transaction's validity on the same channel. The strategy involves the use of codes with mathematical properties adapted to simultaneous transmission on the same channel.

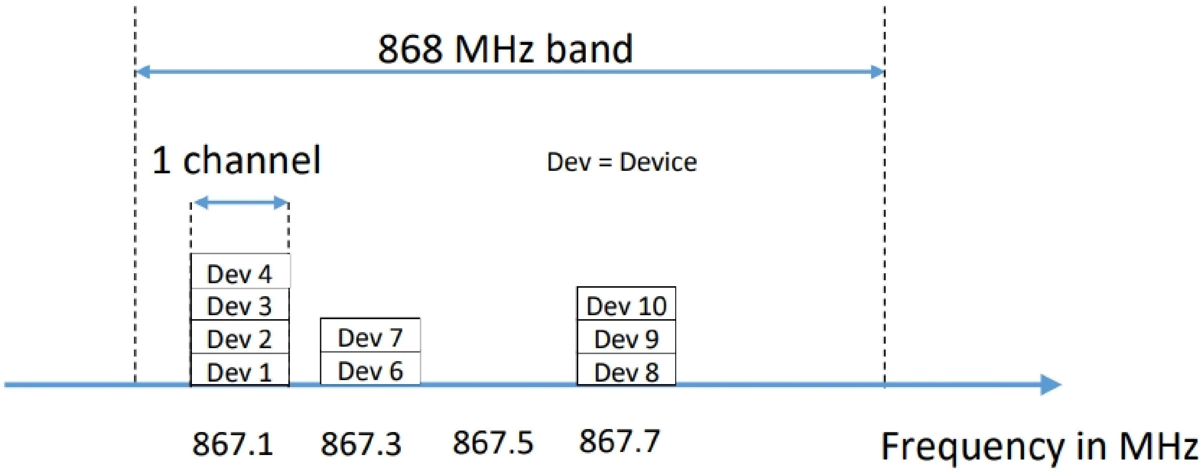



Figure 3.4: Using Spread Spectrum in LoRa [15].

| | | | | |
|---|---|---|---|---|
| **Orthogonal Code User 0** | **1** | **1** | **1** | **1** |
| **Orthogonal Code User 1** | **1** | **-1** | **1** | **-1** |
| **Orthogonal Code User 2** | **1** | **1** | **-1** | **-1** |
| **Orthogonal Code User 3** | **1** | **-1** | **-1** | **1** |

Table 3.2: Hadamart (mathematician) matrix of order 4.

### 3.2.3 LoRa Modulation

SemTech invented the LoRa modulation system, which is a patented modulation scheme. It offers a number of features that make it ideal for LPWAN technology, including Doppler and multipath fading resistance, as well as low power consumption for long-range communication [20].

### 3.2.4 The Chirp

In the Figure 3.5, the LoRa modulation is referred to as a Compressed High Intensity Radar Pulse (Chirp) modulation. A closer look into LoRa reveals that the information carrying element is the frequency shift at the start of the symbol, and the chirp resembles a carrier. As a result, LoRa is better defined as a Frequency Shift Chirp Modulation (FSCM) [21].

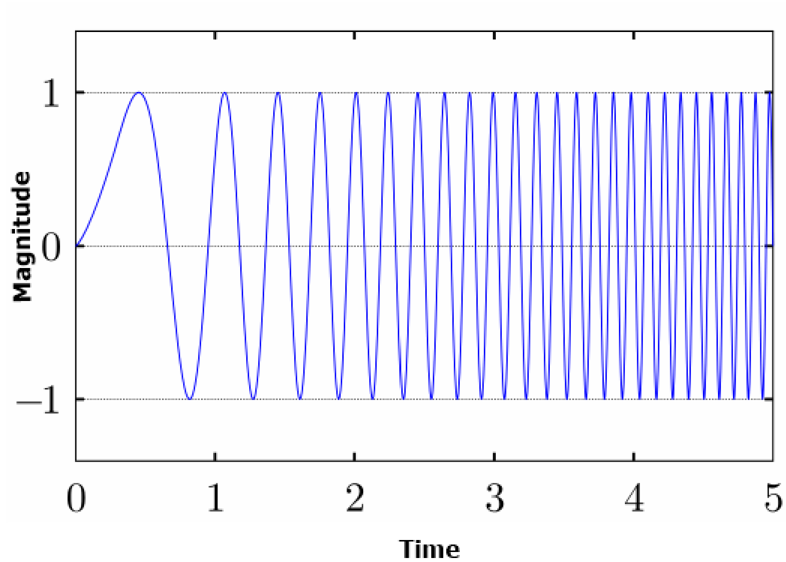



Figure 3.5: A Chirp [22].

### 3.2.5 Symbol transmission time

The Figure 3.6 shows the Spreading Factor (SF), that determines the transmission time of each symbol ($T_{\text{symbol}}$) in LoRa. The longer the transmission time, the higher the SF. The transmission time of a symbol in SF8 is twice as long as the transmission time of a symbol in SF7 for the same bandwidth. Up to SF12, this is the case.

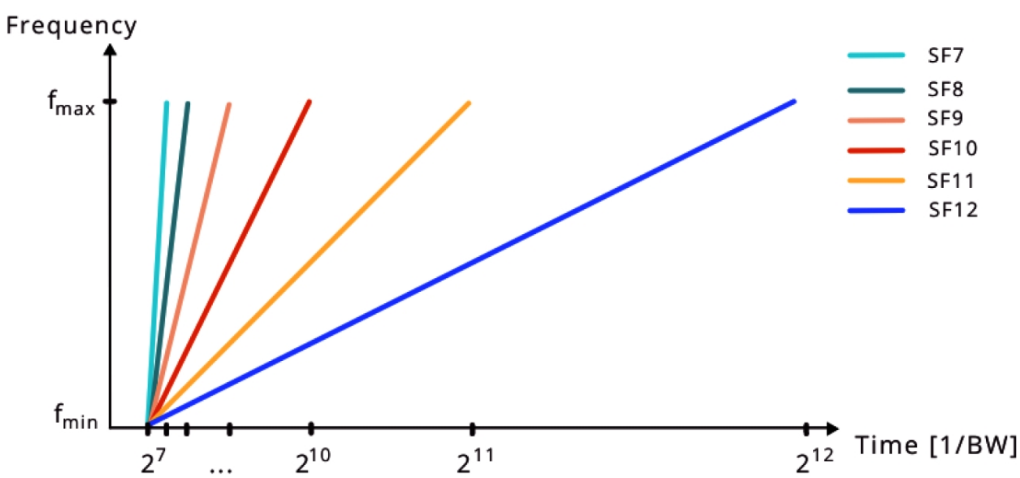



Figure 3.6: Symbol Transmission Time [18].

The bits are packed together in packets of SF bits during emission. Then, for each packet, a specific symbol is chosen from a list of available symbols. The sole distinction between symbols is that they all begin with a certain frequency that represents a packet of bits. A theoretical example of SF2 modulation at 868,1 MHz with a bandwidth of 125 kHz is shown in Figure 3.7. Each symbol corresponds to two bits [15].

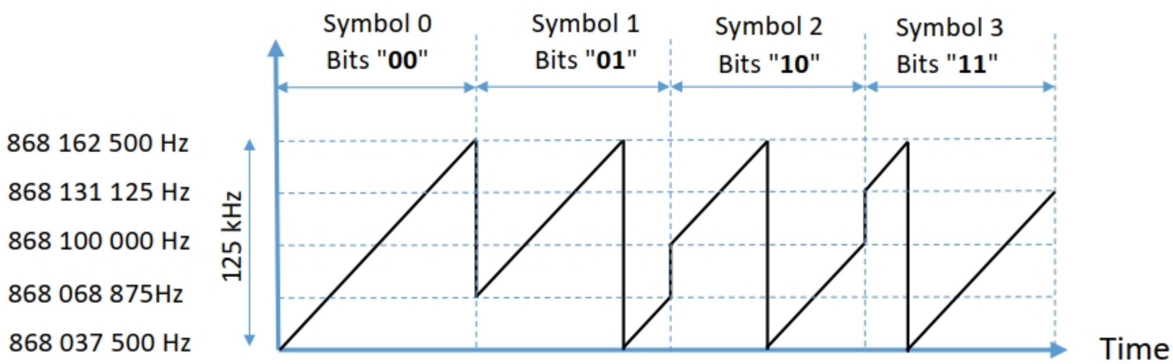



Figure 3.7: Symbols transmitted in LoRa modulation in SF2 [15].

For a bandwidth of 125 KHz, the Table 3.3 shows the transmission time as a function of SF.

| Spreading Factor | Symbol transmission time |
|---|---|
| **SF7** | **1.024 ms** |
| **SF8** | **2.048 ms** |
| **SF9** | **4.096 ms** |
| **SF10** | **8.192 ms** |
| **SF11** | **16.384 ms** |
| **SF12** | **32.768 ms** |

Table 3.3: Symbol transmission time for BW125.

## 3.3 LoRaWAN

The Long Range Network Protocol (LoRaWAN) is a LPWAN category that includes certain rechargeable battery devices for bidirectional communication. The LoRaWAN standard demonstrates that IoT gadgets may be perfectly integrated without the requirement for complicated local jobs.

The LoRaWAN network is built on a star network architecture. The advantages of employing star topology include saving battery life and reducing network complexity, while nodes do not have to broadcast or forward data from other nodes; instead, each node gets just its own data [23].

### 3.3.1 LoRaWAN gateways

The primary goal of the LoRaWAN gateway is to provide connectivity for IoT devices, there is still the danger of IoT devices being left without a connection owing to inadequate network planning. To address this problem, more LoRaWAN gateways may be deployed in the environment to increase coverage and network performance. At the same time, the LoRaWAN gateways listen on all channels and all SF. When a LoRa frame is received, it sends its content across the internet to the Network Server that has been set up in the gateway before [24], this configuration is shown in the Figure 3.8.

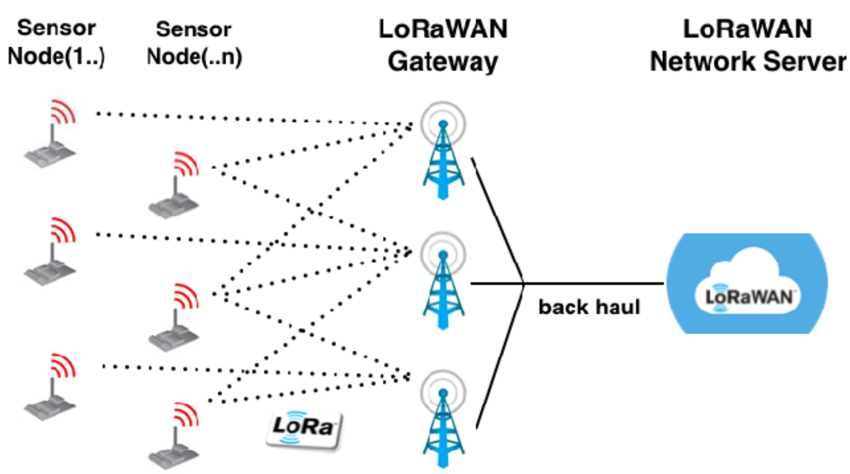



Figure 3.8: The LoRaWAN gateway [25].

### 3.3.2 Application Key

Application Key (Appkey) is a 128-bit key, that is being applied to create two session keys: Network Session Key (NwkSKey) and Application Session Key (AppSKey). Both the end-device and the network server use the NwkSKey to produce and validate the message integrity code. This protects message integrity and produces a unique signature for each device. The AppSKey is identical to the NwkSKey, except it is used to encrypt and decode application data payloads. NwkSKey, AppSKey, and the up-link or down-link counter of the messages are used to construct a key stream in LoRaWAN. To construct the encrypted payload, each message is encrypted by applying the XOR operation with the associated key from the key stream [26].

### 3.3.3 LoRaWAN Unique Identifier

The LoRaWAN Device Extended Unique Identifier (DevEUI) is equivalent to a MAC address on Ethernet. Some LoRaWAN end-devices have a fixed DevEUI that was programmed into the factory firmware and cannot be changed.

The network server generates Device Address (DevAddr) based on the DevEUI carried in the terminal node's Join Request frame. DevAddr is still generated randomly to ensure the reliability of the generation method and reduce the collision probability of the generated DevAddr. The network server uses DevEUI as seeds and the Xor-shift algorithm to generate DevAddr's low 25-bit Network Address (NwkAddr), which is then combined with a fixed high 7-bit Network Identifier (NwkID) [27].

### 3.3.4 LoRaWAN Application Unique ID

This parameter has different meaning depending on the LoRaWAN versions. In LoRaWAN 1.0.3 and anterior versions, it was an Application Extended Unique Identifier (AppEUI). From LoRaWAN 1.0.4, this parameter has been renamed in Join Extended Unique Identifier (JoinEUI) [26].

### 3.3.5 Activation by Personalization

In the type of Activation By Personalization (ABP) activation, the information required for the activation will already be stored on the end device. When the device is turned on, it automatically joins the network specified in the information. This type of personalization isn't used very often, and it's only used in a few cases. Simply send a join request and join accept message between the end device and the network for the end device to activate using the ABP method. This method also ensures network security and authenticity [28]. For the ABP activation methode, these parametres are needed for end device to work:

- DevAddr
- NwkSKey
- AppSKey

### 3.3.6 Over the Air Activation

The device is not personalized with any information in the Over The Air Activation (OTAA) type of end device activation. To join any network, the end device must go through a join procedure. The information is loaded onto the end device before it joins the network. When the session context information is lost, this must be repeated for each transmission over the network. While roaming, this method ensures that the end devices are not tied to a single service provider and can join any network service provider [28]. For the OTAA activation method, these parameters are needed for end device to work:

- DevEUI
- AppEUI
- Appkey

### 3.3.7 Data Rate

The Data Rate (DR) refers to the amount of information sent per second. The data rate can be calculated using the spreading factor SF as a starting point [29].

The Table 3.4 shows the data rate for every spread factor and bandwidth.

| Data Rate | Spreading Factor | Bandwidth |
|---|---|---|
| **DR0** | **SF12** | **125 kHz** |
| **DR1** | **SF11** | **125 kHz** |
| **DR2** | **SF10** | **125 kHz** |
| **DR3** | **SF9** | **125 kHz** |
| **DR4** | **SF8** | **125 kHz** |
| **DR5** | **SF7** | **125 kHz** |
| **DR6** | **SF7** | **250 kHz** |

Table 3.4: Data Rate(DR) according to SF and bandwidth.

## 3.4 LoRaWAN protocol layers

The LoRaWAN protocol is made up of several layers, each of which is responsible for a specific task. The first layer is called **LoRa PHY**, and it is a LoRa modulation method for transferring data from one point to another. The second layer is called **LoRa Medium Access Control (MAC)**, and it is the LoRaWAN protocol that adds end-device authentication, data encryption, acknowledgment, and network administration. Finally, the **Application layer** is simply the raw user data. The Figure 3.9 down below reveals the different layers of LoRaWAN [30].

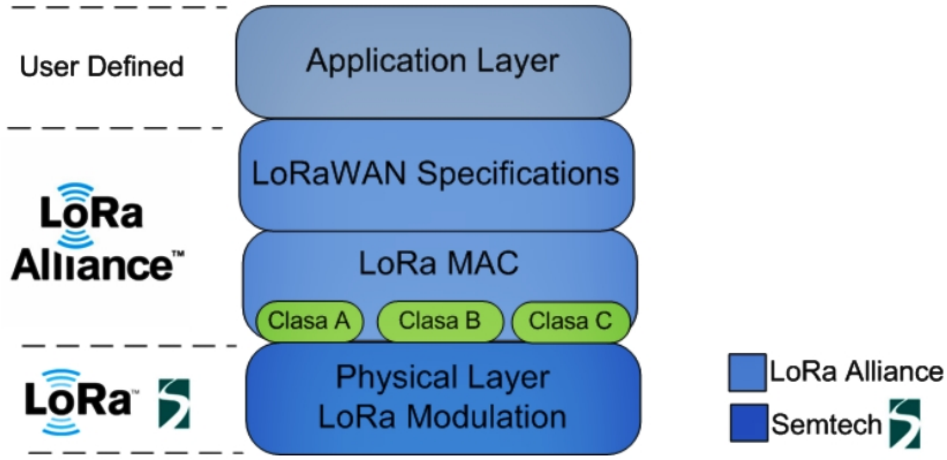



Figure 3.9: LoRaWAN protocol layers [30].

As illustrated in Figure 3.10, these layers have various frames and headers.

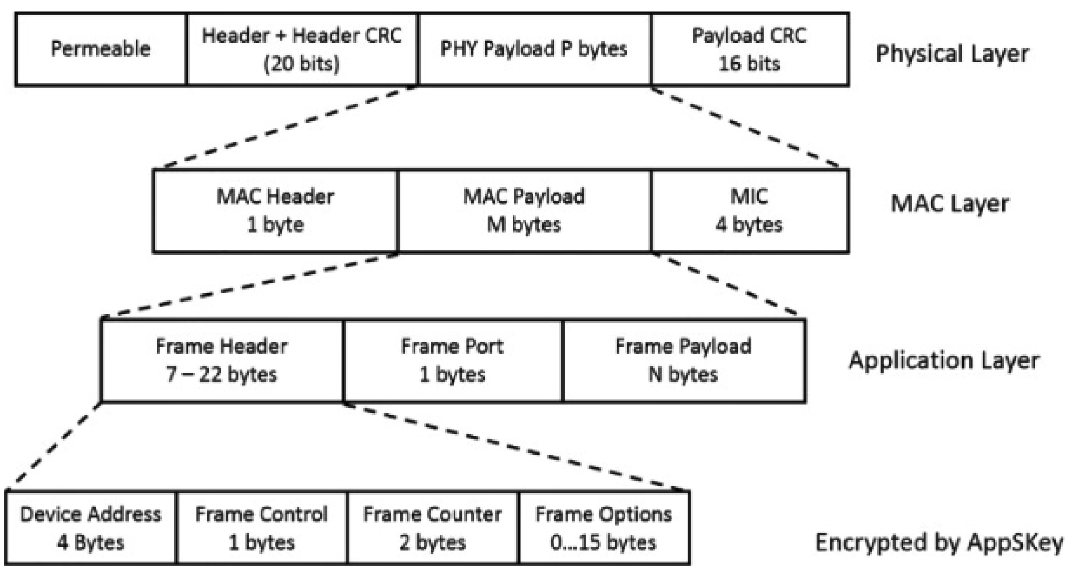



Figure 3.10: LoRaWAN Frame Format [31].

### 3.4.1 Application Layer

By default, the user data resides in the Application Layer before the LoRaWAN frame encrypts it as shown in the Figure 3.11. The AppSKey encryption tool was created to protect the transaction throughout the transmitting process. The data can be as simple as a single byte from a sensor. The user can structure the frame payload freely in whatever way he wants as long as it fits within the overall maximum size of a LoRaWAN frame [32].

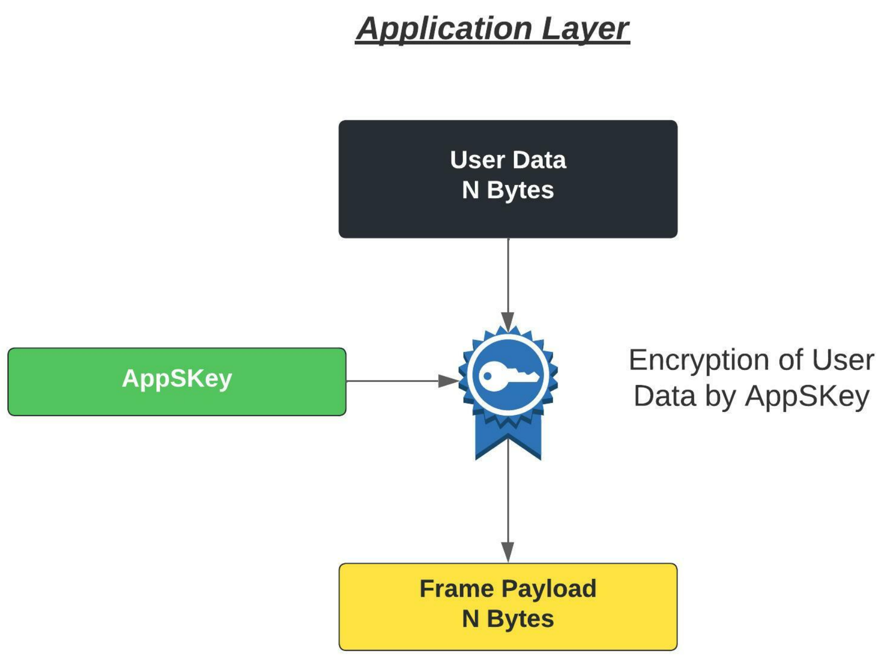



Figure 3.11: LoRaWAN application layer.

### 3.4.2 MAC Layer

MAC Layer is a section of the PHY Layer that is separated into three sections: the MAC Header, the MAC Payload, and the Message Integrity Control (MIC) (as shown in the Figure 3.12 below).

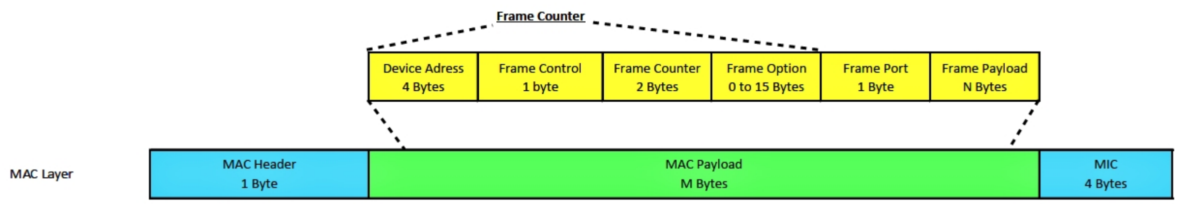



Figure 3.12: LoRaWAN MAC frame layer.

- The **MAC Header** field defines the type of message: Join-Request, Join-Accept, data up, data down, confirmed, unconfirmed.
- The **DevAddr** is the Device Address.
- The **Frame control** gives information on the ADR (Adaptive Data Rate), the acknowledgment of messages and also gives the length of the optional "Frame Option".
- **Frame counter**: This number increments itself each time a new frame is transmitted on the end-device.
- The **Frame option** field carries eventual MAC Command.
- **Frame Port** is the application port.
- The **Frame Payload** is the encrypted user data.
- **MIC** is the message that allows the message to be authenticated by the Network Server.

The maximum number of bytes that can be transmitted as a MAC Payload (M bytes) is given in the following Table 3.5:

| Data Rate | Spreading Factor | Bandwidth | Max Frame Payload (Number N) |
|---|---|---|---|
| **DR0** | **SF12** | **125 kHz** | **51 bytes** |
| **DR1** | **SF11** | **125 kHz** | **51 bytes** |
| **DR2** | **SF10** | **125 kHz** | **51 bytes** |
| **DR3** | **SF9** | **125 kHz** | **115 bytes** |
| **DR4** | **SF8** | **125 kHz** | **242 bytes** |
| **DR5** | **SF7** | **125 kHz** | **242 bytes** |
| **DR6** | **SF7** | **250 kHz** | **242 bytes** |

Table 3.5: Maximum MAC Payload Size.

### 3.4.3 LoRa PHY layer

The PHY layer is the main layer that holds all of the data that has to be sent; it is also a very light layer that just comprises a preamble, an optional header, and a Check Redundancy Cycle (CRC). The Figure 3.13


Figure 3.13: Physical Layer.

# Chapter 4

# System development components

This chapter covers all of the theoretical information needed to comprehend and develop the work. Starting with a study of the hardware components in section 4.2, section 4.3 discusses the software used, and section 4.4 discusses the data communication used in this project.

## 4.1 Hardware Components

According to [33], the board that will be used in this project is made by the Instituto Politécnico de Bragança (IPB) Centro de Investigação em Digitalização e Robótica Inteligente (CeDRI) Lab, it contains an ATMEGA328P microcontroller, a 3,3V buck converter, a LoRa RFM95W module, an 18650 Lithium battery, a DHT11 temperature and humidity sensor, five analog inputs for flame sensors of type YG1006 phototransistor LED, and three free digital input/output pins which are Pin 7, Pin 8 and Pin 9 of the microcontroller. The Pin 4 is already used to enable the buck converter to work. In this project, a gas sensor of type MQ135 will be added to the board, so one of the flame sensors will be replaced in this case. Additionally, while the IPB board was designed to work in an external environment, as mentioned [33], this project will work in an internal environment, in this case the warehouse, so a charger box will be built to charge the 18650 Lithium battery to keep the sequence and continuity of the work. The MQ135 gas sensor and the TP4056 battery charger will be described in greater detail in the following section. The Figure 4.1 show the initial PCB board of the IPB's CeDRI lab.

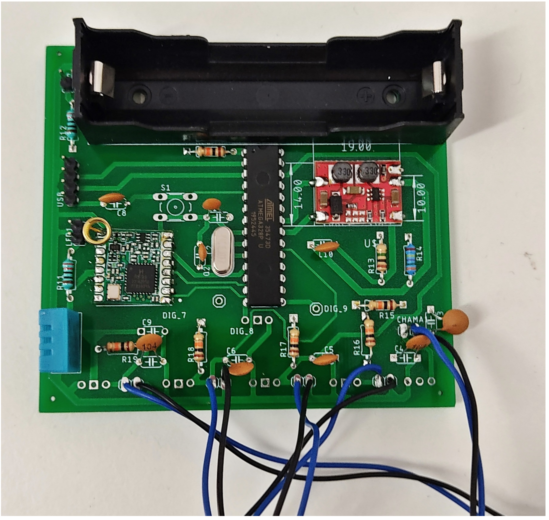


Figure 4.1: IPB's PCB Board [33].

The Figure 4.2 depicts the PCB architecture in greater detail; the underlined parts in the figure represent the main equipment added to the PCB board's initial version.

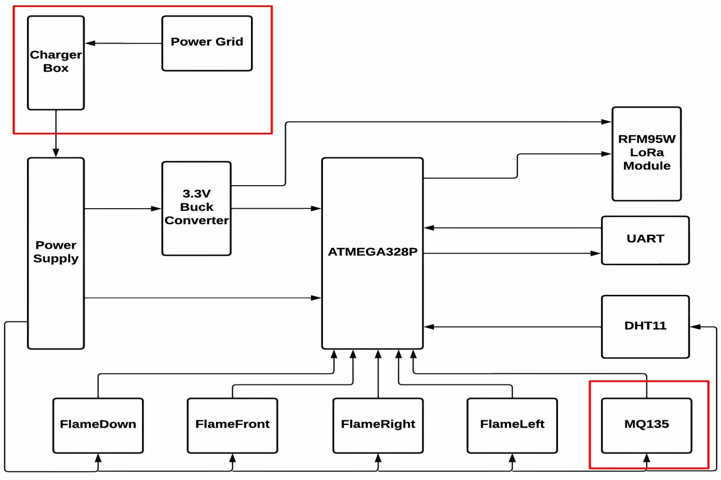



Figure 4.2: PCB Architecture Diagram.

### 4.1.1 Gas Sensor

Gas sensors are required in warehouses, and they play a critical role in determining the great danger of all types of gas. In this case, the **MQ135**, represented in Figure 4.3, is an excellent choice in terms of price and efficiency. MQ135 gas sensors models are used in air quality control equipments for buildings/offices and are suitable for detecting of NH3, NOx, alcohol, Benzene, smoke, CO2 [34].

Figure 4.3: MQ135 [35].

### 4.1.2 Battery Charger Board

For the battery charging, TP4056 (Figure 4.4) is the best choice in this case, while it's cheap, less power consumer and short circuit protected.

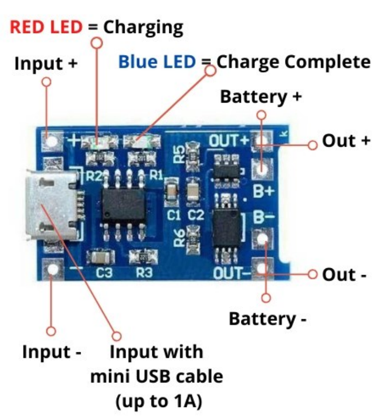



Figure 4.4: TP4056 Charging Board [36].

## 4.2 Data Communication

As shown in the Figure 4.5, this section will describe the data acquisition system block that was used in this project to obtain the graphs in real-time simulation, as well as all of the IoT platforms used to complete this work

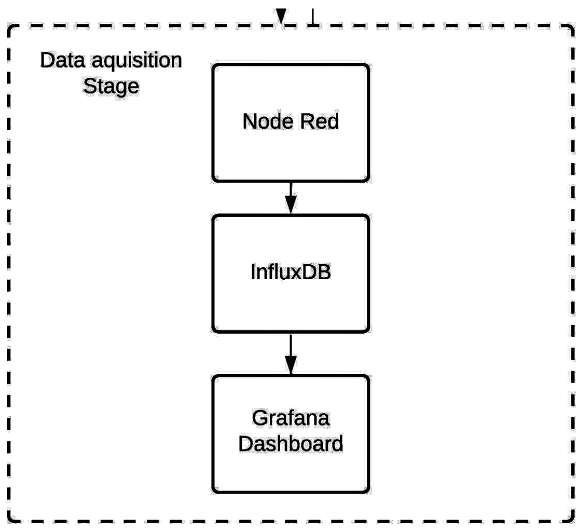



Figure 4.5: Data Acquisition Block.

### 4.2.1 The Things Networks

The Things Network (TTN) (Figure 4.6) is a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN. The Things Network runs The Things Stack Community Edition, which is a crowd sourced, open and decentralized LoRaWAN network. This network is a great way to get started testing devices, applications, and integrations, and get familiar with LoRaWAN [37].


Figure 4.6: The Things Networks [38].

### 4.2.2 Node Red

Node-RED (Figure 4.7)is a visual programming tool that was originally developed by IBM for connecting hardware devices, APIs, and online services as part of the Internet of Things. It includes a flow editor that can be used to create JavaScript functions in a web browser. Reusable application elements can be saved or shared. Node.js is used to create the runtime. JSON is used to store the flows created in Node-RED. MQTT nodes have been able to make properly configured TLS connections since version 0.14. In 2016, IBM contributed Node-RED to the JS Foundation as an open source project [39].

Figure 4.7: Node Red [40]

### 4.2.3 MQTT

MQ Telemetry Transport (MQTT) (Figure 4.8) is a lightweight publish-subscribe network protocol for sending and receiving messages between devices. Although MQTT is most commonly used with TCP/IP, it can be used with any network protocol that provides ordered, lossless, bidirectional connections. It's made for connections with remote locations where there are resource constraints or network bandwidth limitations. The protocol is an ISO recommendation (ISO/IEC 20922) and an open OASIS standard [41].

Figure 4.8: MQTT [41]

### 4.2.4 InfluxDB

InfluxDB (Figure 4.9) is an open-source time series database (TSDB) developed by the company InfluxData. It is written in the Go programming language for storage and retrieval of time series data in fields such as operations monitoring, application metrics, Internet of Things sensor data, and real-time analytics. It also has support for processing data from Graphite [42].

Figure 4.9: InfluxDB [43]

### 4.2.5 Grafana

Grafana (Figure 4.10) is a web-based analytics and interactive visualization application that runs on a variety of platforms. When connected to supported data sources, it provides web-based charts, graphs, and alerts. Using interactive query builders, end users can create complex monitoring dashboards. Grafana is split into two parts: a front end and a back end, both written in TypeScript and Go [44].

Figure 4.10: Grafana [45]

# Chapter 5

# Practical implementation

The implementation and realization of the project is a critical component of its design. This stage entails concretizing the developed conceptual model, allowing for model confirmation on the one hand and the discovery of previously undetected issues on the other.

## 5.1 Problem and Solution

Warehouses are properties that are used for the storage of commodities. Despite their common purpose, warehouses vary on the basis of size, types of materials stored, design, storage configurations, construction and other factors. The National Fire Protection Associations (NFPA) has long recognized that warehouses present special challenges for fire protection because their contents and layouts are conducive to fire spread and present obstacles to manual fire suppression efforts. An increase in the number of very large warehouses in recent years, with attendant increases in their potential fuel loads, is likely to have an impact on both the warehouse fire experience and warehouse fire protection systems [46].

Following this unforeseeable event beyond the control of the owner, the solution lies in the creation of a supervision module that displays the interior state of the wood warehouses in the event of a fire or gas leak.

The temperature and especially the humidity play a crucial role in the degradation of the state and the quality of the stored wood, hence, the presence of a humidity and temperature sensor is mandatory.

For the follow-up of the mutations of the acquired data, a real time monitoring takes care of the sending of the internal state of the warehouse to the person in charge, using LoRa technology, as well as, the platforms of the internet of the objects.

## 5.2 Development Procedures

In order to make the Supervision Module, the first step is to test the circuit by breadboarding it. This will verify if the developed board can generate accurate values, if the connection between the LoRa RFM95W module and the TTN services has been established, and if the precision of the sensors against fire ignition has been verified, among other things, all that will be discussed in this section.

### 5.2.1 Bootloader Flashing

The first step after forming the system in Chapter 1 is to flash the bootloader, which is a program that runs as soon as the machine is turned on and is responsible for launching the operating system. The Figure 5.1 shows the wiring diagram used to flash the bootloader in the ATMEGA328P microcontroller.

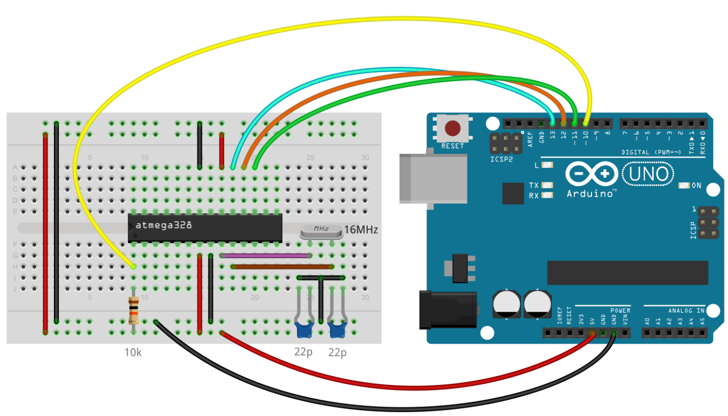
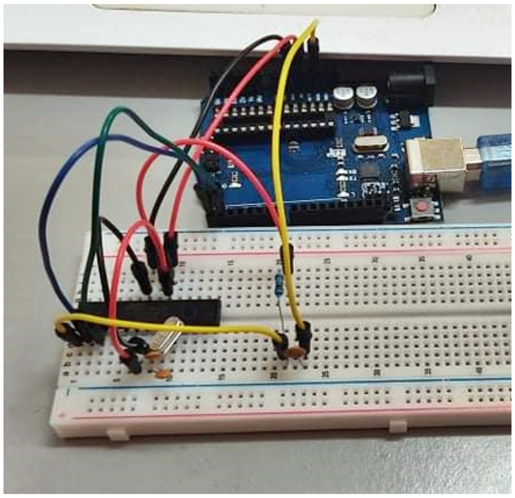
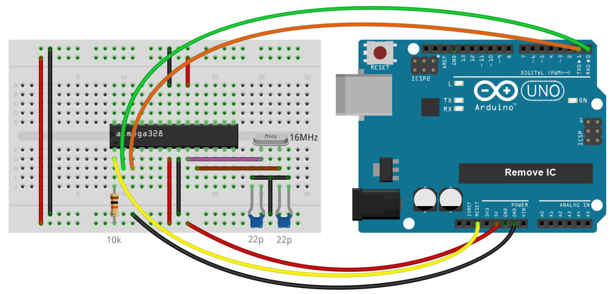



Figure 5.1: Bootloader Flashing Schematic.



(a) UART Protocol Debugging Breadbording.




(b) UART Protocol Debugging Schematic.

Figure 5.2a and Figure 5.2b shows the schematic of the ATMEGA328P microcontoller code debugging after burning the bootloader.

### 5.2.2 Sensors Data Acquisition

In order to verify if the developed system is able to generate accurate values, a simulation of the sensors has been developed. In this way, the objective is to measure the precision of the sensors while operating in real time, so the defined values will take place in the sketch code, thus, the operation of the system is guaranteed. The scenario for the analysis of this simulation was developed with a MQ135 gas sensor, a DHT11 temperature and humidity sensor and a YG1006 photo-resistance LED as the flame sensor. Figure 5.3 shows the breadboarding of the scheme, with all the sensors connected to the ATMEGA328P microcontroller.

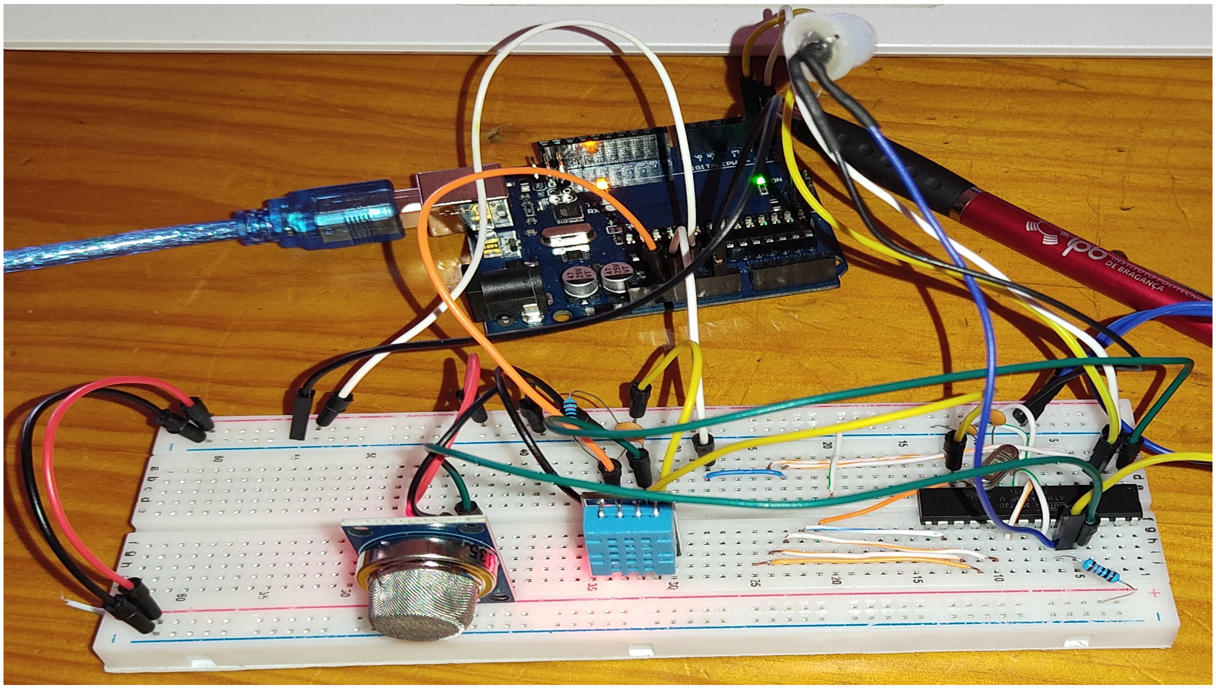


Figure 5.3: Sensors Data Acquisition Breadboarding.

The values obtained from the sensors in normal conditions are shown in the Figure 5.4.


Figure 5.4: Data Value in Normal Situation.

The values obtained while gas distribution and flame occurred are shown in the Figure 5.5.

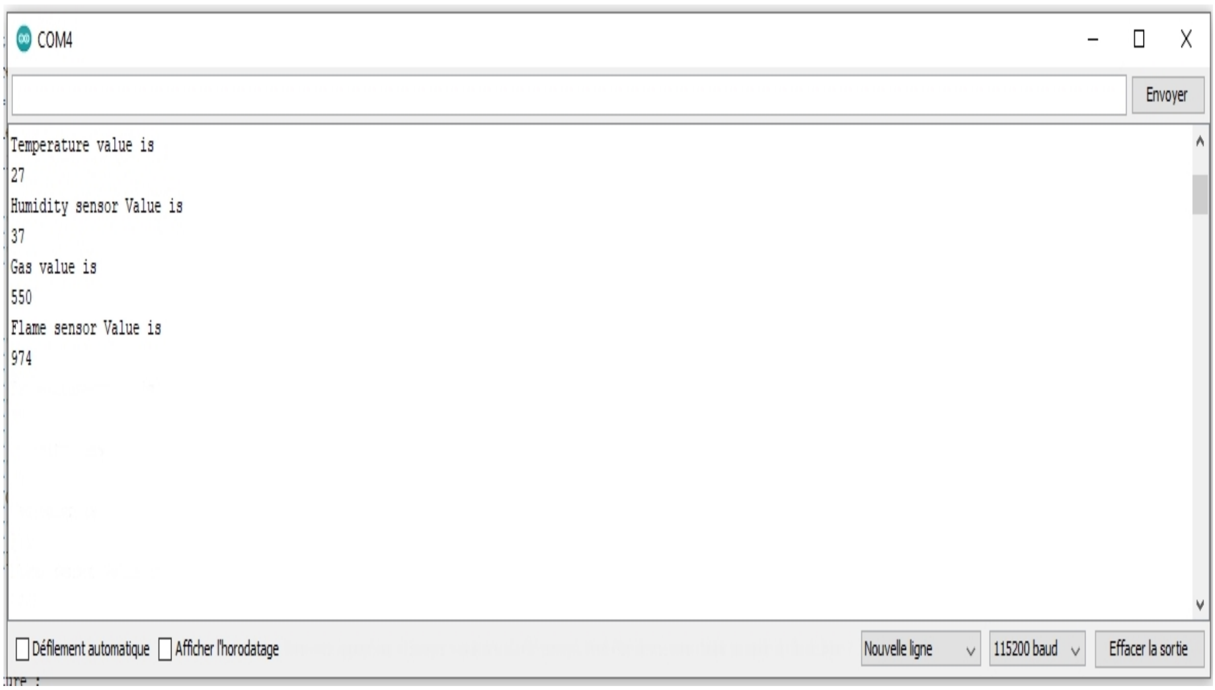



Figure 5.5: Data Value in Presence of Flame and Gas.

### 5.2.3 Sending Process

The goal of this project is to send data collected by sensors to the cloud of TTN, so that it can be monitored by Internet of Things platforms. To accomplish this, the LoRa module is required; in this case, the RFM95W is used to send data from the sensor to the microcontroller to the TTN webservices, as shown in Figure 5.6. As a result, the first test will be simulated based on the accuracy of the sensors. To make sure that the procedure of the breadbording is working, short wires need to be connected between the microcontroller and the LoRa RFM95W module, otherwise, the module will not work, the reason behind this is that the LoRa module is Low Power module, means that, as long as the connection wires are long, an important current loss will appear in this case.

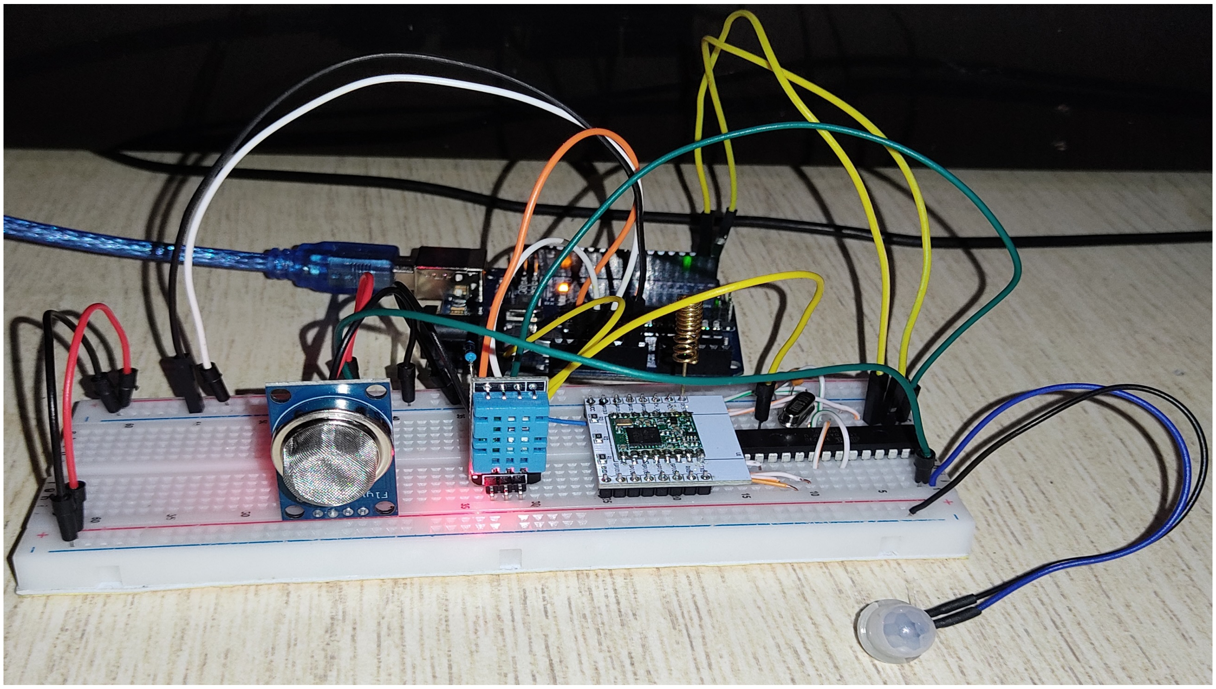


Figure 5.6: Sensors Data Sending Breadboarding.

The Figure 5.7 shows that the message is sent in the serial monitor of the microcontroller, it is clear that all the data from the sensors are accurate, as well as the message is accepted by the LoRa gateway and all the information has been joined successfully.

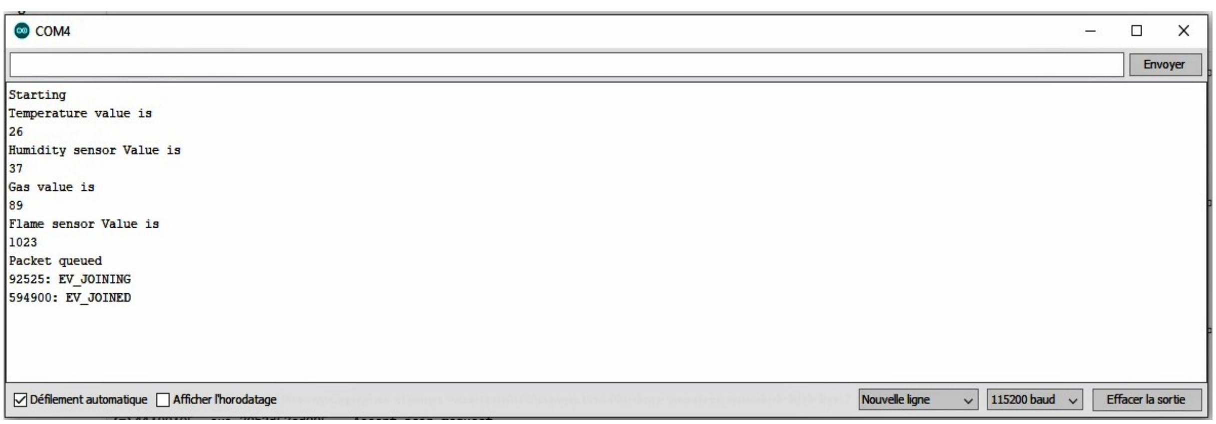



Figure 5.7: Serial Monitor Data Values.

The results attached by the TTN service are shown in the Figure 5.8, but as can be seen, the data is only collected when the microcontroller is reseted, this problem is due to data collusion on the LoRa gateway, as the data is too large to be sent successively.

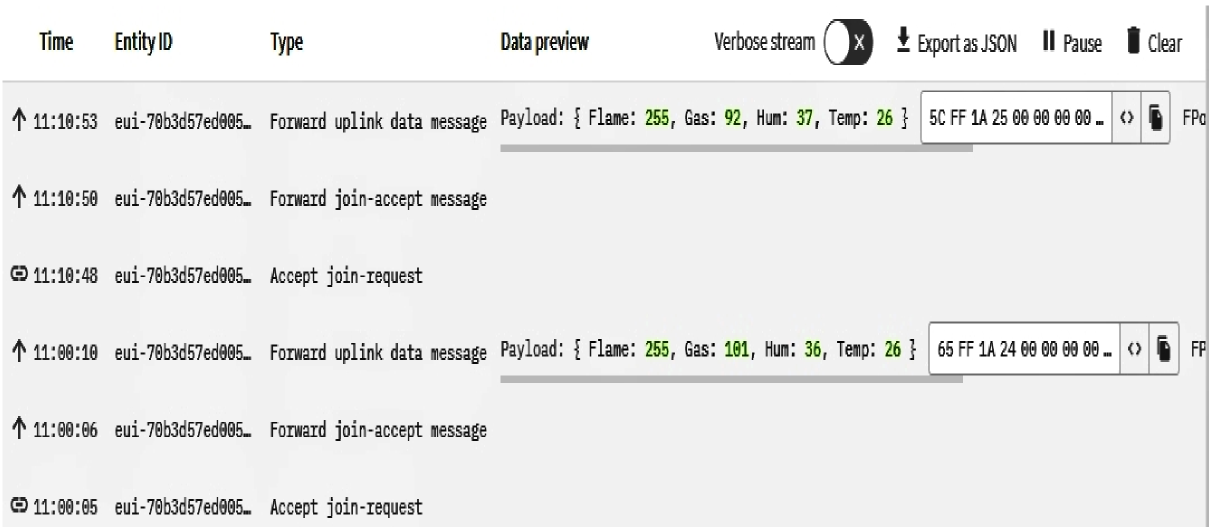



Figure 5.8: TTN Data Receiving.

The payload formatter is illustrated in the Listing 5.1 below.

Listing 5.1: Payload Formatter

```
function Decoder(bytes, port)
{
    var decoded = {};

   decoded.Gas = bytes[0];
   decoded.Flame = bytes[1];
   decoded.Temp = bytes[2];
   decoded.Hum = bytes[3];

return decoded;
}
```

### 5.2.4 Charger Schematic

Although the board is powered by a battery, a charger is required to ensure the working system's durability and for the board to work sequentially and without interruption. Before delving into the specifics of why the load control was added, it should be noted that the load card contains the TP4056 chip, which, according to its datasheet [36], is protected against overcharging, overload, and short circuit. The purpose of the load control, however, is to reduce the range of the load voltage level, the TP4056's load voltage ranges between 2.75V and 4.2V, while the supervision module must be in a range between 3.5V minimum and 4.2V [36], otherwise the DC converter has 0.2 drop between the input and output voltage. As a result, the scheme shown in Figure 5.9 must be built.

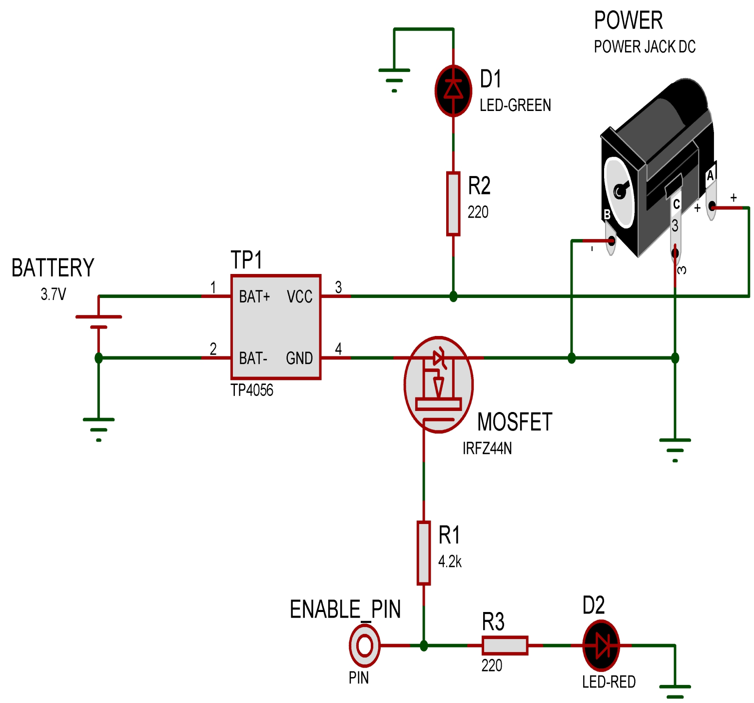



Figure 5.9: Charger Schematic.

### 5.2.5 Power Calculation

The supervision module consumes, as shown in the Figure 5.10, 0,156 A as current and 4,12 V as voltage, so in total, 0,642 W, but, the voltage will fluctuate over time, reaching 3,5 V before the charging process, while the current will remain constant and the power consumption will decrease until roughly 0,546 W. In total, the supervision module consumes 0,7 W at the maximum voltage rate of the battery and 0,540 W at the minimum voltage rate. As a result, the module only uses a little amount of energy while operating, thus, it can operate for up to 23 hours on a 3600 mAh battery and 14 hours on a 2600 mAh battery.

The purpose of using a battery power supply for this module, even though there is a power grid inside the warehouses, is to keep it operating when the power grid supply to the charger box is interrupted. To put it another way, the battery presence is the solution to keep the supervision module operating simultaneously without the presence of an external power supply for a predetermined period of time known as the emergency period.

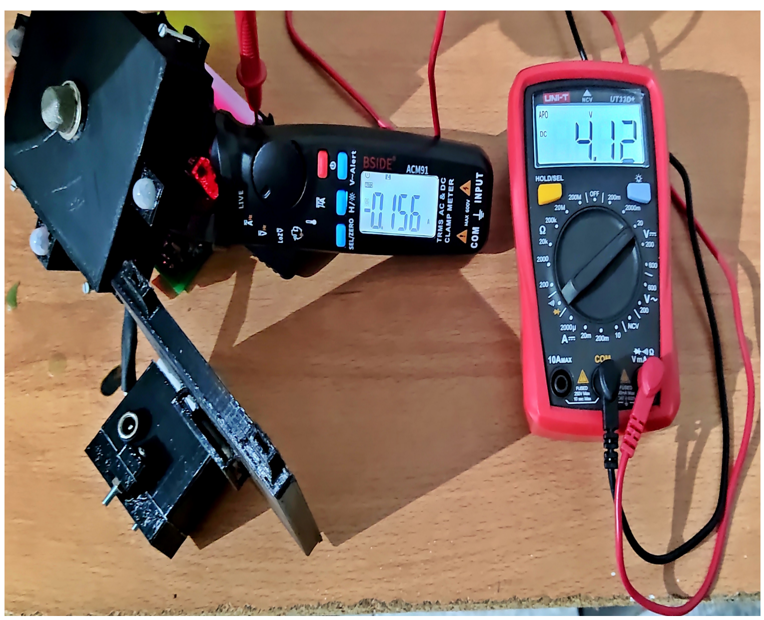



Figure 5.10: Power Test.

## 5.3 Proposed System

After verifying that the sensors are accurate, that the data has been sent to the TTN services, and that all of the breadbording procedures were completed successfully, this section will discuss the next steps, which include creating the full schematic of the Supervision Module, designing its PCB board, designing its enclosure, and discussing the algorithm that has been used to prevent data collusion in the sending process, additionally, the program explanation.

### 5.3.1 Schematic

The goal of this project is to monitor weather conditions, fire detection, and the presence of smoke in the warehouse. In order to accomplish this, a breadbording of the sensors is required in order to simulate data behavior before moving on to the construction phase. As a result, the (Figure 5.11) depicts the schematic that allows this task to be completed.

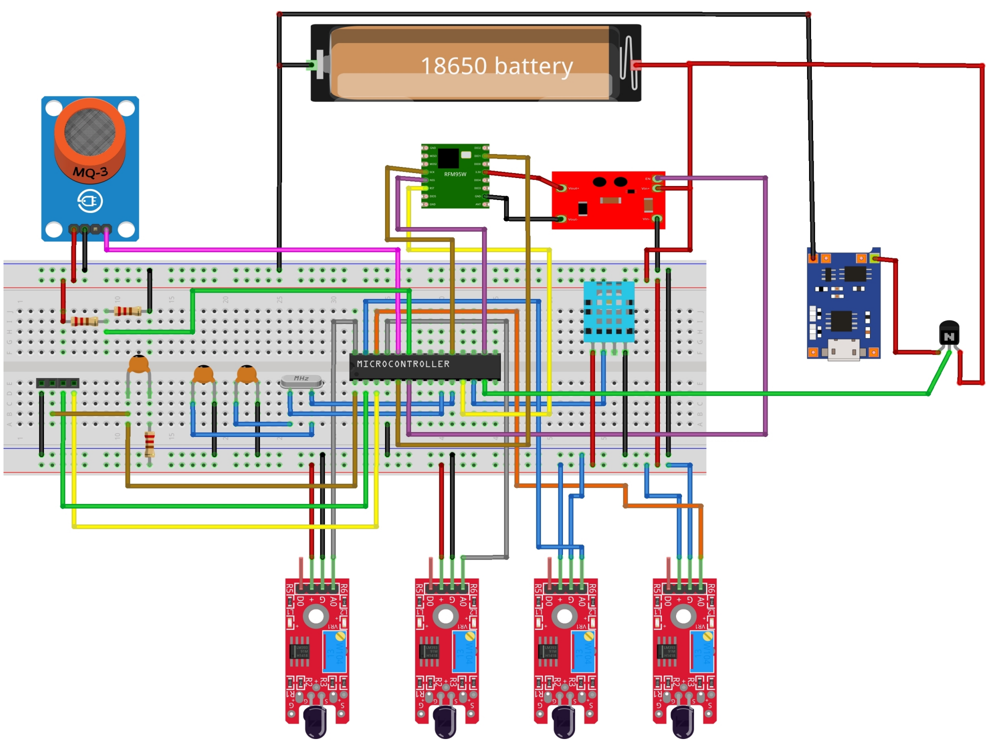



Figure 5.11: Warehoue Supervision Breadbording Schematic.

The wiring diagram of the sensors connected to the microcontroller shows that each sensor's power pins are connected to VCC and GND, as well as the microcontroller's power pins and the buck converter's power inputs. VCC is the battery's plus terminal, and GND is the battery's minus terminal in this case. Second, as shown below, the signal pins of the sensors are connected to the microcontroller in the following order:

- RFM95W: **DIO0, DIO1, SCK, MISO, MOSI, NSS and Reset** to **PIN2, PIN3, PIN19, PIN18, PIN17, PIN10 and PIN5** of the microcontroller.

- Flame Sensors: **Flame Sensor 1, Flame Sensor 2, Flame Sensor 3 and Flame Sensor 4** to **PIN A2, PIN A3, PIN A4 and PIN A5** of the microcontroller.

- Gas Sensor: **MQ135 DATA PIN** to **PIN A1** of the microcontroller.

- Temp and Hum Sensor: **DHT11 DATA PIN** to **PIN12** of the microcontroller.

Third, since the LoRa module requires a 3.3V maximum voltage input, it must be connected to the buck converter's power outputs.
Finally, the debugging terminals are connected to the microcontroller's PIN1, 2, and 3, with PIN1 being connected to a capacitor of 0.1uF in series and a resistance of 10kOhm wired in parallel with VCC to ensure that debugging is working.

### 5.3.2 Library Installation

The first step in programming the code in this case is to properly install the libraries required to ensure that the sketch code works; thus, the library names are listed below:

- MCCI LoRaWAN LMIC Library

- MCCI Arduino LoRaWAN Library

- SimpleDHT

After that, the config.h file must be parametrized with the warehouse module's installation location, which in this case is Europe, and the parameters that need to be discommented are listed below:

- #define CFG_eu868 1
- #define CFG_sx1276_radio 1
- #define LMIC_DEBUG_LEVEL 2
- #define LMIC_FAILURE_TO Serial
- #define DISABLE_PING
- #define DISABLE_BEACONS

The file that needs to be modified is located in this local Link:
Documents\Arduino\libraries\arduino-lmic-master\src\lmic\

### 5.3.3 Program Explanation

Second, in the first row, the configuration of the sensors and other components must be made, to do so, an account in The Things Networks is required, he will provide the user with three parameters, which are [AppEUI, DevEUI, AppKey], the AppEUI needs to be in MSB Type, the DevEUI needs to be in LSB Type and the AppKey needs to be in MSB Type.

The code architecture was proposed by the project SAFe: "Forest Monitoring and Alert System", and it's mentioned in Thadeu Brito article [33], means that, the code sketch is confidential and belong to the project owner, thus, the code steps are described in the article [33], but, in this case, a flame sensor was replaced by one gas sensor, also, a charge box was designed to maintain the charging process of the battery during the working time range, as well as, a digital output was used to enable or disable the charging process which in this case Pin 7 of the microcontroller,

## 5.4 Payload Format Architecture

Before the sending process, encoding the sensors data needs to be done to gain bytes while transferring the information to LoRa Gateway.

### 5.4.1 Payload Encoding

An embedded system written in the C programming language performs the encoding. The proposed C code for encoding is detailed further in Thadeu Brito arcticle [47] under the project SAFe: "Forest Monitoring and Alert System" that was done in the IPB's CeDRI Laboratory. The modification done in this project is that the one flame sensors of the initial board created by the Safe project, will be replaced by an MQ135 gas sensor, therefore, a data encoding for the gas sensor also needs to be done, and while the flame sensor and the gas sensor works in 10Bits of the microcontroller, in this case, no need to modify anything in the encoding map that will be sent to the TTN service's. The Figure 5.12 shows the payload encoding map proposed by Thadeu Brito article [47], as well as, the modification that was made.

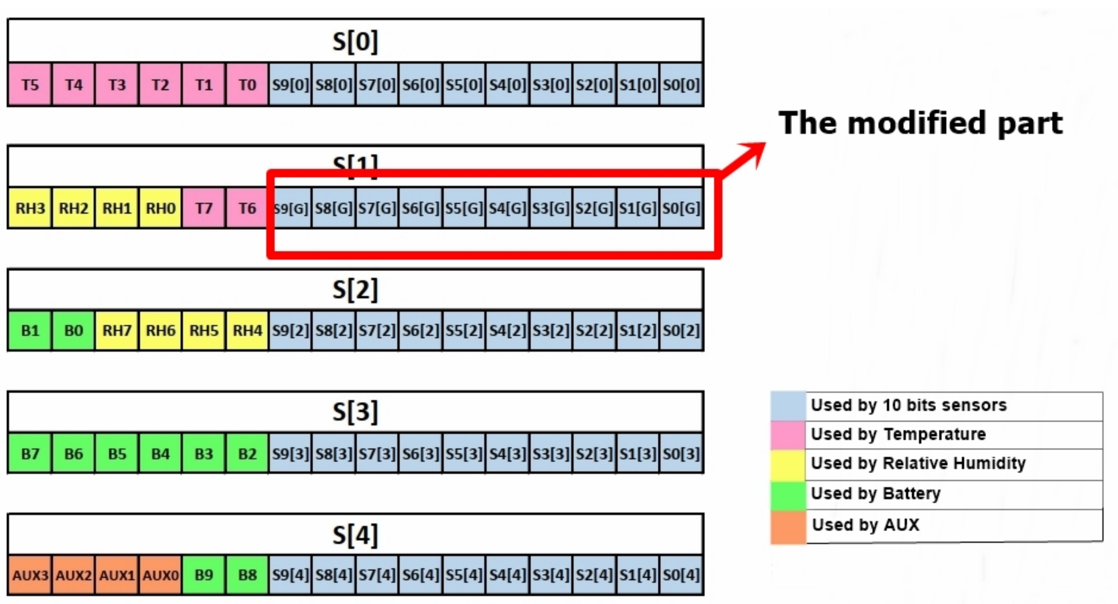



Figure 5.12: Modified Encoding Map. Adapted from [47].

### 5.4.2 Payload Decoding

The encoding map, as mentioned in the previous section, belongs to Thadeu Brito article [47] and was created as part of the project SAFe: "Forest Monitoring and Alert System" at the IPB's CeDRI Laboratory, as does the decoding part. The names of the sensors that will be shown in the TTN service, as well as the battery data conversion, will be added to the decoding code in this section; the rest of the code will remain the same.

Listing 5.2: TTN Data Decoding

```
function Decoder(bytes, port)
{
  var decoded = {};
  var S =[0x0000,0x0000,0x0000,0x0000,0x0000];
  var i;
  for (i=0;i<5;i++)
  { S[i]=(bytes[2*i+1] << 8) | bytes[2*i]; }

  decoded.Temperature = ((S[0] & 0XFC00) >> 10) | ((S[1] & 0X0C00) >> 4);
  decoded.Humidity = ((S[1] & 0XF000) >> 12) | ((S[2] & 0X3C00) >> 6);
  decoded.FlameFront = ((S[2] & 0XC000) >> 14) | ((S[3] & 0XFC00) >> 8)
  | ((S[4] & 0X0C00) >> 2);
  decoded.AUX = ((S[4] & 0XF000) >> 12);
  decoded.Battery = ((((S[0] & 0X03FF)* 5.0)/1024)) * 0.907;
  decoded.CO2 = S[1] & 0X03FF;
  decoded.FlameRight = S[2] & 0X03FF;
  decoded.FlameLeft = S[3] & 0X03FF;
  decoded.FlameDown = S[4] & 0X03FF;
 return decoded;
}
```

Listing 5.2: In the first part of the data decoding is to define a function called Decoder with two parameters [Bytes, Port], then, an table array to stock the data incoming, after that, a conversion from Bytes to Hex is needed, Finally, the decoding of the sensors values is done referring to the encoding map

## 5.5 Enclosure Design

In order to simulate a real-life fire ignition, the Supervision Module must be placed in such a way that it can collect data on top of the fire. As a result, a 3D printed enclosure must be created to ensure the simulation of this module, and while the module is placed in an enclosure, it comes the part of designing an enclosure for the battery charger board, which it will be placed in top of the Supervision Module enclosure.

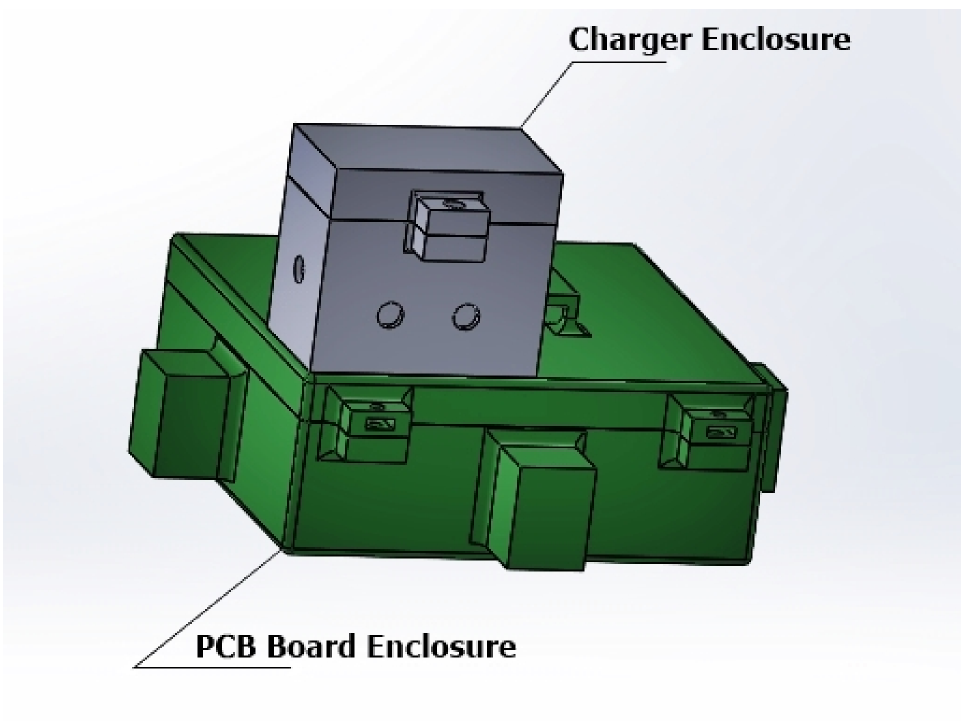



Figure 5.13: Enclosures Design.

As it can be seen in the Figure 5.13, The two enclosure are designed with the Solidworks CAD software, as well as, all the dimensions of the two enclosures are defined in the Appendix A, Appendix B, Appendix C and Appendix D.

# Chapter 6

# Result and Discussion

This chapter analyzes and discusses the results obtained from the Supervision Module in order to analyze data behavior and discuss all conditions that occur during real-time working, as well as, to evaluate the module's working state in a real case scenario.

## 6.1 First Result

The final result of the fabrication process, as well as the results of the IoT platform after testing the working process of the first Supervision Module, will be demonstrated in this section.

### 6.1.1 Node Red

As shown in the Figure 6.1, a MQTT server (which all the informations can be found in the TTN integrations section) is used to retrieve data from the TTN service, after which orange-colored function blocks are added to decode the incoming link before connecting it to the Node Red Gauges, as well as an influxDB function block, to send the data to the Grafana server, and log the data to ensure that no data is lost after the final installation.

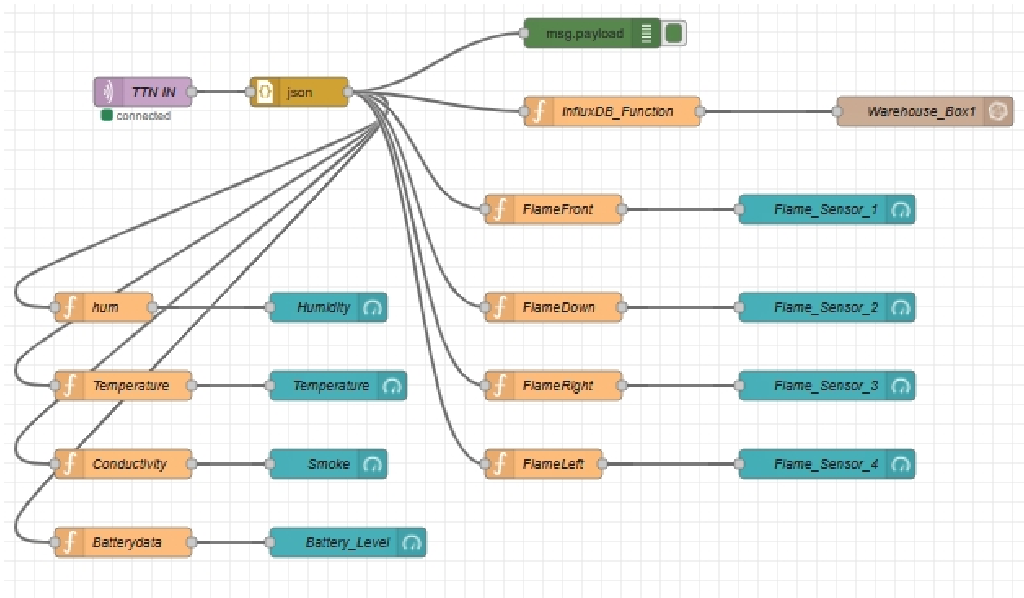



Figure 6.1: Node Red Result.

### 6.1.2 InfluxDB

The inluxDB logging data is defined automatically by a table that contains all of the data information sent by the Node Red Server, in this case the data is logged in "Warehouse_data" file, with a column of each sensor, as shown in the Figure 6.2.

```
> SELECT * FROM Warehouse_data LIMIT 10
name: Warehouse_data
time                Bat               CO2  FLD FLF FLL FLR Hum Temp
----                ---               ---  --- --- --- --- --- ----
1649092139174000000 3.805243445692884 1023 159 159 159 159 18  19
1649092206451000000 3.805243445692884 1023 159 159 159 159 17  19
1649092340970000000 3.805243445692884 1023 159 159 159 159 17  19
1649092408230000000 3.805243445692884 1023 159 159 159 159 18  19
1649092475501000000 3.805243445692884 1023 159 159 159 159 17  19
1649092541791000000 3.805243445692884 1023 159 159 159 159 18  19
1649092609043000000 3.805243445692884 1023 159 159 159 159 17  19
1649092676453000000 3.805243445692884 1023 159 159 159 159 17  19
1649092743576000000 3.805243445692884 1023 159 159 159 159 17  19
1649092810874000000 3.805243445692884 1023 159 159 159 159 17  19
>
```

Figure 6.2: InfluxDB Data Logging.

### 6.1.3 Grafana

The data logged as the first test of the Supervision Module is shown in the Figure 6.3, which shows the behavior of each sensor in relation to the weather attitude in the lab. This data was logged for only 2 hours in order to test the module and ensure that it works as expected, otherwise, the real case test will be discussed in the next chapter.

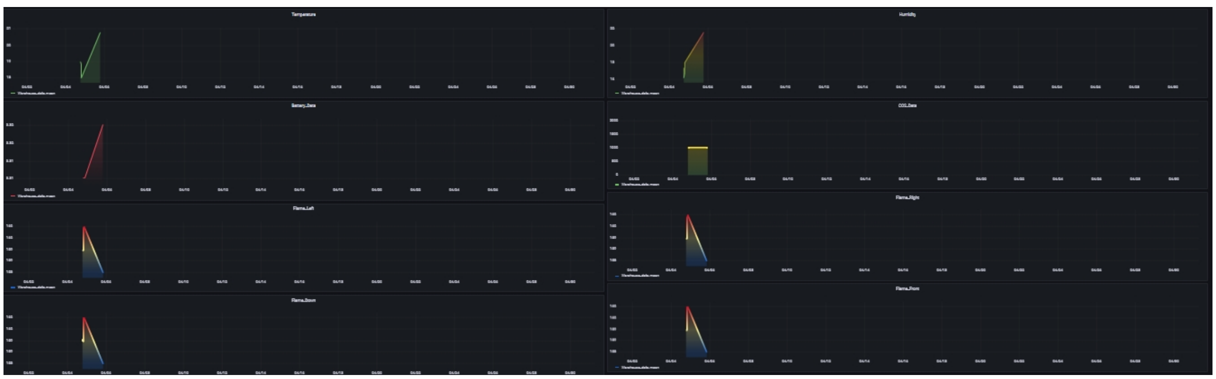


Figure 6.3: Grafana Result.

### 6.1.4 Supervision Module

The Supervision Module with microcontroller and sensors, all soldered to the PCB board, gathered all in a plastic enclosure made with 3D printing method, designed in Solidworks CAD, that makes up the data acquisition stage of the system. In this case, only one module is built for the test; otherwise, depending on the warehouse space area, N number of modules can be built; all that is required is to change the TTN server parameters from one module to the next, and the rest of the procedures remain the same.

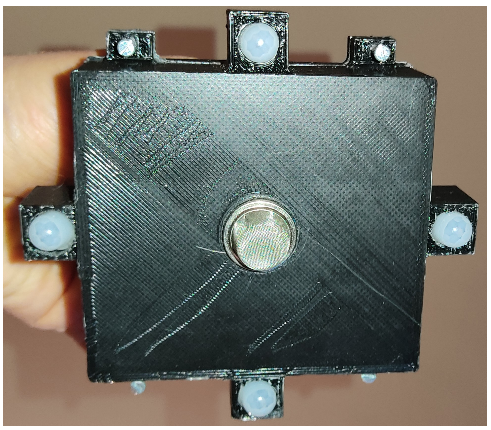


Figure 6.4: Supervising Module Enclosure.

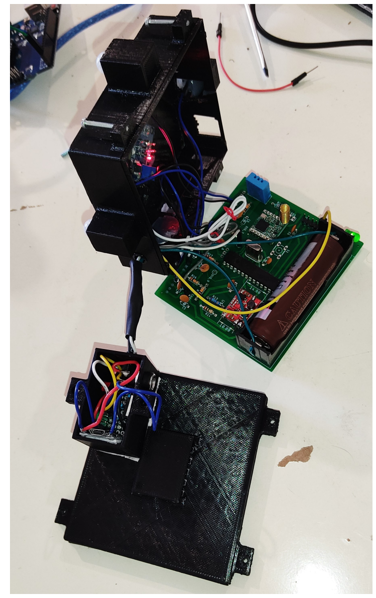


Figure 6.5: Supervising Module Enclosure Full View.

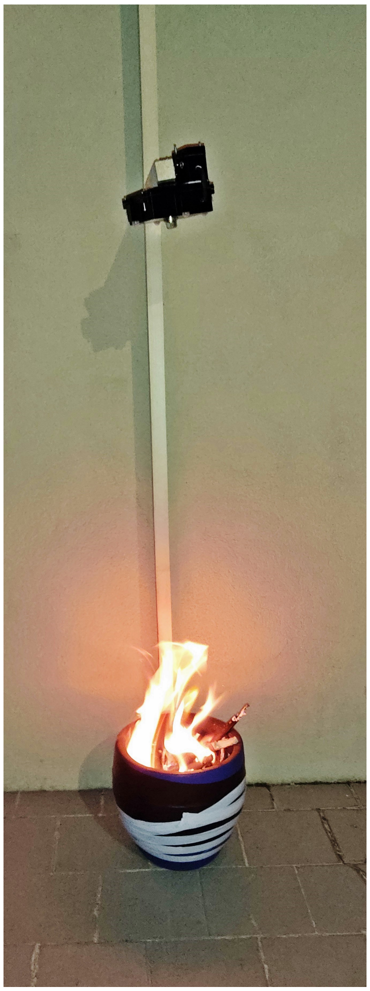
Figure 6.4 is the Supervising Module Enclosure and Figure 6.5 Enclosure Full View.

## 6.2 Final Results

The results of the developed module's acquisition, transmission, and recording will be presented in this section. The behavior of flame sensors and gas sensors in relation to distance will be discussed first. The gas sensor has a fast response and high sensitivity due to its composition, which is a small heater inside with an electrochemical sensor, and the flame sensor is based on a 940 nm flame detection diode that can be used to detect fire sources and infrared.

### 6.2.1 Supervision Module Assay

Some lab tests in a controlled environment are required before placing the supervision module prototype in warehouses. Laboratory tests are required to ensure that prototypes can collect and send data over long distances. This eliminates the risk of communication breakdowns and false alarms. Figure 6.6a and Figure 6.6b depicts a scenario in which a 1 meter wood stick was hooked with a pottery vessel containing the fire ignition, and the module was fixed above the pottery vessel container, initially positioned at 1000 mm for about 8 minutes. The module was then moved 500 mm closer to the pottery vessel for 11 minutes after the first period.



(a) Fire Simulation Front View.

(b) Fire Simulation Side View.

### 6.2.2 Real-Time Monitoring

The real-time monitoring implementation is done in Grafana with a new database to store the resulting prediction values from the modules. Figure 6.7 depicts real-time monitoring for one week, from 18/05/2022 to 24/05/2022, including all of the exception data that will be discussed in the next section. Both the module environment and the battery voltage affect the measured parameters.


Figure 6.7: 7 Days Data Logging.

### 6.2.3 Normal Condition Behavior

The first step is to analyze the normal conditions of warehouse monitoring, which includes all sensor data collected when there is no fire ignition or gas distribution, and the battery voltage level is in the safe range (4.2 V > Battery > 3.3 V), as shown in the Figure 6.8.

Figure 6.8: Normal Condition Behavior.

The charging and discharging processes of the battery are shown in Figure 6.9. This means that the charge box is working properly, and the condition set for Charge Enable is also working. To ensure the battery's safety and that the microcontroller reads the battery's actual values, the code includes several threshold conditions that check this information, and they are all in perfect working order and as it can be seen, that the maximum and minimum voltages are in the range of the 18650 lithium battery safety range ( Max= 4.07V and the Min=3.64V).

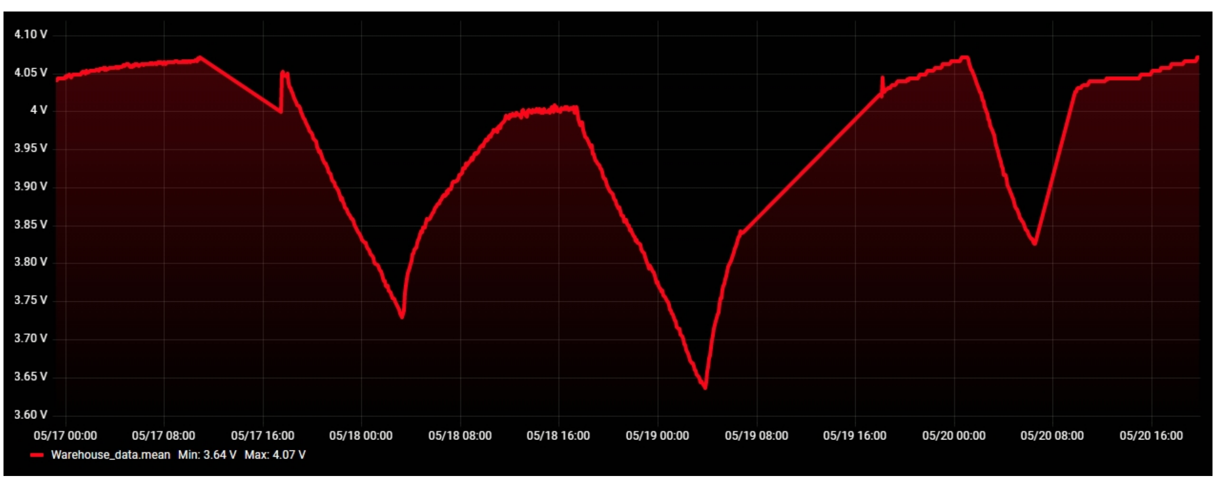


Figure 6.9: Battery Behavior in Normal Conditions.

A temperature and humidity test was performed to verify the sensor data behavior during the prototyping phase in order to simulate the internal meteorological conditions inside the warehouse. As it can be seen in the Figure 6.10, the temperature inside the lab varies between 19.8°C and 24°C as maximum values in normal conditions, and the humidity values vary between 44%H and 63%H in the same conditions as the temperature, proving that the temperature and humidity gathered from the sensor are in the safe range for maintaining the quality of the wood. The simulation period was done from 2022-05-16 21:59:17 to 2022-05-22 03:11:27 which means a simulation for six days during the day and the night. As expected the temperature and humidity levels increases during the day and decrease in the night period.


Figure 6.10: Temperature and Humidity Behaviors in Normal Conditions.

Due to their very sensitive phototransistor behavior to light, the flame sensors give values between 1023 and 1019 when there is no fire ignition, so the values will not remain stable during the simulation process while there is a brilliant light around, as in the lab simulation.


Figure 6.11: Flame Sensors Behavior in Normal Conditions.

In normal conditions, and while there is no gas distribution, the gas sensor values range between 133 and 216 ppm; however, this variation in data is due to some air pollution in the lab, and the reason is that the heater inside the sensor is extremely sensitive to any type of gas.


Figure 6.12: CO2 Behaviors in Normal Conditions.

The Figure 6.11 the values of the flame sensors which are combined in a single graph with the Max and Min values of each sensor, as well as, the Figure 6.12 illustrate the behavior of the gas sensor (CO2) in normal conditions, with Max and Min values.

### 6.2.4 Low Battery Condition

The supervision module in this project uses an 18650 lithium battery, and a charger box is connected to it to ensure that the charging process continues when the battery voltage falls below 3.5V and stops when the battery voltage rises above 4.1V. As a result, the charger box must be connected to an external 5V charger to keep the charging process going, and a power line must be present in the warehouse.

The behavior of the supervision module will be demonstrated in this section when there is no power line and the battery is discharged until it reaches 1.13V.

The figure 6.13 shows that if this condition occurs, spikes in readings will appear in the graphs of the sensors, including the flame, gas, humidity and temperature sensors. The values for the flame sensors will drop from 1023 to 0, for the gas sensor, the value will increase from an average of 180 ppm to 800 ppm and higher, for the temperature, the value will increase from an average of 20°C to 180°C and higher, and finally, the humidity sensor value will drop from an average of 35%RH to 2%RH. As a result, the battery voltage should be lowered to a maximum of 3.2V to ensure that the reading of the sensor values remains.

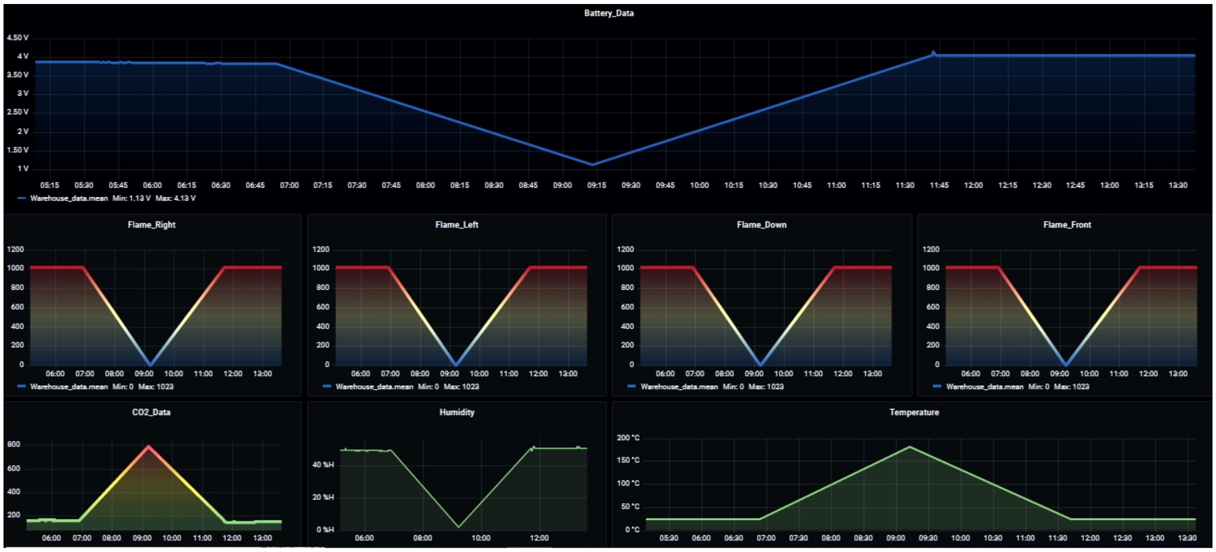



Figure 6.13: Sensors Reading Spikes.

### 6.2.5 Flame Detection Simulation

A simulation of fire detection using the various sensors of the supervision module is performed in this section. The different simulation results obtained representing the ranges of flame sensor, gas sensor, humidity sensor, and temperature sensor when a fire occurred are presented after creating the project to be simulated. In the industrial field, this detection philosophy is critical for the safety of personnel and equipment. As a result, the created solution has been successful in developing this safety philosophy.

#### Flame Sensors

It was possible to detect the presence of fire at about 1000 mm to 400 mm by simulating warehouse fire ignition in the lab with a pottery vessel. It's also important to note that the differences in the flame sensors' values could have been caused by their range of vision, as each one had a radial view range of 90 degrees when mounted in the module box. As a result, the orientation in which they were fixed could have influenced the infrared radiation spectra acquisition. The solution that will be used on the prototype is to use Fresnel lenses to adjust the sensors' radial view.In short, the real-flame simulation only demonstrated that the sensors could detect a small flame and provide data in the correct manner. The fire simulation was made for 30 minutes successively, from 2022-05-23 21:17:30 to 2022-05-23 21:47:48 which prove that the data behavior is very sensitive to fire ignition presence.

The Figure 6.14 shows that for each flame sensor there is a variation of values from 1001 to 1023, moreover, in the presence of fire, the value of the first flame sensor (FlameDown) decreases from 1023 to 1009, for the second sensor (FlameFront), the value drops from 1023 to 1001, the value of the third flame sensor (FlameRight) falls from 1023 to 1002, and the value of the last flame sensor (FlameLeft) value breakdown from 1023 to 1007, so depending on the degree of installation of the sensor in the module box, the value will react to the ignition of the fire.


Figure 6.14: Flame Sensors Fire Simulation Graph.

### Gas Sensor

The presence of a fire was confirmed by data from the flame detectors, and as a result of this fire, there was a massive release of smoke into the air, as shown in the Figure 6.15, the gas sensor recorded a variation in values when the fire occurred. The data was recorded in in the time range between 2022-05-23 21:17:30 and 2022-05-23 21:47:48 which prove that the sensor sensitivity is very high, thus, the simulation of the smoke was successful.


Figure 6.15: Gas Sensor Fire Simulation Graph.

### Humidity and Temperature Sensor

As was expected, the variation of the humidity and temperature data rises progressively during the fire ignition simulation which comes to noticeable data changing with insignificant delay comparing to the other sensors.The simulation was made from 2022-05-23 21:17:30 to 2022-05-23 21:47:48. The Figure show the variation of the humidity and temperature values from 18°C to 29°C for the temperature and from 27%RH to 51%RH for the humidity in the fire simulation.


Figure 6.16: Temperature and Humidity Sensor Fire Simulation Graph.

#### Battery Data

The Figure 6.17 show that there is no appliance from the fire ignition simulation on the battery data, moreover, the energy consumed by the sensors remains stable comparing to the behavior of the normal condition simulation. The frequency with which the transmission rate is set is a factor in the battery's energy discharge. However, due to the TTN server's transmission policies, it is not possible to select any transmission rate. In the case of data transmission, the values were collected with a transmission rate of 60 seconds to intensify the battery discharge and without the use of sleep mode.

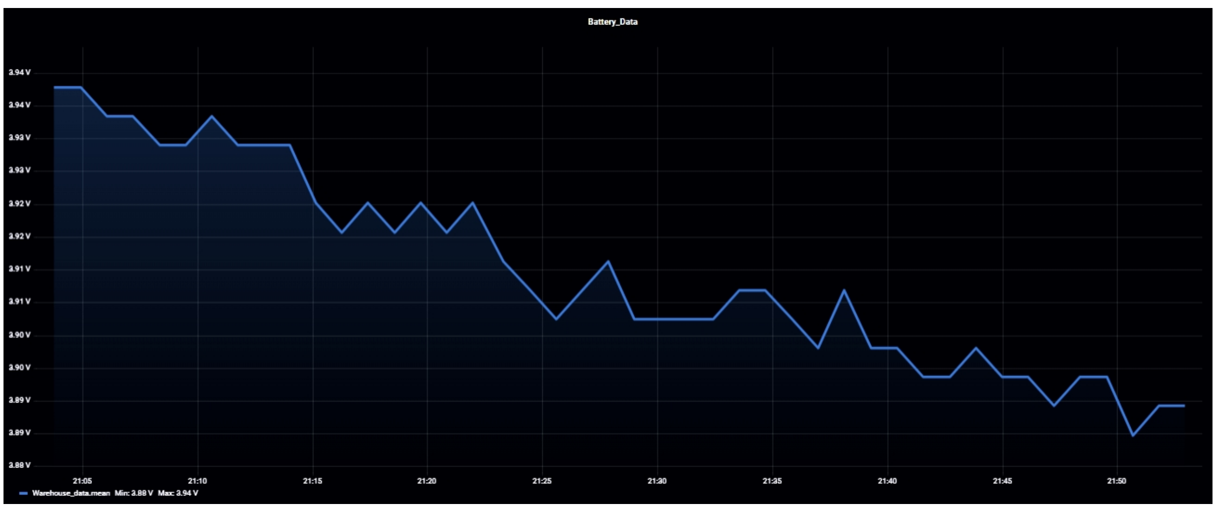



Figure 6.17: Battery Data Fire Simulation Graph.

### 6.2.6 Data Correlation

In order to prove the consistency of the data collected from the sensors, a correlation study is performed for this purpose. Correlation is a statistical term that describes how closely two variables are related.

The Figure 6.18 shows the correlation matrix of all sensor values made with Matlab software.

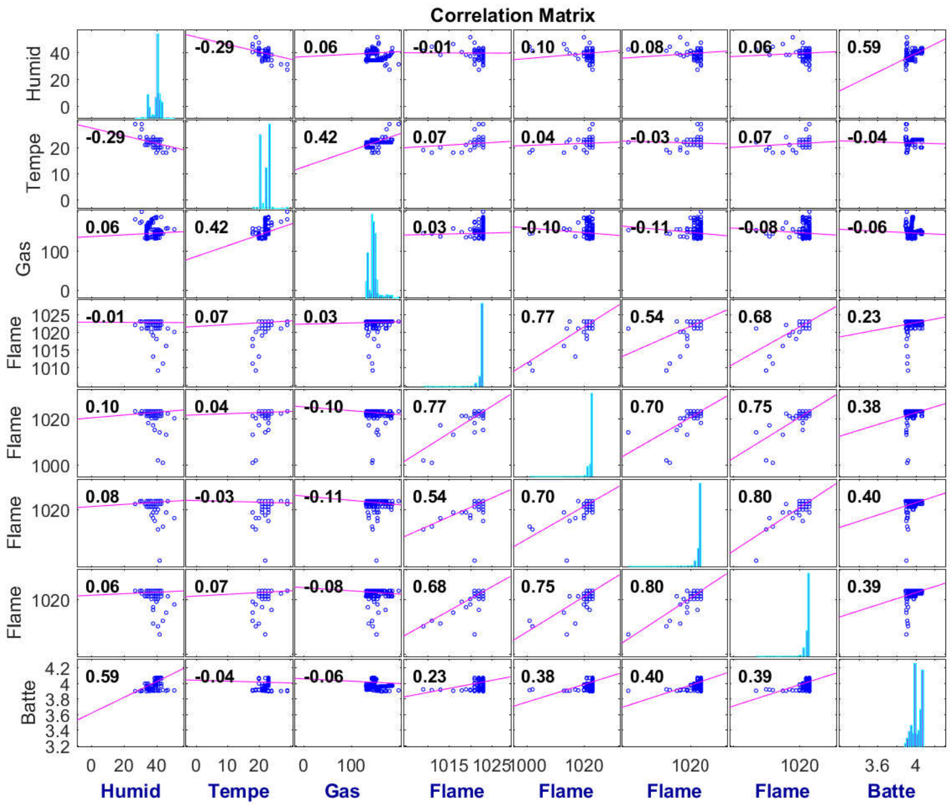



Figure 6.18: Sensors Correlation Matrix.

Referring to the Eyad Al-Samman thesis [48], a correlation coefficient table (Figure 6.19) will be used for the evaluation of the correlation matrix of this project.

| Correlation Coefficient (r) Value | Indication |
|---|---|
| Between ± 0.8 to ± 1.0 | High correlation |
| Between ± 0.6 to ± 0.79 | Moderately high correlation |
| Between ± 0.4 to ± 0.59 | Moderate correlation |
| Between ± 0.2 to ± 0.39 | Low correlation |
| Between ± 0.1 to ± 0.19 | Negligible correlation |

Figure 6.19: Correlation Coefficient Table [48].

### Flame Sensors Correlation

In this section, the flame sensors values will be evaluated comparing to the other sensors, first, the correlation coefficient between the four flame sensors ranges between 0.54 as minimum to 0.80 as maximum, means that, 0.67 in average, thus, the average coefficient prove that the consistency between the flame sensors is moderately high correlation as mentioned in the correlation coefficient table, resulting that the flame sensors are very sensitive to fire ignition, and works in perfect condition.

### Flame Sensors Correlation to Gas Sensor

The correlation coefficient between the four flame sensors and the gas sensor ranges between -0.08 as minimum to 0.03 as maximum means that, 0.055 in average, thus, the average coefficient prove that the consistency between the flame sensors and the gas sensor is negligible correlation as mentioned in the correlation coefficient table, this result is very low due to the values difference between the flame sensors and the gas sensor values (the max value of the flame sensors is 1023 and the max value of the gas sensor is 180), but this does not prove that the gas sensor is not working like it should, on the contrary, the correlation in this case prove that there's linearity between the two type of sensors (-0.11 in the matrix), means, that when a fire ignition occurs, the two types of sensors react to that event, as a conclusion, the two types of sensors works in perfect condition when a fire ignition occurs.

### Flame Sensors Correlation to Humidity and Temperature

The correlation coefficient between the four flame sensors and the humidity and temperature sensor ranges between -0.01 as minimum to 0.10 as maximum for the humidity and -0.03 as minimum to 0.07 as maximum for the temperature means that, 0.055 average for the humidity and 0.05 average for the temperature, thus, the averages coefficients prove that the consistency between the flame sensors and the humidity and temperature sensor is negligible correlation as mentioned in the correlation coefficient table, this result is very low due to the values difference between the flame sensors and the humidity and temperature sensor values,means that when a fire starts, the two types of sensors react to it, and as a result, the two types of sensors are in perfect working order when a fire starts.

#### Humidity Sensor Correlation to Temperature Sensor

The correlation coefficient between the humidity sensor and the temperature sensor is -0.29, thus, the coefficient prove that the consistency between the humidity sensor and the temperature sensor is low correlation as mentioned in the correlation coefficient table, this result is very low due to the reflections that occur when sensing between the day and night, moreover, in the day the temperature rises while the humidity decreases and verse versa, as a conclusion, the temperature and humidity sensor prove that he is precise in the data reading while there's difference between the day and night values.

#### Gas Sensor Correlation to Humidity and Temperature Sensor

As shown in the correlation coefficient table, the correlation coefficient between the gas sensor and the humidity and temperature sensors is 0.06 for humidity and 0.42 for temperature. Thus, the coefficients show that the consistency between the gas sensor and the humidity sensor is negligible correlation and between the gas sensor and the temperature sensor is moderate correlation. As can be seen, the correlation between the gas sensor and temperature is relatively high, because when the gas sensor value rises, the temperature value rises as well; however, the correlation value between the gas sensor and humidity values is relatively low, because when the gas sensor value rises, the humidity value falls.

# Chapter 7

# General Conclusion

The issue of supervising warehouses in remote locations was addressed in this work, where dynamic data management is required for optimal data analysis. As a result, a monitoring system was developed that combines real-time access to information, accurate data gathering systems, and long-distance data communication via the LoRa communication protocol to reduce the alert time of warehouse fires ignitions.

This project will contribute to actual surveillance systems, providing more details and real-time information to firefighters and civil protection. The acquisition and communication modules that will be spread throughout the warehouses will serve as the project's base, gathering information about a variety of relevant data for efficient characterization of existing warehouse conditions.

This work provides a wireless sensor network approach based on four types of sensor modules. These sensor modules collaborate in order to extract various types of data from the warehouse. The proposed and developed modules perform as expected in terms of data acquisition, transmission, and recording, according to preliminary tests. This data can be used in the future with artificial intelligence, pattern recognition, and cluster algorithms to provide alerts and predictions for fire ignitions. As a next step, this algorithm will be optimized using a genetic algorithm to determine the number of sensor modules and their optimal location in order to ensure that the maximum warehouse area is under surveillance. The enhancement of previously developed modules with industrial-grade components and waterproof enclosure can also be point to be addressed.

Finally, in the point of view of the author, this work has revealed a first step into the world of IoT using a comprehensive approach that combines data acquisition, electronics, embedded systems, and communication protocols, as well as internet of things security systems.

## 7.1 Future works

Several points can be identified based on the work presented that can be used to support future research. The following topics can be used to find out about future research projects:

- Replace the sensors used in this project with more precise industrial sensors to better guarantee the accuracy of data reading
- Developpe a new pcb board containing all the components that were used in this project after the simulation, as well as, design a new encloser for the pcb board that can endure the conditions in case of fire ignition.
- Implement a control system that controls fans inside the warehouse in case of high humidity or temperature, as well as adding a water mist system in case of fire.

# Bibliography


[1] R. B. Campbell, *Structure fires in warehouse properties*. National Fire Protection Association. Fire Analysis and Research Division, 2016.

[2] K. Lopienski, *What is warehousing? shipbob's guide to warehousing solutions and logistics*, https://www.shipbob.com/blog/warehousing/.

[3] bradley johnson, *What is warehouse?: Warehouse concepts*, https://www.bluecart.com/blog/what-is-warehouse.

[4] J. L. Systems, *6 different types of warehouses*, https://www.gojarrett.com/blog/6-different-types-of-warehouses.

[5] *Akcp remote sensor monitoring | data center monitoring*, https://www.akcp.com/blog/how-to-monitor-warehouse-temperature-and-humidity/.

[6] Aranet, *How to monitor warehouse humidity and temperature effectively*, https://aranet.com/monitor-warehouse-humidity-effectively/.

[7] B. B. School, *Environmental impact of warehousing: A scenario analysis for the united states*, https://openaccess.city.ac.uk/id/eprint/17118/.

[8] *Consequences of fire damage in warehouses*, https://www.restorationsos.com/education/commercial/fire-damage-in-warehouses/consequences-of-fire-damage-in-warehouses.asp.

[9] *O que é a internet das coisas (iot)?*, https://www.tibco.com/sites/tibco/files/media_entity/2020-05/IoT.png.

[10] *What is industrial iot (iiot)*, `https://www.splunk.com/en_us/data-insider/what-is-industrial-iot.html/`, author = Splunk, year=2021, month=December.

[11] *What is the difference between iot and iiot?*, `https://optiware.com/blog/what-is-the-difference-between-iot-and-iiot/`, author = DK-2600 Glostrup, year=2018.

[12] *Iiot vs. iot: What is the difference?*, `https://www.omega.nl/technical-learning/iiot-vs-iot.html`, author = OMEGA Engineering, year=2003-2022.

[13] I. Froiz-Mıguez, T. M. Fernández-Caramés, P. Fraga-Lamas, and L. Castedo, "Design, implementation and practical evaluation of an iot home automation system for fog computing applications based on mqtt and zigbee-wifi sensor nodes", *Sensors*, vol. 18, no. 8, p. 2660, 2018.

[14] *Lora technology*, `https://www.saftbatteries.com/sites/saftbatteries.com/files/public/wireless_iot_communicationtechnologies.jpg`.

[15] *Lora - lorawan and internet of things*, `https://www.univ-smb.fr/lorawan/en/book-lora-lorawan-and-internet-of-things-2/`, author = Ms Donna Moore,

[16] A. Lavric and V. Popa, "A lorawan: Long range wide area networks study", in *2017 International Conference on Electromechanical and Power Systems (SIELMEN)*, IEEE, 2017, pp. 417–420.

[17] *Lora technology*, `https://alphamicroppe.com/lora-technology`,

[18] V. Fialho, "Integer n synthesizer design for lora transceivers", *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 10, no. 10, pp. 101–106, 2021.

[19] H. Mroue, A. Nasser, S. Hamrioui, B. Parrein, E. Motta-Cruz, and G. Rouyer, "Mac layer-based evaluation of iot technologies: Lora, sigfox and nb-iot", in *2018 IEEE Middle East and North Africa Communications Conference (MENACOMM)*, IEEE, 2018, pp. 1–5.

[20] B. Dunlop, H. H. Nguyen, R. Barton, and J. Henry, "Interference analysis for lora chirp spread spectrum signals", in *2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*, IEEE, 2019, pp. 1–5.

[21] L. Vangelista, "Frequency shift chirp modulation: The lora modulation", *IEEE Signal Processing Letters*, vol. 24, no. 12, pp. 1818–1821, 2017. DOI: 10.1109/LSP.2017.2762960.

[22] *Lora: Symbol generation*, http://www.sghoslya.com/p/lora-is-chirp-spread-spectrum.html,

[23] D. M. Ibrahim, "Internet of things technology based on lorawan revolution", in *2019 10th International Conference on Information and Communication Systems (ICICS)*, 2019, pp. 234–237. DOI: 10.1109/IACS.2019.8809176.

[24] N. Matni, J. Moraes, H. Oliveira, D. Rosário, and E. Cerqueira, "Lorawan gateway placement model for dynamic internet of things scenarios", *Sensors*, vol. 20, no. 15, 2020, ISSN: 1424-8220. DOI: 10.3390/s20154336. [Online]. Available: https://www.mdpi.com/1424-8220/20/15/4336.

[25] J. H. Huh, D.-H. Kim, and J.-D. Kim, "Proposal of seamless communication method in shadow area using lorawan", 2017.

[26] E. Aras, G. S. Ramachandran, P. Lawrence, and D. Hughes, "Exploring the security vulnerabilities of lora", in *2017 3rd IEEE International Conference on Cybernetics (CYBCONF)*, 2017, pp. 1–6. DOI: 10.1109/CYBConf.2017.7985777.

[27] X. Fan, X. Liang, Q. Liu, K. Yang, and H. Chen, "A consistent address allocation algorithm mitigating address conflict for large-scale lora-enabled iot networks", in *2020 IEEE 23rd International Conference on Computational Science and Engineering (CSE)*, 2020, pp. 8–15. DOI: 10.1109/CSE50738.2020.00009.

[28] S. Devalal and A. Karthikeyan, "Lora technology - an overview", in *2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, 2018, pp. 284–290. DOI: 10.1109/ICECA.2018.8474715.

[29] Y. Li, J. Yang, and J. Wang, “Dylora: Towards energy efficient dynamic lora transmission control”, in *IEEE INFOCOM 2020 - IEEE Conference on Computer Communications*, 2020, pp. 2312–2320. DOI: 10.1109/INFOCOM41043.2020.9155407.

[30] A. Lavric and A.-I. Petrariu, “Lorawan communication protocol: The new era of iot”, *2018 International Conference on Development and Application Systems (DAS)*, pp. 74–77, 2018.

[31] H. Noura, T. Hatoum, O. Salman, J.-P. Yaacoub, and A. Chehab, “Lorawan security survey: Issues, threats and possible mitigation techniques”, *Internet of Things*, vol. 12, p. 100 303, 2020, ISSN: 2542-6605. DOI: https://doi.org/10.1016/j.iot.2020.100303. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2542660520301359.

[32] C. Khamsaeng and S. Mongkolluksamee, “Providing an end-to-end privacy preservation over lora wanplatforms”, in *2020 - 5th International Conference on Information Technology (InCIT)*, 2020, pp. 56–60. DOI: 10.1109/InCIT50588.2020.9310934.

[33] T. Brito, A. I. Pereira, J. Lima, and A. Valente, “Wireless sensor network for ignitions detection: An iot approach”, *Electronics*, vol. 9, no. 6, p. 893, 2020.

[34] *Mq135ds*, https://www.olimex.com/Products/Components/Sensors/Gas/SNS-MQ135/resources/SNS-MQ135.pdf,

[35] *Mq135*, https://www.rhydolabz.com/images/body_images/SEN2061_img2.jpg,

[36] https://aws1.discourse-cdn.com/arduino/original/4X/8/a/6/8a657c2bbf18e44ca01bd6775b
jpeg,

[37] *What is openvpn and is it suitable for you?*, https://www.thethingsindustries.com/docs/getting-started/ttn/,

[38] https://www.thethingsindustries.com/docs/img/TTS-logo.svg,

[39] N. Havard, S. McGrath, C. Flanagan, and C. MacNamee, “Smart building based on internet of things technology”, in *2018 12th International Conference on Sensing Technology (ICST)*, 2018, pp. 278–281. DOI: 10.1109/ICSensT.2018.8603575.

[40] https://raw.githubusercontent.com/diglopes/node-red-contrib-resolv-risk/master/docs/node-red-logo.png,

[41] N. Naik, "Choice of effective messaging protocols for iot systems: Mqtt, coap, amqp and http", in *2017 IEEE International Systems Engineering Symposium (ISSE)*, 2017, pp. 1–7. DOI: 10.1109/SysEng.2017.8088251.

[42] S. N. Z. Naqvi, S. Yfantidou, and E. Zimányi, "Time series databases and influxdb", *Studienarbeit, Université Libre de Bruxelles*, vol. 12, 2017.

[43] https://serverdo.in/wp-content/uploads/2020/04/Influxdb_logo.svg.png,

[44] *Dashboard anything. observe everything*, https://grafana.com/grafana/,

[45] https://www.influxdata.com/wp-content/uploads/Grafana-logo-2.png,

[46] *Structure fires in warehouse properties*, https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Building-and-life-safety/oswarehouse.pdf,

[47] T. Brito, M. Zorawski, J. Mendes, B. F. Azevedo, A. I. Pereira, J. Lima, and P. Costa, "Optimizing data transmission in a wireless sensor network based on lorawan protocol", in *International Conference on Optimization, Learning Algorithms and Applications*, Springer, 2021, pp. 281–293.

[48] E. Al-Samman, *The influence of transparency on the leaders' behaviors: A study among the leaders of the ministry of finance, yemen*, Apr. 2012.

# Appendix A

# Warehouse Box Top Cover

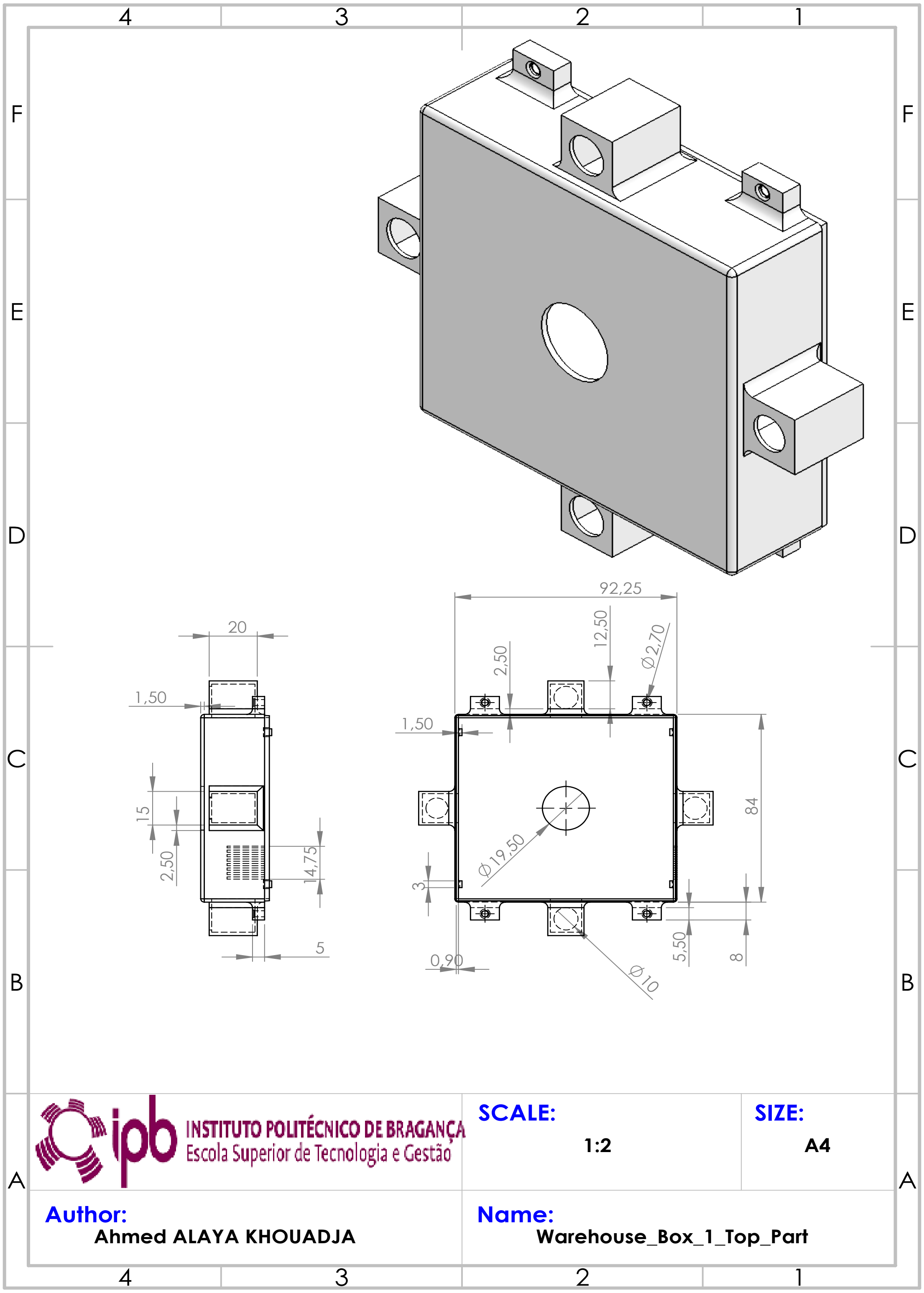



Figure A.1: Warehouse Box Top Part

# Appendix B

# Warehouse Box Bottom Cover

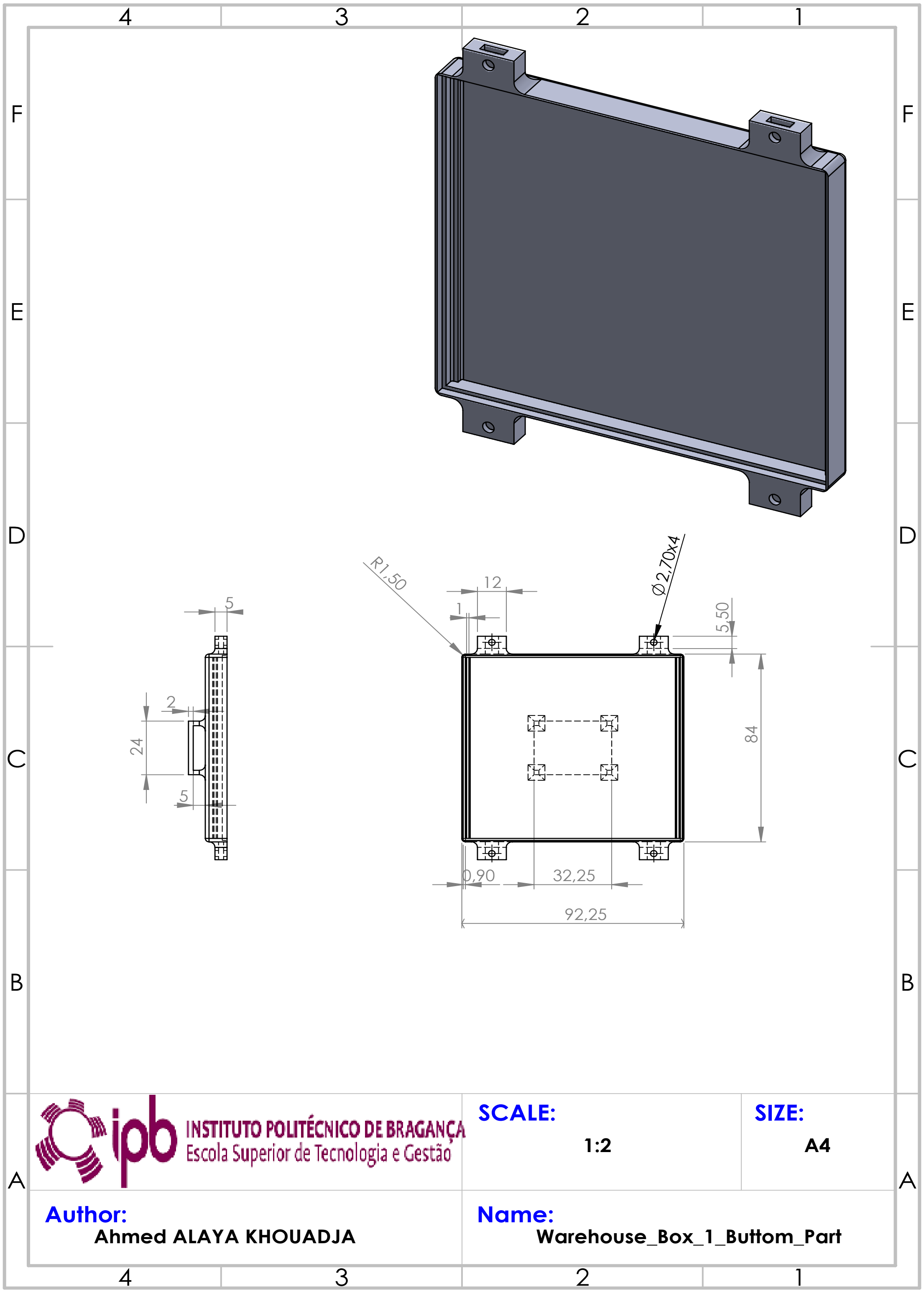



Figure B.1: Warehouse Box Bottom Cover

# Appendix C

# Charger Box Top Cover

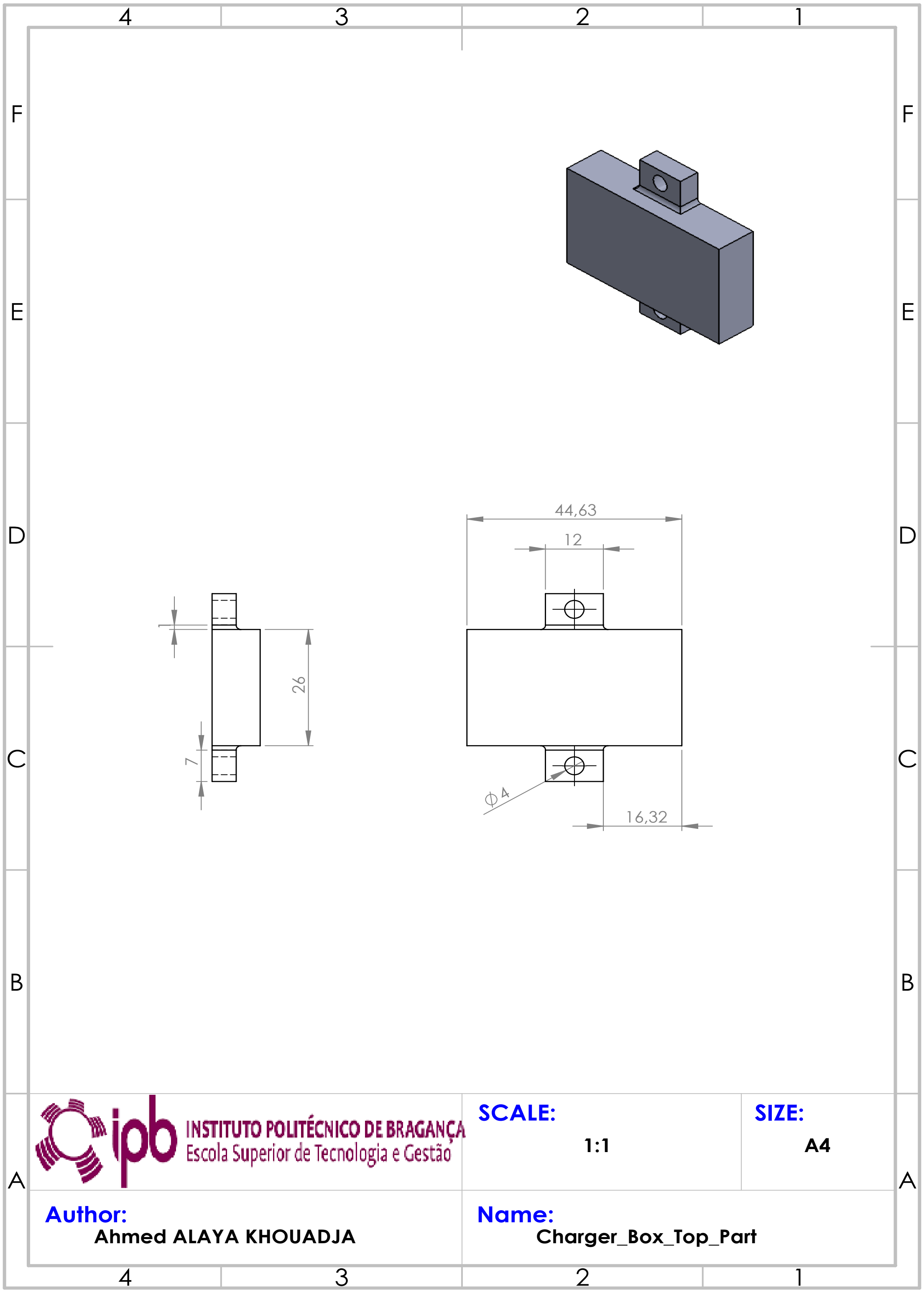



Figure C.1: Charger Box Top Cover

# Appendix D

# Charger Box Bottom Cover

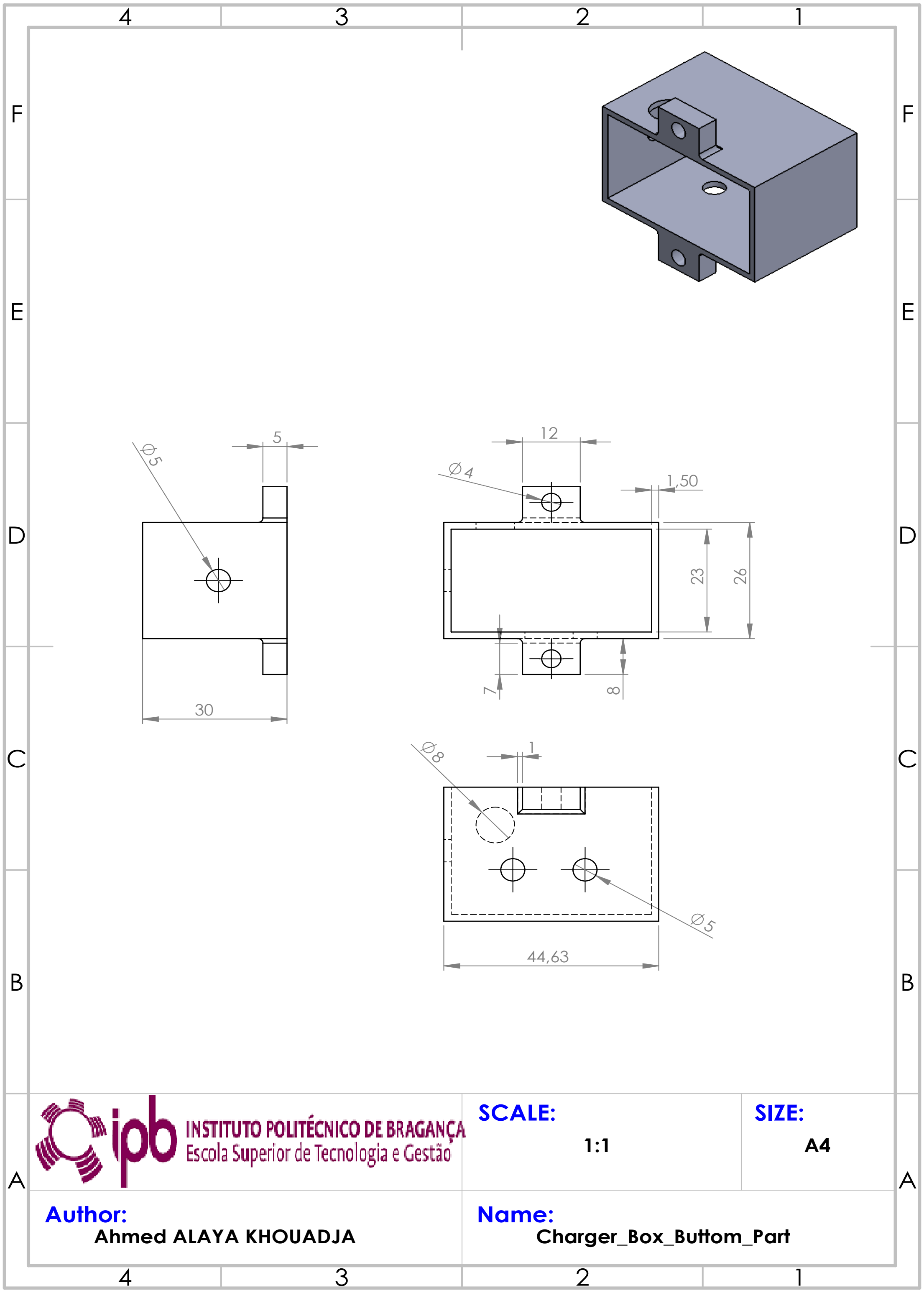



Figure D.1: Charger Box Bottom Cover