ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA
(ICAI)

Grado en Ingeniería en Tecnologías Industriales

Development of Low-Cost IoT-Based Crop Monitoring system using LoRa and Wireless Sensor Networks

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Madrid
July 2023

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título Development of Low-Cost IoT-Based Crop Monitoring system using LoRa and Wireless Sensor Networks en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el curso académico 2022-23 es de mi autoría, original e inédito y no ha sido presentado con anterioridad a otros efectos. El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido tomada de otros documentos está debidamente referenciada.

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DESARROLLO DE UN SISTEMA DE SEGUIMIENTO DE CULTIVOS BASADO EN IoT EMPLEANDO LoRa Y REDES DE SENSORES INALÁMBRICOS

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RESUMEN DEL PROYECTO

1. Introducción

Las tecnologías actuales han permitido mejorar la calidad de vida de las personas. Por ejemplo, los teléfonos móviles se han convertido en un dispositivo esencial en nuestro día a día, estos nos permiten estar comunicados permanentemente. Estos ofrecen aplicaciones que han contribuido a nuestro bien estar y ya forman parte de nuestro día a día. Entre estas aplicaciones se pueden encontrar aplicaciones útiles que a partir de unos parámetros medidos pueden sacar conclusiones y predicciones relacionadas con el objeto de estudio.

En este proyecto se desarrolla un sistema de seguimiento de cultivos basado en la tecnología Internet of Things (IoT). IoT es la tecnología que permite conectar dispositivos u objetos cotidianos a un servidor a través de protocolos de redes IoT. Concretamente en este proyecto se miden, con sensores, variables relacionadas con el mantenimiento de cultivos y son transmitidas a una página web, de forma que el usuario pueda acceder a dicha información desde sus dispositivos privados. Las varibles medidas corresponden a temperatura del aire, humedad del aire y humedad del suelo. Con esta información recogida en la página web los agricultores (usuarios) podrán tomar decisiones relacionadas con el mantenimiento de los cultivos en base a esos datos, así como hacer predicciones y mejorar procesos actuales.

Este proyecto pretende combinar la agricultura tradicional con las nuevas tecnologías para alcanzar una agricultura más eficiente. Se considera que este proyecto contribuye a algunos de los Objetivos de Desarrollo Sostenible. Especialmente al objetivo “Industria, Innovación e Infraestructura”, la combinación de la agricultura tradicional con la tecnología permite implementar las tecnologías, de forma más consolidada, en áreas rurales donde la conectividad e infraestructura tienden a ser reducidas. Se considera también que este proyecto puede contribuir al objetivo “Producción y Consumo Responsables”, ya que en base a la información recogida en la página web o aplicación, los agricultores pueden tomar decisiones más eficientes relacionadas con el consumo de recursos como el agua o evitar productos dañinos para el ecosistema como fertilizantes o pesticidas.

2. Metodología

Para llevar a cabo este proyecto IoT la estructura empleada está formada por nudos. Se consideran nudos al conjunto de dispositivos conectados físicamente y que cumplen una o varias funciones. En este proyecto se trabajarán con dos tipos de nudos, nudos que envían los datos medidos por los sensores (sender nodes) y el nudo receptor o Gateway que recibe dichos datos.

Los "sender nodes" se colocarán en distintos puntos estratégicos del campo de cultivos, el número de "sender nodes" no es limitado, se pueden implementar los que sean necesarios, aunque supone un coste mayor. Mientras que sólo se implementará un nodo receptor que se ubicará en casa del agricultor. Esto implica que las distancia entre los "sender nodes" y el nodo receptor es considerable, por lo que para transmitir los datos de un nodo al otro es necesario emplear un protocolo de redes que sea capaz de transmitir datos a larga distancia. Para ello se emplea el protocolo de redes LoRa (Long Range) que se caracteriza por poseer un largo alcance entre 10 y 20 km. La frecuencia de transmisión de datos empleada por este protocolo es 868 MHz, adecuada en Europa.

El hardware de cada "sender node" está formado por un microcontrolador conocido como ESP32. A este dispositivo electrónico, se le conectan los dos sensores del sistema, una antena específica para recibir o transmitir datos a través de LoRa y una batería de litio que carga el módulo ESP32. El primer sensor empleado corresponde con sensor DHT22, se trata de un sensor digital que mide la temperatura y humedad del aire del lugar donde está ubicado. El segundo sensor mide la humedad del suelo.

En cuanto al hardware del nodo receptor o Gateway, está formado por un miniordenador conocido como Raspberry Pi. La Raspberry Pi no permite recibir o transmitir información a través del protocolo LoRa, por lo que es necesario añadir una extensión que permita recibir datos a través de LoRa. Para ello se ha conectado a través de un cable USB un dispositivo ESP32 a la Raspberry Pi. Los datos recibidos via LoRa serán recogidos por el módulo ESP32 y a continuación serán transmitidos a la Raspberry Pi a través de Serial.

El software desarrollado para los "sender nodes" se encarga de tres aspectos. Primero lee los datos medidos por los sensores, a continuación crea un formato Standard conocido como JSON (JavaScript Object Notation) que agrupa los datos medidos por el "sender node" junto con su propio identificador y finalmente envía este documento JSON a través de LoRa al nodo receptor.

En cuanto a los software que se llevan a cabo en la Gateway del sistema, el dispositivo ESP32 se encarga de recibir los documentos JSON de los distintos "sender nodes" y los imprime en el monitor Serial.
En cuanto al programa de Python ejecutado en la Raspberry Pi, este cumple las siguientes tres tareas. En primer lugar lee los documentos JSON recibidos a través de Serial. A continuación almacenar los datos contenidos en el documento JSON junto con la fecha y hora en una base de datos de tipo PostgreSQL en la Raspberry Pi. Y por último transmite a través de Wi-Fi (HTTP) los datos a una plataforma web, en este caso se emplea la plataforma web Ubidots que permite mostrar datos de variables en tiempo real tomados por sensores.

En la siguiente Figura 1, se muestran las diferentes partes que componen el sistema de este proyecto.

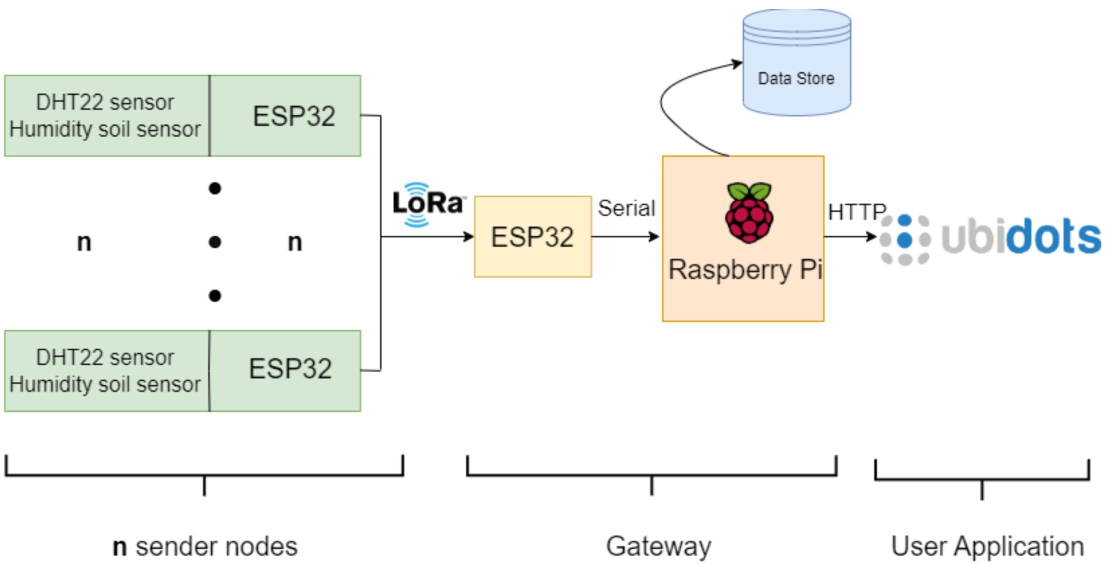

Figure 1: Diagrama componentes del proyecto

3. Resultados

Por motivos razonables en vez de implementar este proyecto en campos de cultivos, se va a implementar en un invernadero de la Universidad. Dado que el invernadero está compuesto por dos estantes, se han desarrollado únicamente dos “sender nodes”, uno para cada estante.

Los resultados finales obtenidos se observan accediendo a la cuenta de la aplicación de Ubidots. Desde la aplicación se pueden observar que se actualizan los datos de las variables medidas cada minuto. Este margen de tiempo se estableció en el código correspondiente a los “sender nodes”, este valor puede ser cambiado.

En la Figura 2 se muestra una captura de pantalla de la página web donde se pueden visualizar en tiempo real las variables medidas por ambos "sender nodes".

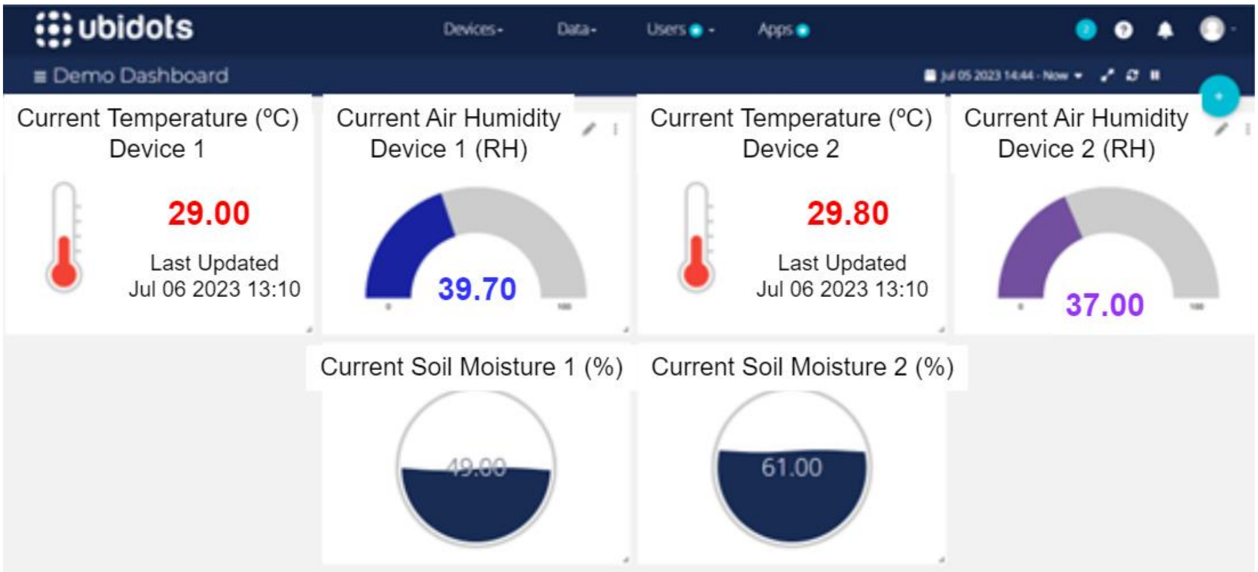

Figure 2: Captura página web Ubidots valores en tiempo real

Además la aplicación Ubidots, permite crear gráficas con la evolución en el tiempo de las variables medidas. Se pueden mostrar los datos recogidos durante una hora, un día entero o durante un mes por ejemplo.

La Figura 3 muestra la temperatura del “sender node” número 2 recogida en un periodo de dos horas. En este caso al tratarse de un periodo de dos horas, los valores de temperatura no fluctúan y se mantienen entorno al mismo (28ºC).

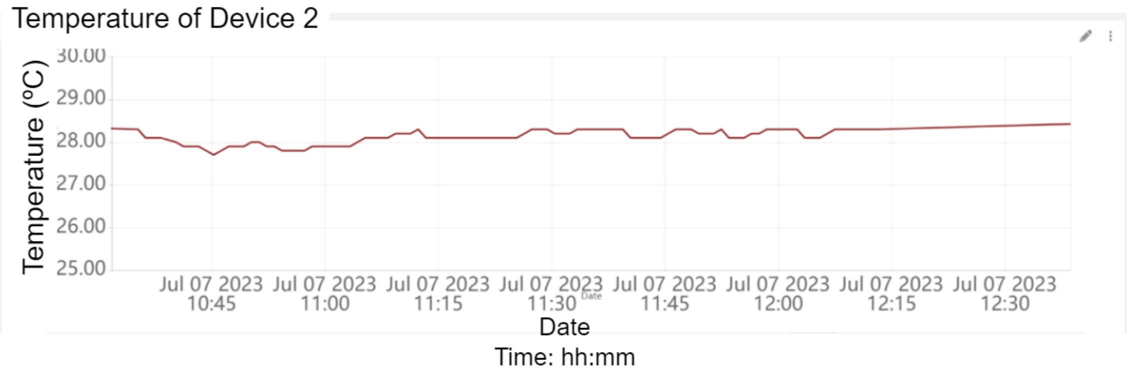

Figure 3: Gráfica medidas de la variable temperatura en un periodo de dos horas

4. Conclusiones

La herramienta tecnológica IoT ha sido clave para el desarrollo de este proyecto. La implementación de las tecnologías IoT en el sector de la agricultura pueden contribuir de forma muy positiva a mejorar los procesos y hacer predicciones útiles para el agricultor.

Dada la baja conectividad e infraestructura de las zonas agrícolas es conveniente destacar la importancia que ha tenido emplear el protocolo de redes LoRa (Long Range). Esta herramienta se caracteriza por ser capaz de transmitir datos de un dispositivo a otro, separados por una larga distancia (hasta 20 km) y por ser de bajo consumo. Otro aspecto que destacar también corresponde con los módulos ESP32 empleados. Este tipo de microcontrolador ha facilitado la transmisión de datos a través de LoRa gracias a que poseen un módulo integrado que permite recibir o transmitir datos a través de LoRa.

Por último algunas ideas para ampliar este proyecto de cara al futuro podrían ser añadir paneles solares a los dispositivos colocados en el campo, de forma que sean lo más autosuficientes posibles, añadir otras variables de medida como medi- das del CO_2 o de la radiación solar o automatizar procesos como de regadío.

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DEVELOPMENT OF LOW-COST IoT-BASED CROP MONITORING SYSTEM USING LoRa AND WIRELESS SENSOR NETWORKS

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PROJECT SUMMARY

1. Introduction

Today's technologies have made it possible to improve people's lifestyle. For exam- ple, mobile phones have become an essential device in our daily lives, allowing us to be in constant communication. They offer applications that have contributed to our well-being and now are part of our daily lives. Among these, there are useful applications that can draw conclusions and predictions related to the object of study based on recorded parameters.

In this project a crop monitoring system based on Internet of Things (IoT) tech- nology has been developed. IoT is the technology that allows devices or everyday items to be connected to a server through IoT network protocols. Specifically, in this project, variables related to crop maintenance are measured with sensors and transmitted to a web page, so that users can access this information from their private devices. The variables measured are air temperature, air humidity and soil moisture. With this information, farmers (users) will be able to make decisions related to crop maintenance based on this data, as well as make predictions and improve current processes.

This project aims to combine traditional agriculture with the new technologies to achieve a more efficient agriculture. This project is considered to contribute to some of the Sustainable Development Goals set by the United Nations. To the goal "Industry, Innovation and Infrastructure", the combination of traditional agriculture with technology creates a type of innovative agriculture sector that allows the implementation of technologies, in a more consolidated way, in rural areas where connectivity and infrastructure tends to be limited. The other goal that this project can contribute is "Responsible Production and Consumption", since the information provided to the farmers can enable farmers to make more efficient decisions related to the consumption of resources such as water or to avoid products harmful for the ecosystem such as fertilisers or pesticides.

2. Methodology

To carry out this IoT project, the structure used is made up of nodes. Nodes are considered to be a set of physically connected devices that fulfill one or more functions. In this project two types of nodes will be used, sender nodes that send the data measured by the sensors and the receiver node or Gateway that receives the data measured.

The sender nodes will be placed in different strategic points of the crop field, the number of sender nodes is not limited, although it implies a higher cost. Whereas only one receiver node will be implemented and it will be located at the farmer's house. This implies that the distance between the sender nodes and receiver node or Gateway is considerable, so that in order to transmit data from one node to the other, it is necessary to use a network protocol that is capable of transmitting data over long distances. For this purpose, the LoRa (Long Range) network protocol is used, which is characterised by having a long range capacity, between 10 and 20 km, and a low power consumption. The data transmission frequency used by this protocol is 868 MHz, which is suitable in Europe.

The hardware of each sender node consists of a microcontroler known as ESP32. To this electronic device, the two sensors of the system are connected, a specific antenna to receive or transmit data via LoRa and a lithium battery that powers the ESP32 module. The first sensor used corresponds to the DHT22 sensor, which is a digital sensor that measures the temperature and humidity of the air where it is located. The second sensor measures the humidity of the soil.

As for the hardware of the receiving node or Gateway, it consists of a minicomputer known as Raspberry Pi. The Raspberry Pi does not allow receiving or transmitting information through the LoRa protocol, so it is necessary to add an extension that allows receiving data through LoRa. To do this, an ESP32 device is connected to the Raspberry Pi via a USB cable. The data received via LoRa will be collected by the ESP32 and transmitted to the Raspberry Pi via Serial.

The software developed for the sender nodes is responsible for reading the data measured by the sensors, creating a standard format known as JSON (JavaScript Object Notation) that groups the data measured by the sender node together with its own identifier and finally sending this JSON document via LoRa to the receiving node.

Concerning the software that is carried out on the system gateway, the ESP32 device is responsible for receiving JSON documents from various sender nodes and printing them on the Serial monitor. As for the Python program running on the Raspberry Pi, it is responsible for the three following functions. Read the JSON documents received via Serial. Store the data contained in the JSON document along with the date and time in a PostgreSQL database on the Raspberry Pi. Transmit via Wi-Fi (HTTP), the data to a web platform, which allows real-time variable data taken by sensors to be displayed.

Figure 4 below shows the different parts that make up the system of this project.

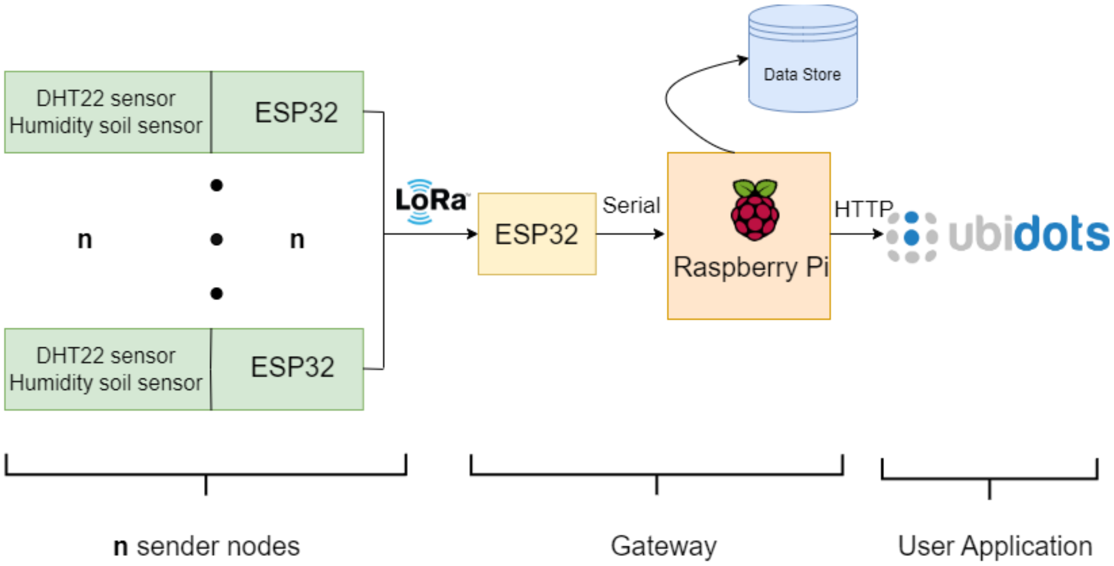

Figure 4: Project system diagram

3. Results

For reasonable reason, instead of implementing this project in crop fields, it will be implemented on a greenhouse at the University. Since the greenhouse consists of two floors, only two sender nodes have been developed, one for each floor.

The results obtained can be seen by accessing the Ubidots application account. From the application, it can be observed that the data of the measured variables are updated every minute. This time frame was established in the code corresponding to the sender nodes, this value can be changed.

Figure 5 shows a screenshot of the application web where the variables measured by both sender nodes can be viewed in real time.

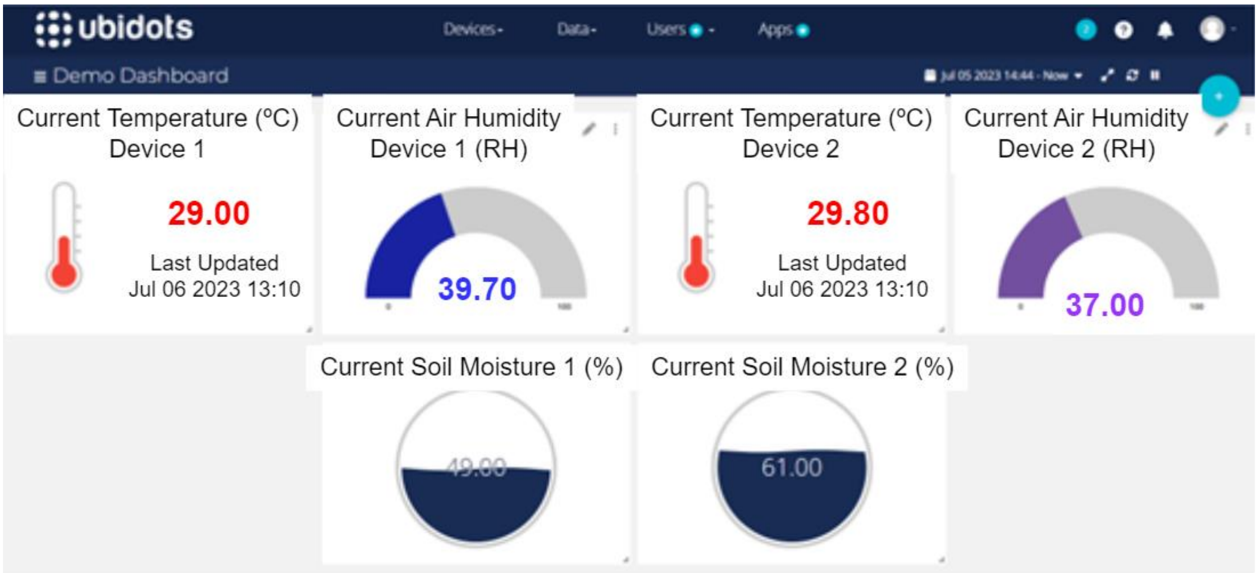

Figure 5: Screenshot of Ubidots web page values in real time

In addition, the Ubidots application allows to create graphs with the evolution over time of the measured variables. Data collected over an hour, a whole day or over a month, for example, can also be displayed.

Figure 6 shows the temperature measured by the sender node 2, during a period of two hours. In this case, as it is a two-hour period, the temperature values do not fluctuate and remain around the same (28ºC).

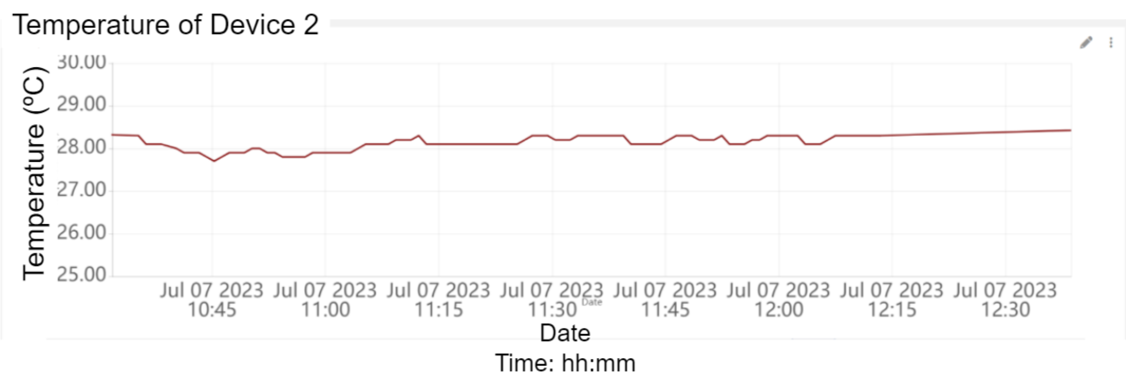

Figure 6: Graphic of temperature measurements collected over a period of two hours

4. Conclusions

The IoT technology tool has been key for the development of this project. The implementation of the IoT technologies in the agricultural sector can contribute in a very positive way for improving processes and make useful predictions.

Given the low connectivity and infrastructure in agricultural areas, it is important to highlight the importance of using the LoRa (Long Range) network protocol. This tool is characterised by its ability to transmit data from one device to another, separated by a long distance (up to 20 km) and by its low power consumption. Another aspect to be highlighted is the ESP32 modules used. This type of microcontroler has facilitated the transmission of data through LoRa as they have an integrated LoRa module chip.

Finally, some ideas for expanding this project in the future could be to add solar panels to the devices placed in the field, so that they become more self-sufficient, to have other measurements variables such as CO2 or solar radiation measurements, or to automate processes such as irrigation.

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Abstract

This work consists on a practical implementation of a crop monitoring system based on the Internet of Things (IoT) technology. This system measures the temperature, humidity and soil moisture parameters of crop fields and sends them to a web application. In this way, farmers can visualize in real time the measurements related to the care of their crops from the application, and therefore make wiser decisions, regarding the maintenance of their crops. As this project takes place in areas of low connectivity and it is assumed that the farmer does not have regular access to these areas, it is important to choose hardware and software components that are well-adapted to the requirements of the area.

Keywords: Internet of Things (IoT), LoRa, ESP32, Raspberry Pi, DHT22 sensor, Capacitive Soil Moisture sensor and Ubidots

To my precious mother,
always with me in my heart.

Acknowledgments

Very grateful for the dedication and enthusiasm for the project of my mentors Gopal Lal Rajora and Cristina Puente Águeda. Also grateful to Professor Rafael Palacios Hielscher for his involvement in the work. Grateful to the University Pontificia Comillas (ICAI) for this opportunity. I am very thankful to my parents, brother, friends, and partner Pablo Campos for always supporting me.

Contents

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Chapter 1

Introduction

Through new technologies and the era of digitalisation, our society has been increasing its comforts over the last years. These technologies have been designed to connect people to each other and facilitate their lifestyles.
A clear example is the evolution of mobile phones, which initially only allowed telephone calling. Now their functionalities are very diverse and have come to be called smartphones, as they allow, among other things, connecting people to each other from different places of the planet through network protocols such as Wi-Fi. They also allow access to all kinds of applications, for instance real-time monitoring applications for medical parameters, home security alarm alerts or environmental crop data.

This Internet of Things (IoT) is the current technology that makes it possible to connect everyday items, animals or people to the Internet.
This technology is mainly based on sensoring devices that take measurements of their environment and following, these measurements are transmitted to a server. For example, measurements related to a person's medical parameters, such as blood oxygen level or heartbeat, are subsequently transmitted to a server that stores and displays the evolution of the data.

The implementation of recent technologies such as IoT has been implemented in the different fields that make up society. These have generated a significant impact for the better in different aspects of society. For example, in the education, medical, security, tourism or production and supply chain industries. This has led to greater economic growth, in societies where this technology has been implemented, and a better quality of life for their inhabitants.

According to the United Nations, the world's population is expected to reach. 9.7 billion by 2050. Resources are scarce and imply that not all of the world's population has access to the basic resources of water and food. This means that resources must be managed intelligently so that the global population will have access to them. This is a very complicated task due to the inequalities that exits in the world and the lack of awareness, but it is our responsibility to continue to fight against these inequalities.

Due to the scarcity of resources the management of the agricultural industry becomes an important aspect of coping with this situation. The agriculture industry must be efficient and make a sustainable use of resources. The main activities that make up agriculture are crop care and growing processes, animal farming processes and greenhouses.

A powerful tool that contributes to creating an efficient agricultural activity is IoT. By implementing this technology in the activities involved in agriculture, processes can be automated, and situations predicted. This makes it possible to create an intelligent agricultural system based on IoT that improves current processes by making them more efficient and comfortable.

IoT-based agriculture contributes to some of the goals set by the United Nations to be achieved by 2030. The first goal to which this type of systems can be related is "Industry, innovation and infrastructure". The combination of traditional agriculture with IoT technology gives rise to a new type of agricultural activity that enables, for instance, food production to be more efficient and productive. In addition, it brings and implements new technologies in a more consolidated way to areas such as the countryside where they have low connectivity and infrastructure.

This type of project is also considered to contribute to the "Responsible, consumption and production" objective. It is considered to contribute to this objective by both efficient consumption and production.
On the consumption side, in agricultural activities farmers use fertiliser and pesticide products, which are useful for crop growth but harmful to the ecosystem. With an IoT system based on smart agriculture, the consumption of these products could be controlled and reduced. This would lead to a more sustainable agriculture. The same applies with water resource, these IoT smart systems can contribute to a more effective use of water. For example, by automating irrigation processes only when necessary.
As for production, it can also be controlled. This could be done by using predictions based on IoT-data collected from previous processes. These analyses can contribute to efficient decision-making by farmers.

After analysing the importance of efficient agricultural activities, the project carried out will be presented in this paper. This project aims to link IoT technology and wireless sensor networks with agricultural activities. Specifically in relation to activities related to crop growth in large areas.

The project consists of a crop monitoring system that collects crop-related environmental data and sends it to a web application. With the information collected, farmers will be able to make better decisions regarding the maintenance of their crops. The analysis of the data will provide predictions for the future and therefore the farmer will be able to anticipate or make more efficient decisions.

In order to develop this project in a practical way, several aspects must be taken into account. First, it must be clear which devices are needed and how they will be placed. The structure of an IoT project is usually organised by nodes. A node is a set of devices that are physically connected to each other and perform one or more joint functions. Nodes are mainly classified according to their functionality. In this project, two types of nodes will be distinguished, depending on whether they send or receive data.

The nodes sending data will be placed in the crop fields. This type of node will consist of the wireless network sensors connected to a module with an integrated processor that, will be programmed to send the data measured by the sensors to a receiving node. Since the project aims to develop in large scale areas, it must be considered that the values measured by a node may be erroneous or represent only a small fragment of the whole area. To avoid such problems, it is proposed to place several sender nodes at different strategic point in the study area. In this way, the measures will be more accurate, and it will be easier to detectif there is any outlier measure.

As for the receiver node, this is made up of a device characterised as a mini-computer called Raspberry Pi. This node will also be called Gateway throughout this work. In this work only one receiving node will be implemented. It will simultaneously receive data from all the sender nodes placed in the field. In contrast to the sender nodes, it is intended to place the receiver node close to or at the farmer's farmhouse. Therefore the information sent must be able to be transmitted over long distances (20 km).

Figure 1.1 illustrates the system structure with n sender nodes sending data to one gateway or receiver node.

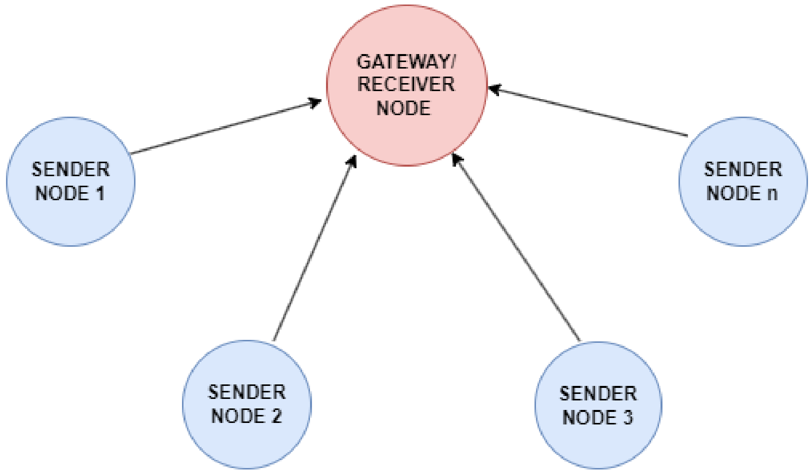

Figure 1.1: Scheme of n nodes transmitting information to the receiving node or Gateway

IoT-based projects require a network protocol to transmit information among the nodes that make up the system. There are several communication protocols. Although each protocol has its own characteristics, they can be classified according to their low or long range, their low or high-power consumption and their low or long data range.

In this project, the main requirement for the network protocol to be used is that it must be capable of transmitting data over a long range. That is why the network protocol implemented is LoRa (Long Range). Since the system is implemented in the countryside, where connectivity tends to be low and distances between nodes are large, it is necessary to use a protocol that has a long range of at least 20 km. Another advantage of using this network protocol is that it is power efficient. This feature is very attractive for projects located in the field, as they are intended to be low-power and long-lasting. These features allow the maintenance of these systems to be better and last longer and provide a lower cost in terms of maintenance and energy consumption.

The measurements taken by the sender nodes are air temperature, air humidity and soil moisture. The sender nodes send the measured data in real time every one minute period. And they are received by the Gateway.

The Gateway acts as the controller node of the system. Each time it receives new data from a sender node, it simultaneously stores this content in a database and sends it via WiFi network protocol to a web platform for the farmer to view the data.

Data storage is useful in cases where the Gateway is unable to connect to WiFi for external reasons. This allows the values to continue to be collected for further analysis.
The platform used to visualise the data in real time is Ubidots. This tool allows the variables measured by each of the sender nodes to be visualised. It also creates graphs with the measurements collected over a given period of time. Ubidots platform is very useful as it avoids the need to create a personal server.

For reasonable reasons, the project will be implemented on a small scale. Instead of being implemented in large crop fields, it will be realised in a greenhouse of the University. Although in this case because reasonable reasons, instead of being carried out in a field, the project will take place in a greenhouse of the University. Since the greenhouse has two floors, the number of sender nodes will be limited to two, one sender node for each floor.

Chapter 2

Technological tools review

2.1 Internet of Things

The term Internet of Things (IoT) refers to the technology that makes it possible to connect everyday items, animals, or humans to the Internet.
IoT technology consists of a set of interconnected devices exchanging actual data over a wired or wireless network [1].
The transmitted data is stored to provide the user with relevant information about the study object and consequently facilitate possible decision-making.
This infrastructure mainly comprises a series of electronic devices such as sensors and devices with microchips, communication protocols used to transmit the data, data storage, and user applications.

To understand this, a simple application example would be to implement the IoT tool on a thermometer. The thermometer outputs an analogical value corresponding to the environment temperature, this value will be digitalized and transmitted as data using computer standards (network protocol). This data will be filtered by a Gateway. The Gateway is located between the sensor and the cloud. Once filtered by the Gateway, the data is transmitted to the server [2].

Due to the COVID-19 pandemic, this technology has gained strength and the society has been forced to integrate it. IoT was a key tool during the COVID-19 pandemic, particularly for logistics and healthcare-related issues.

According to McKinsey, the economic impact value of the IoT could be between USD 3.9 trillion to 11.2 trillion by 2025 [3].
In 2023 there are around 15 billion IoT-connected devices around the world. It is expected that by 2030 this figure will have doubled [4].

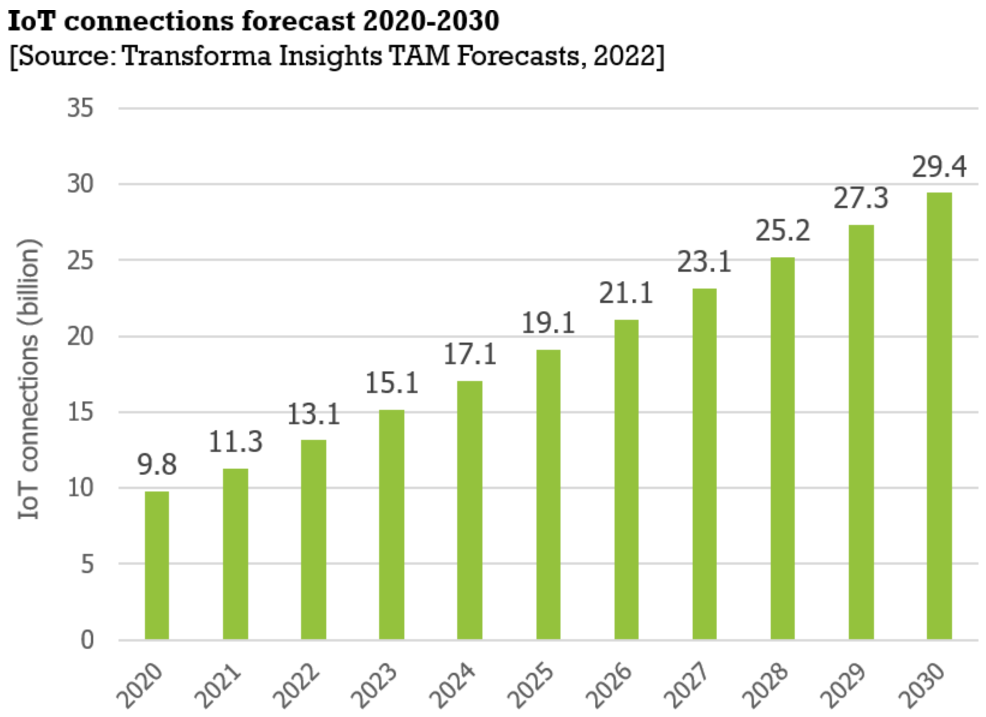

Figure 2.1: IoT connections forecast 2020-2030
(Source: Transforma Insights TAM Forecasts, 2022)

This technology has multiple application possibilities like crop monitoring systems, car safety systems such as driver assistance or medical controls, and manufacturing. The most current trends where this type of technology is found are in the development of smart cities, blockchain, 5G technology, artificial intelligence, and digital twins.

2.1.1 IoT architecture

The architecture of the Internet of Things is mainly structured in four layers. Depending on the complexity of the project, the layers that make up the architecture may vary. According to the article "4 Layers of IoT Architecture Explained" written by Ralph Heredia [5].

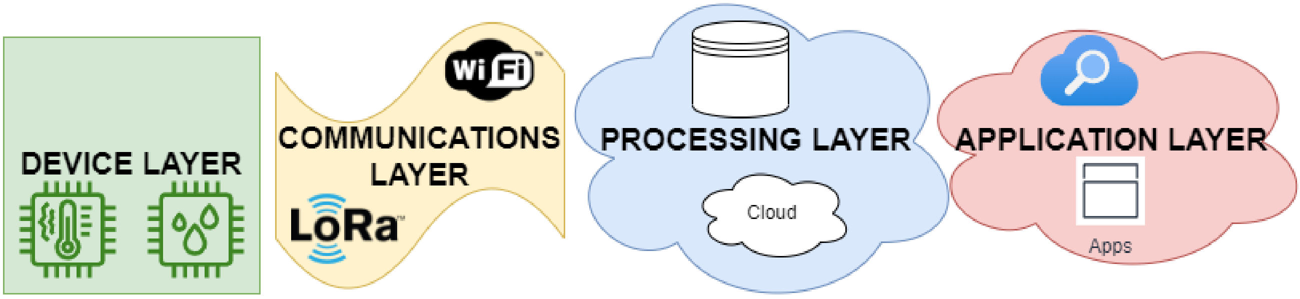

Figure 2.2: IoT Architecture Layers

Device Layer

The first layer of an IoT project's architecture is mainly made up of sensors that take measurements of the environment in which they are located, such as temperature and humidity sensors.
This layer includes electronic devices with embedded microchips, actuators, and computers.

Communications Layer

The second layer in the system corresponds to the communication protocol responsible for transmitting data between connected devices. Once the sensors collect data, it is transmitted to a Gateway using the established network protocol.
Examples of network protocols used for IoT projects are Bluetooth, Cellular, LoRa/LoRaWAN, Wi-Fi and ZigBee.

Cloud Ingest, Data Storage and Processing Layer

The Could Ingest, Data Storage, and Processing Layer play a crucial role in handling the data collected by the sensors. This layer is responsible for processing the data, and it can be performed either at the Gateway or in the cloud.
In the data storage stage, the collected data is analysed to extract valuable insights, generate useful warnings, or make predictions. By leveraging data analysis and machine learning techniques, this layer enables the extraction of meaningful information from the collected sensor data.

Application Layer

The Application Layer, located in the cloud, provides users with access to visualize the measured data and make informed decisions based on it. Users can interact with applications to gain insights into the collected data, enabling them to make better decisions and take appropriate actions.
These applications can also incorporate predictive capabilities, offering users future predictions based on the data analysis. They can be implemented across various domains, including the creation of smart cities, crop monitoring systems, and health monitoring systems, among others.
Applications can be implemented, among others, for the creation of smart cities, crop monitoring systems, or health monitoring systems for example.

2.1.2 IoT Network Protocols

There are several IoT network protocols that differ from each other according to:

- Short or long distance range
- Short or long data range
- High or low power consumption

Figure 2.2 shows different IoT network protocols according to their characteristics. The diagram is based on the article "IoT Network Protocols" by Devang Delvadiya [6].

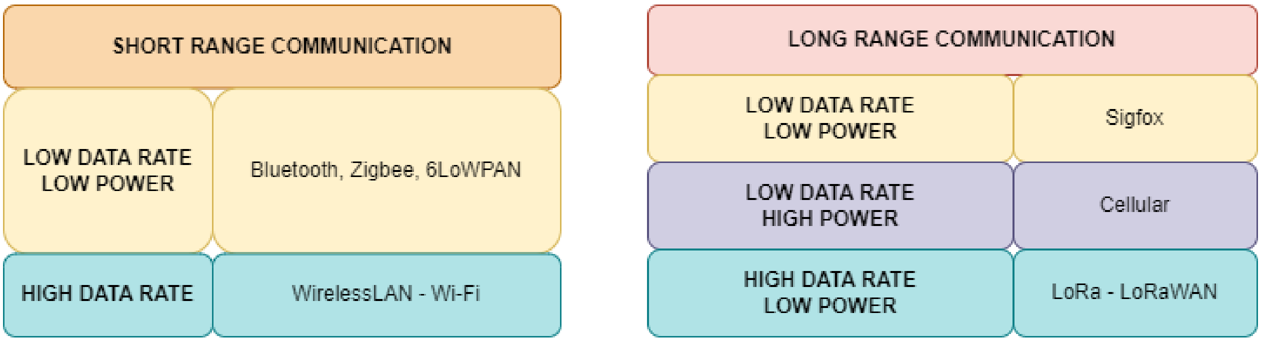

Figure 2.3: IoT Network Protocols

2.1.3 Short Range Protocol

Bluetooth Low-Energy (BLE)

The Bluetooth Low-Energy network protocol is a wireless communication system based on radio waves.

It is a low-range communication system, with a range of 10 to 100 meters, although this may vary due to obstacles that may interfere with the communication such as people, metals, and the environment [7].
Specialized in data transfer over short distances, preferably low-range data (single files or non-complex applications). It is also a low-power consumption system.
The frequency used ranges from 2400 to 2483 MHz.

It is used for voice transfer and data support in mode point-to-point (one master device and one slave device) and in mode multiplier-to-point (several slave devices device and one master device) applications [8].

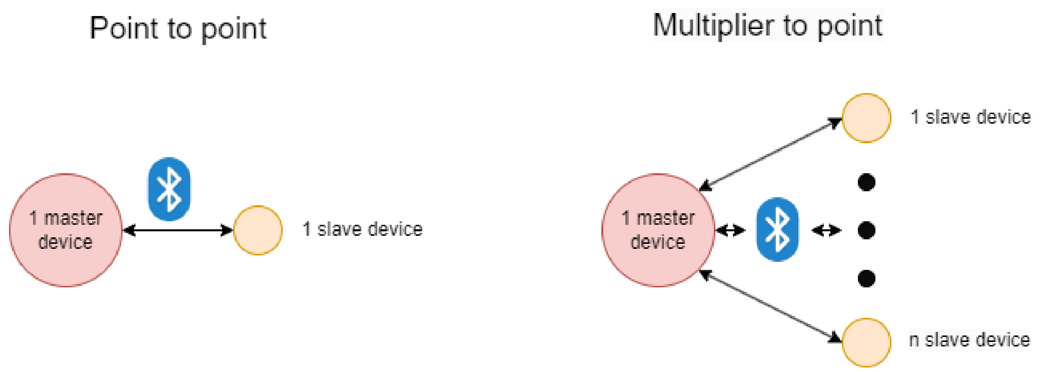

Figure 2.4: Bluetooth Point-to-Point and Multiplier-to-Point topologies

This network protocol is compatible with Windows and Linux operating systems, allowing peripherals such as a mouse, keyboard, and headphones to be connected to computers and laptops via Bluetooth.

We can also find this open technology in our society by connecting headphones to our mobile phones, computer games, and the health field.

ZigBee

ZigBee wireless technology is characterized by low power consumption and low data transfer rates.

This network protocol automatically manages the network, dynamically creating and maintaining routes. This feature allows the network to solve automatically, without having to physically access, situations of partial disconnections of some network nodes [9].

This technology is applied mainly in home automation, such as light bulb control systems, camera-based surveillance systems, or electrical measuring equipment. In ZigBee networks, mesh topologies are used.
There are three types of nodes in this type of network:

1. **Coordinator:**
   In each ZigBee network there is only one node of this type. The network is created based on this node, acts as a coordinator route and allows connections to the rest of the nodes.
   In addition, this node has access to a WiFi connection, so the user can access to the network data from an application.

2. **Router:**
   This node is one step below the coordinator node. There are usually several of them in the network and like the coordinator node, they can branch out into other nodes(routing packets).

3. **End device:**
   These nodes do not branch and are the most common type of node in the network, as they represent the network's sensor devices, such as sensors or cameras. Their consumption can be controlled, by activating them automatically only when they are needed.

The main advantages of a ZigBee network over Bluetooth are a higher number of devices that can be connected to the network and a longer range rate.
However, compared to WiFi, ZigBee has a lower data transmission rate.
ZigBee is based on the 802.15.4 standard.

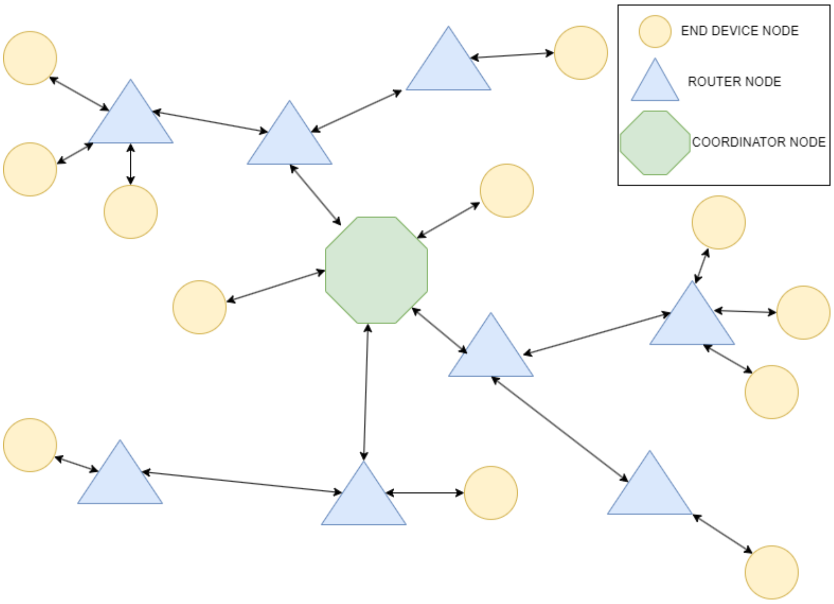

Figure 2.5: ZigBee Network Structure

6LoWPAN

The full name of the 6LoWPAN network is "Ipv6 over Low-Power Wireless Personal Area Networks". It consists of a network technology or layer that enables efficient forwarding of IPv6 packets within small link-layer frames, as defined by IEEE 802.15.4 (ZigBee standard).
This technology through a border router connects to Wi-Fi, this router exchanges data among 6LoWPAN nodes and the Internet [10].

Unlike other network protocols such as ZigBee, and Bluetooth, this network protocol does not need application layers to transmit data from the border router to the Internet. This speeds up the processing load, allowing lower-power devices to be used [11].

WiFi

This protocol uses radio frequencies (RF) for communication among devices and is based on IEEE 802.11 standards, i.e., wireless local area network (WLAN). The devices connected to WiFi have a unique IP address that identifies them.

The structure of a WiFi-based system consists of a wireless router that creates a WiFi connection. This allows devices such as mobile phones or computers to access the Internet [12] [13].

2.1.4 Long Range Protocol

Cellular

Cellular networks use 2G, 3G, 4G, and 5G cellular standards for their data communication. The "G" refers to the generation to which each wireless communication standard belongs.

These Cellular standards are classified into two groups Global System Mobile Communication (GSM) and Long-Term Evolution (LTE).

The GSM group includes the 2G and 3G standards. Their functions mainly allow the transmission of voice data, SMS (Short Message Service), and GPRS (General Packet Radio Service).

The LTE group corresponds to the fourth generation. This is where we can place the 4G and 5G technology.

Cellular networks are extended to another category called NarrowBand-IoT (NB-IoT). It is a communication standard for IoT-connected devices. It is characterized by its low speed, low power consumption, and long range. Similar to the NarrowBand-IoT category, there is an extension of LTE called Long Term Evolution Machine Type Communication (LTE-M).

LoRa - LoRaWAN

LoRa (Long Range) communication technology is characterized by its long connection range. This ranges between 10 and 20 km. This characteristic makes the implementation of this tool in IoT projects very suitable.

LoRa is an LPWAN (Low Power Wide Area Network) tech- nology. In addition to the aforementioned, it is considered secure connectivity.

LoRa allows bidirectional data transmission, and low-power technology capable of accurate geolocation outdoors and indoors.

Another advantage of this technology is its low cost and low energy consumption. The speed with which the LoRa protocol works depends on the geographical location of the project. In Europe 868 MHz, in Asia 433 MHz and in the US 915 MHz.

It is relevant to list the differences between LoRa and LoRaWAN:

- LoRa is a type of modulation patented by Semtech.
- LoRaWAN is a network protocol that uses LoRa technology to communicate and manage LoRa devices [14].

Communication between LoRa nodes can be done in two ways:

- The first consists of point-to-point communication. Where two LoRa nodes interact by exchanging information with each other.
- The second one consists of a mesh where there are at least three nodes and one of them acts as a coordinator communicating individually with the rest of the nodes.
  However, communication using LoRaWAN mode requires the mesh nodes to connect to a gateway node.
  In LoRaWAN communication mode there are three types of end bidirectional nodes or classes [15]:
  - Class A: Once the node sends data to the gateway node, it becomes a receiver-equivalent node. Because of this it provides low power consumption and can be powered by batteries.
  - Class B: The node has programmed reception windows. These nodes can be powered by batteries or external sources.
  - Class C: These nodes always act in listening mode, so it is the one that offers the highest power consumption. It should be connected to an external power supply.

2.2 HTTP Protocol

The acronym HTTP stands for Hypertext Transfer Protocol. It is a communication protocol that transmits information among devices connected to the network. This protocol works by means of requests, of which there are two methods:

1. The first would be a GET type, where access to an application or web page has been requested.
2. The second would be a POST request, a data transmission to a web application has been made.

Each request must indicate the URL to which the user wants to access or send information [16].

Chapter 3

Hardware and Software Components

3.1 Global Project

As illustrated in Figure 3.1, the different stages that make up the project can be seen.

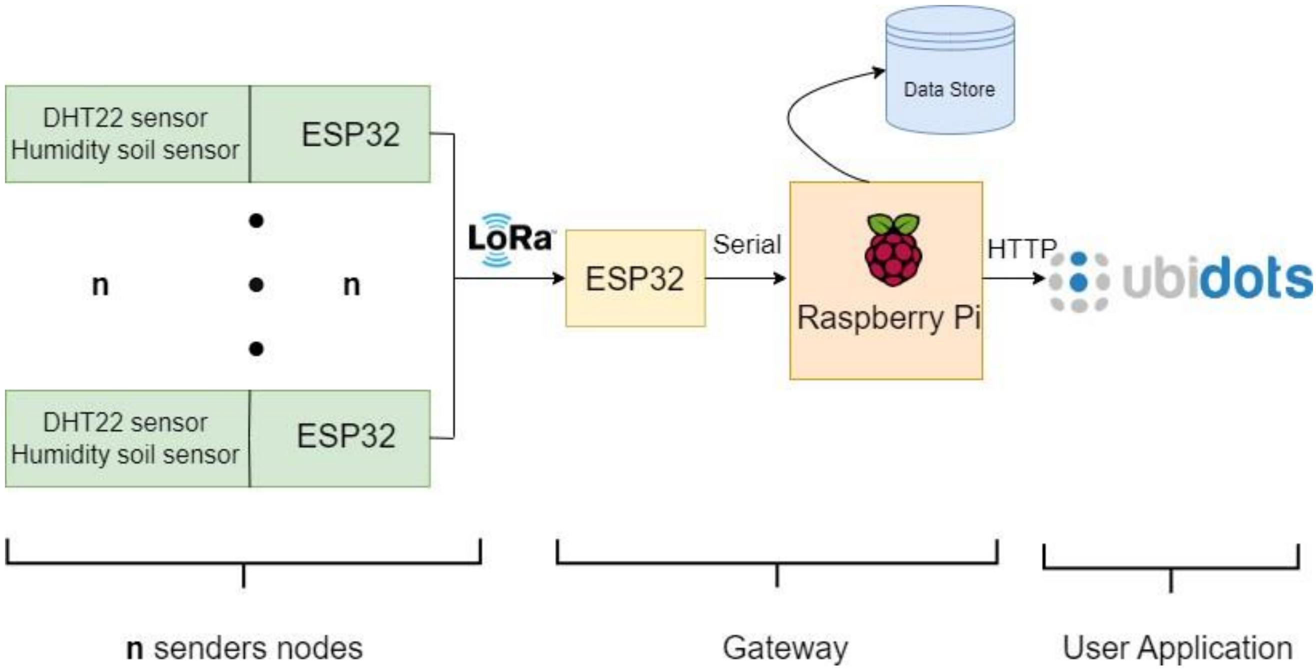

Figure 3.1: Project Components Diagram

Analyzing Figure 3.1 from left to right:

- The first block is composed of nodes acting as senders. Each node consists of an electronic device with an embedded chip integrated (ESP32), to which sensors are connected.
  The number of sender nodes is extensible to the desired number. These nodes will be placed in the crop fields so that the sensors will take the measurements of temperature, air humidity, and soil moisture. Referred to a greenhouse in the context of this project.

  Since the aim of the project is to be able to carry it out in large crop fields, it is interesting and necessary to have several nodes placed at different strategic points.

- The next step corresponds with data transmission from the sender nodes to the Gateway. The network protocol used is LoRa (Long Range). This protocol was chosen according to the conditions of the field, as it is when developing an IoT project in places with low connectivity such as the countryside, it is convenient to choose a long-range protocol.

- The following block refers to the gateway node of the IoT system. It mainly consists of a microcomputer called Raspberry Pi.

  In order for the Raspberry Pi to receive data via LoRa, a LoRa extension must be added to enable this transmission. In this case, an ESP32 device connected by cable to the Raspberry Pi is used as an extension.

  This ESP32 receives and transfers the data to the Raspberry Pi via serial communication. Once there, it is stored in a database.

- The data is sent to the user's application in the last block. This allows the farmer to access the information related to his crops and so make decisions related to the crops based on the measurements.

3.2 Hardware

3.2.1 DHT22: Temperature and Humidity sensor

DHT22 sensor stands for Digital Humidity and Temperature sensor.
The DHT22 sensor has three pins, as they are shown in Figure 3.2:

- The VCC pin is connected to the supply voltage (3.3 V).

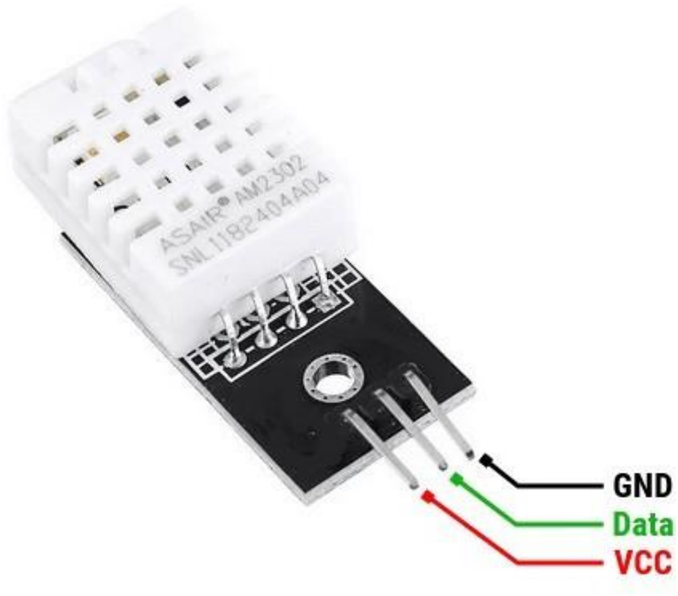

Figure 3.2: DHT22 Pinout

- The middle pin "Data" corresponds to the output. It outputs the temperature in Celsius degrees and humidity (percent) values measured by the sensor.
- The third pin corresponds to GND, which must be connected to the ground.

Documentation of the DHT22 sensor, from the technical specification sheet is shown in the following tables:

Voltage Supply	3.3 - 6 V DC
Output	Digital output
Sensor Device	Polymer capacitor
Humidity Measuring Range	0-100% HR

Temperature Measuring Range	(-40) - 80 ºC
Adquisition Time	2 seconds
Interchangeability	Full interchangeability
Accuracy	Humidity +-2-5% RH Temperature < +- 0.5 ºC

Figure 3.3: DHT22 Datasheet

3.2.2 Capacitive Soil Moisture Sensor v2.0

This sensor measures soil moisture in percent. It has three pins:

- The first pin corresponds to GND (ground).
- The middle pin is the "Vcc" voltage pin.
- The third pin corresponds to the output, it outputs the measured analog value.

To get the output value as a percentage an analog-digital conversion is needed. Figure 3.4 shows a picture of the sensor.

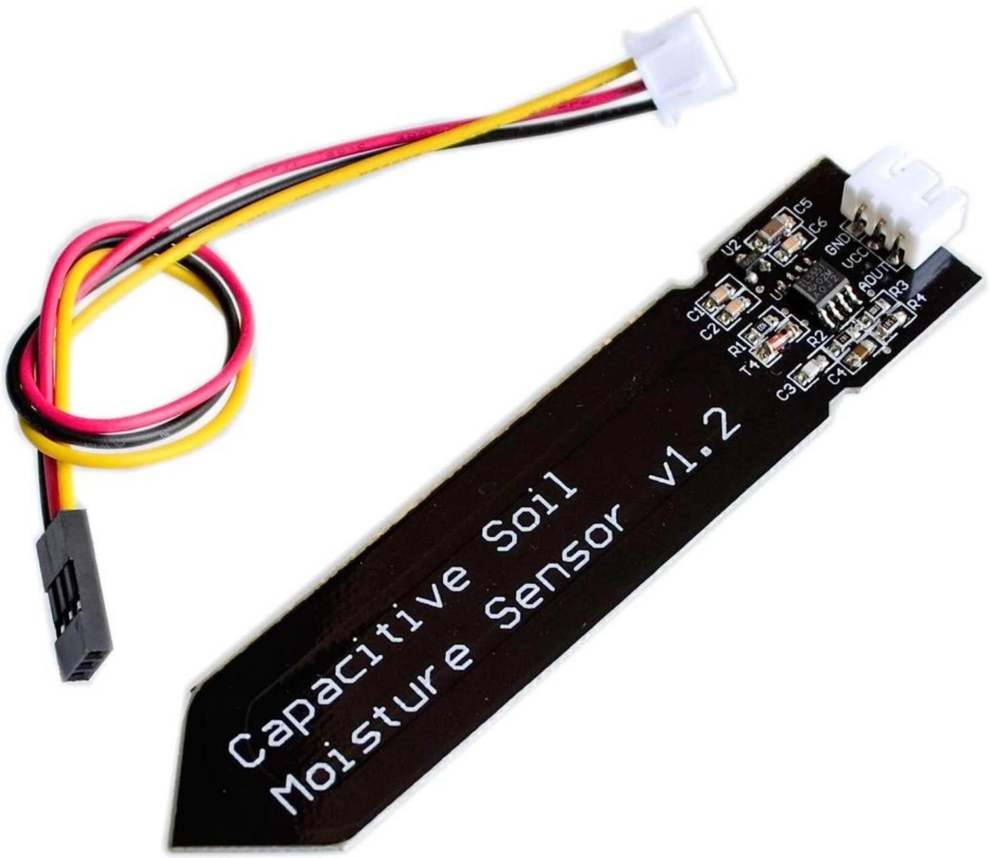

Figure 3.4: Capacitive soil Moisture Sensor v2.0

Documentation of the capacitive soil moisture sensor, from the technical specification sheet is shown in the following tables:

Voltage Supply	3.3 - 5.5V DC	Supports	3-Pin Gravity Sensor Interface
Current	5 mA	Output	Analog Output
Interface	PH2.54-3P	Weight (gm)	15
Dimensions mm (LxWxH)	98 x 23 x4		

Figure 3.5: Capacitive soil Moisture Sensor v2.0 Datasheet

3.2.3 ESP32 Device

The ESP32 electronic module comes from a family of SoC (System on a Chip) chips. This module:

- Integrates computational modules on a chip, (OLED SX1278 ESP32 WIFI).
- Provides wireless radio.
- Has Bluetooth, USB, and WiFi connectivity.
- Incorporates an antenna to connect to the LoRa network protocol.

The transmission frequency is 868 MHz (suitable in Europe). It is an attractive module for IoT projects because of its cheap cost and its embedded processor with interfaces to connect peripherals.
The following Figure 3.6 shows the pin-out diagram of the ESP32.

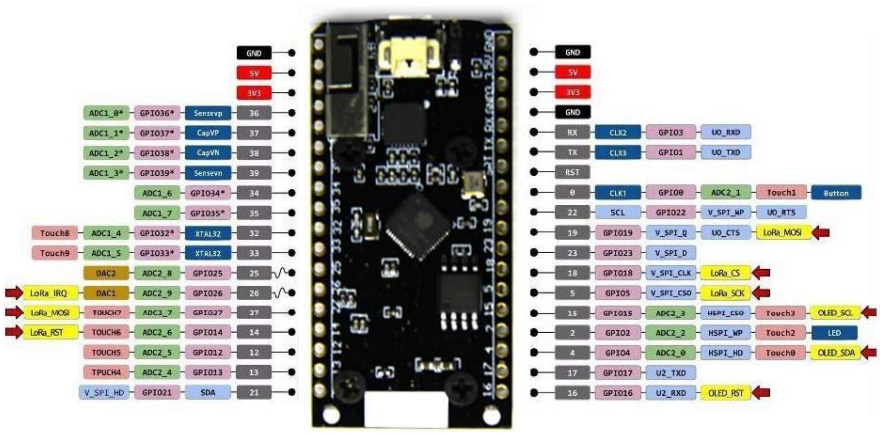

Figure 3.6: DollaTek LORA32 868Mhz ESP32 Bluetooth module WiFi - Pinout

Figure 3.7 shows the technical details of the ESP32 datasheet.

Voltage Source	3.3 -7V	**Power Transmission**	19.5 dBm at 11.5 dB 16.5 dBm at 11 g 15.5 dBm at 11 n
Operating Temperature Range	(-40) - 90 ºC	**Receiver Sensivity**	to -98 dBm
Data speed	150 Mbps for 11n HT40 72 Mbps for 11n HT20 54 Mbps for 11g 11 Mbps for 11b	**Continuous UDP (User Datagram protocol)**	135 Mbps

Figure 3.7: DollaTek LORA32 868Mhz ESP32 Bluetooth module WiFi - Datasheet

3.2.4 Rechargeable Lithium Battery with JST Connector

Batteries for charging ESP32 devices must be included in the project. Since the ESP32 modules are to be placed in crop areas or in a greenhouse, these places have weak access to electric power.

In this case, Li-ion 3.7 V batteries are used and meets the voltage required to power an ESP32 module.

Figure 3.8 shows the technical details of the LI-ION Polymer Battery - Datasheet.

Voltage Source	3.7 V	**Maximum Load Current**	1C (2000 mA)
Standard Charging Method	CC/CV (final current 40 mA)	**Maximum Load Current**	1C (2000 mA)
Standard Charging Current	0.2C (400mA)	**Maximum Discharge Current**	2C (4000 mA)
Maximum Charging Voltage	4.200±0.020V	**Charging Temperature**	0 ~ 45 ℃
Standard Discharge Current	0.2C (400 mA)	**Discharge Temperature**	(-20) ~ +60 ℃
Cut-off Voltage	2.750±0.005 V	**Storage Temperature**	(-20) ~ +25 ℃
Weight	40 g		

Figure 3.8: LI-ION POLYMER BATTERY LP103454-PCM-LD - Datasheet

3.2.5 Raspberry Pi 4B Device

Raspberry Pi is a board containing a series of computers.

It was developed by the Raspberry Pi Foundation in the United Kingdom in 2012.

Its software is based on the GNU/Linux operating system, specifically the Debian operating system or Raspberry Pi OS.

Figure 3.9 shows the format of a Raspberry Pi and its various hardware components.

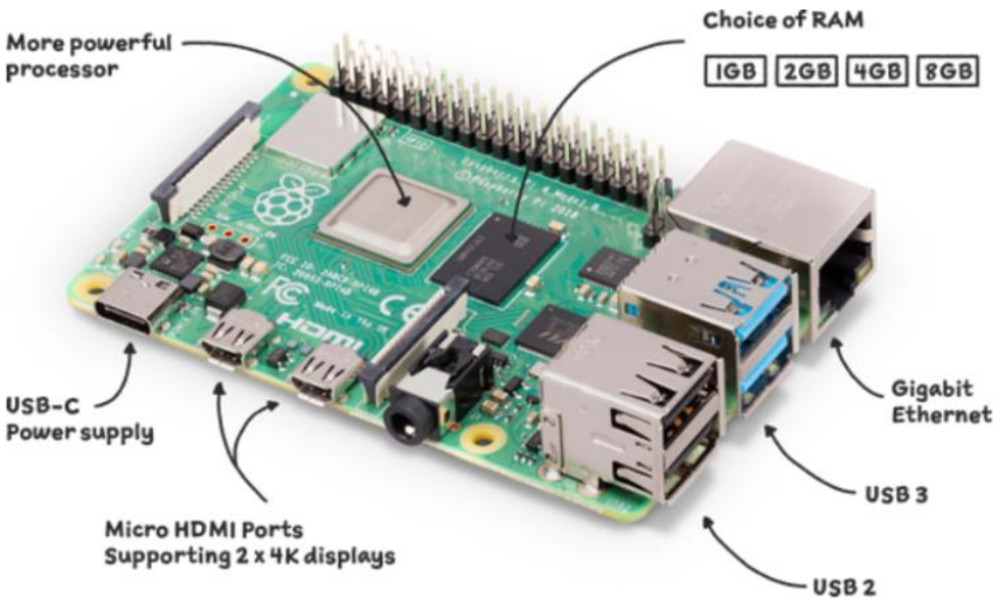

Figure 3.9: Raspberry Pi 4B main components

There are several models of Raspberry Pi. The Raspberry Pi 4b model will be used in this project. Its technical characteristics are shown in Figure 3.10.

Product Dimensions	9.5 x 7.49 x 2.79 cm
Product Model Number	SC15184
Processor manufacturer	Arm-cortex-a72
Processor Type	ARM 610
Processor Speed	1.5
Number of Processors	4
RAM Memory Capacity	2 GB
Memory Technology	SDRAM
Computer Memory Type	DDR3 SDRAM
Memory Clock Speed	1.5 GHz

Hard Disk Drive Interface	USB 2.0
Graphic Memory Type	DDR4 SDRAM
Graphics Card Interface	PCI Express
Wireless Connection Type	802.11a
Number of USB 2.0 Ports	4
Number of USB 3.0 Ports	2
Product Weight	45 g
Voltage Supply	5 V DC
Temperature Range of use	0-50ºC

Figure 3.10: Raspberry Pi 4B - Datasheet

3.3 Software

3.3.1 Arduino IDE Programming

The software part related to the ESP32 devices has been developed with the programming language of the Arduino IDE text editor. This programming language is based on the C language.
Both ESP32 sender nodes and ESP32 receiver node, used in this project, are programmed in C language.

3.3.2 Python Programming

The programs running on the Raspberry Pi have been developed in Python programming language.
Python is a high-level programming language that has many applications, from web application development to data processing.

3.3.3 Raspbian Operating System

Raspbian is a computing platform based on the open Debian operating system (Linux). The Raspbian operating system is exclusively designed for Raspberry Pi devices. Unlike Debian which has a large collection of repositories and packages for all types of architectures, Raspbian has only collections intended for Raspberry Pi devices.

In this project, the "Debian Bullseye with Raspberry Pi Desktop" operating system has been installed on the Raspberry Pi. This system was chosen because it offers a graphical interface that is useful for the development of the project.

3.3.4 Docker and containers

The measurements of the project are stored in a database from Raspberry Pi. For this purpose, the Docker platform tool has been used.

Docker is a software system that manages containers.
Containers cluster together the necessary dependencies for running applications. For instance, container with a database has been created in this project.

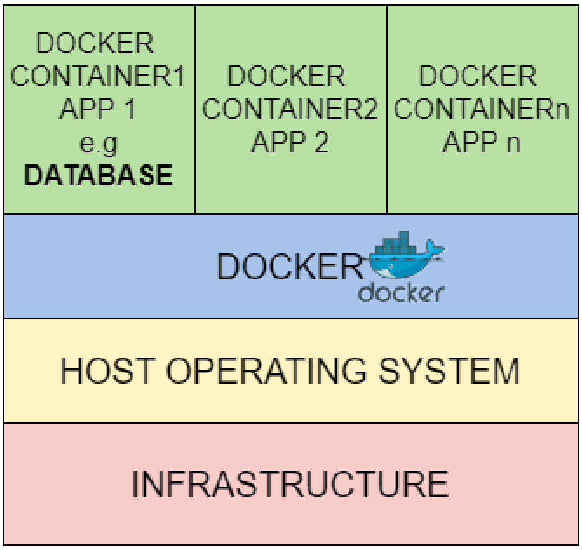

Figure 3.11: Docker and containers structure

3.3.5 PostgreSQL Database

A PostgreSQL database has been installed in a docker container. This is a relational database. Tables can be created within the database.
The table created is formed by six columns:

- ID of the sender node (Integer)
- Timestamp (Date time)
- Temperature value (Float)
- Humidity value (Float)
- Soil moisture value (Integer)

In addition, the variables ID and Timestamp are imposed as primary keys (per row). This means that no more than one row can simultaneously have the same ID and date-time value.
The SQL command to create "measurements" table is listed below:

```
CREATE TABLE measurements (
 temperature  float ,
 humidity float ,
 soilmoisture int ,
 sensor int ,
 timestamp  timestamp ,
PRIMARY KEY (sensor , timestamp)
 );
```

3.3.6 Daemon

Daemon is a task that runs in the background.
To avoid having to run the Python gateway program script manually, when the Raspberry Pi is switched on, a daemon program has been added to the Gateway, to manage the running of the Gateway programs.

3.3.7 Ubidots

Ubidots is a web platform for creating web applications. It allows users (farmers), to follow and supervise the current measurement values. A Python "request library" transmits data from the Raspberry Pi to Ubidots. In this case, the Gateway sends the data to the Ubidots using HTTP communication protocol.
Requests are made from the Raspberry Pi to Ubidots and not the other way around because the IP of the Raspberry Pi is dynamic.

Chapter 4

Project development

4.1 Hardware development

This project has been carried out on a small scale. Instead of being implemented in fields, it has been installed in a greenhouse with two shelves.
The number of sender nodes has been limited to two.

The hardware used in the project will be considered in two types:

- Sender nodes
- Gateway/receiver node

4.1.1 Sender Node Structure

Each sender node is composed by:

- ESP32 device and its respective antenna
- DHT22 sensor
- Capacitive soil moisture sensor
- Battery

The output pin of the DHT22 sensor is connected to a digital pin of the ESP32 device, for instance in this project output pin of DHT22 is connected to pin number 25.
The output pin of the soil moisture sensor is connected to an analog pin of the ESP32 device, for instance in this project output pin of the soil moisture sensor is connected to pin number 34.

Figure 4.1 shows the connections and elements that make up the sender node type.

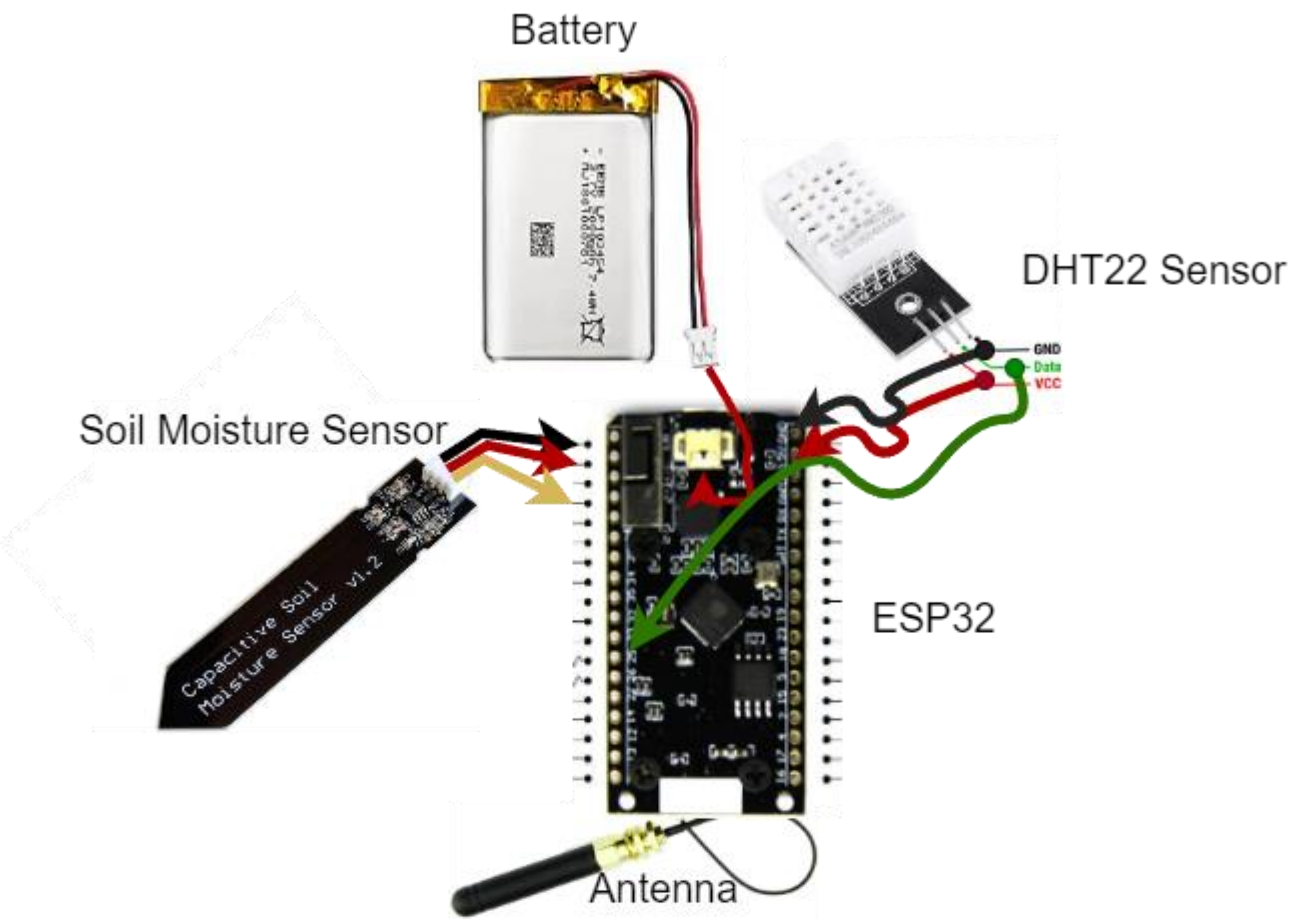

Figure 4.1: Hardware connection of a sender node

4.1.2 Gateway Structure (Receiver node)

The diagram of Figure 4.2 shows the connections and elements that make up the Gateway/receiver node type. It consists of an ESP32 device and its respective antenna connected via cable to the Raspberry Pi 4B.

This connection allows the Raspberry Pi device to receive data sent by the sender nodes via the network protocol LoRa. The serial connection is made trough a USB cable that physically connects the two devices.

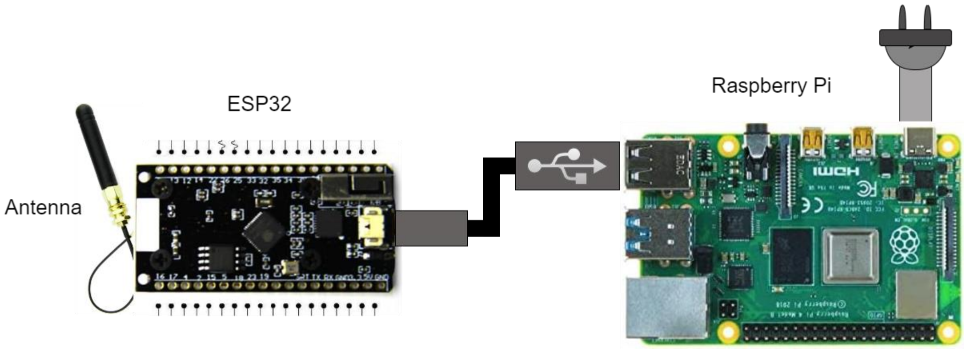

Figure 4.2: Hardware connection of a receiver node

4.2 Software development

This section presents the sender node software and the Gateway software in detail. To carry out this project, it is not enough to only connect the hardware components. Software must be developed for each of the parts that make up this project. This implies that several programs have been developed in different programming languages, specifically in the programming languages C and Python, as well as becoming familiar with the Raspbian (Linux) operating system.

4.2.1 Sender node Software

The sender nodes are programmed using Arduino IDE programming language similar to C. The sender node developed program is mainly divided into 3 parts:

1. First, the values measured by the sensors are read following two modalities:
   - To read the values of the DHT22 sensor, a specific Arduino IDE library is used: DHTesp.
   - While to obtain the value of the soil moisture sensor it is necessary to do an analogical-to-digital conversion. To do this the map function provided by the Arduino IDE is used, it converts a value (analogical value) into its equivalent in another value range (digital value range).
2. Creating a standard format that brings together different data and facilitates the sending to the receiver node. This format is called JSON (JavaScript Object Notation). In this project, the JSON created contains four fields:
   - ID of the sender node
   - Temperature measure

- Air humidity
- Soil moisture

3. Function that sends the current JSON via LoRa. This function is in a loop inside the sender node program, sending data every minute. This can be easily modified.

In order to transfer the program created from the Arduino IDE (desktop computer) to the ESP32 device, it is necessary to indicate on which ESP32 device it is being uploaded. If the device and version does not match with the indicated in the Arduino IDE, the program will not compile.

4.2.2 Gateway Software

The Gateway hardware is distributed in two hardware devices:

ESP32

The ESP32 device is programmed in Arduino IDE (C language). The program checks that a packet has been received via LoRa. If this is the case, this packet (JSON) is read and printed out via serial.
To program this ESP32 device, it was decided to install the Arduino IDE code development platform on the Raspberry Pi, so the code related to the ESP32 receiver is developed from the Raspberry Pi. The advantage of this method is that the serial monitor of Arduino IDE can be used to check that the LoRa packets are being received.

Raspberry Pi

In order to be able to work from the Raspberry Pi, installing applications and running code, it was necessary to install the Raspbian (Linux) operating system. And then acquire the knowledge to handle it correctly.
A Python program runs on the Raspberry Pi with the following instructions:

1. Read via serial the JSON received by ESP32 receiver.

2. Store the data received from the different sender nodes in a database.
   For this, a docker instance has been installed on the Raspberry Pi.
   Besides a PostgreSQL database has been installed in a Docker container.
   To make this connection, the following five parameters must be specified to identify the database:

(a) Host: Identifies the address where the database is located. In this case it is in the same localhost. Therefore, 127.0.0.1 is used by default.

(b) Port: 5432 by default.

(c) Database: Name of the database being accessed. The database name is "tfg".

(d) User name and password, are not disclosed in this document for security reasons.

3. Simultaneously to above point 2), the data are transmitted to the server application (Ubidots).

   The program developed to send data from the Raspberry Pi to the Ubidots platform makes an HTTP request. The URL to which the data is sent is specified within this program.

   As there are two devices, "sender node 1" and "sender node 2", it is convenient to differentiate them. For this purpose, two devices are created on the Ubidots platform. Each device has its own TOKEN assigned to it.

   Within the Python program, a TOKEN MAP variable has been created. This variable, contains the TOKEN of both devices. To differentiate both TOKENs, the TOKEN corresponding to "sender node 1" is named TOKEN 1 and "sender node 2" is named TOKEN 2. The ID parameter value of the JSON document will be read in order to identify the TOKEN to which the data is to be.

4.3 Challenges Faced in the Development

Throughout the development of the project, different methods and devices have been tested. This section will discuss some of the difficulties encountered in developing the project.

Since the Raspberry Pi device cannot receive and send data, via the network protocol LoRa, on its own, it is necessary to connect an extension that allows the LoRa network protocol to be used. To do this, it was initially proposed to use a specific extension for Raspberry Pi that allows communication via LoRa. This extension is known as LoRa Hat for Raspberry Pi and specifically the module used is the SX1268. Another advantage, of using this module, is that the connection between the LoRa Hat module and the Raspberry Pi is simple, as the pins of the module simply snap onto the pins of the Raspberry Pi.

Although numerous tests were carried out, the results did not match with the expectations, this is because the LoRa Hat module does not support the transmission of data from a device like ESP32 to the Raspberry Pi. Since the documentation related to the software to be developed was made specifically to transmit data between Raspberry Pi, each connected to a LoRa Hat module.

This was followed by experiments with the LoRa SX1278 module. The results were also unsatisfactory because the frequency used by the module was 433MHz, which is inadequate in Europe and therefore different from the frequency used with the ESP32 devices, which is 868MHz.
Finally, it was decided to simplify the solution, this was done by connecting an ESP32 to the Raspberry Pi via cable. The ESP32 acts as a LoRa Hat, allowing the Raspberry to receive and send data via LoRa. This final solution worked.

Another obstacle face in the project is related to the ESP32 devices. There are several ESP32 devices on the market from different manufacturers. In the initial stages, tests were done with ESP32 devices from another manufacturer.
These devices worked correctly by reading the data measured by the sensors connected to them but were incompatible with the LoRa libraries and could not transmit the data. This was because we were working with very new versions of these devices and the existing LoRa libraries were obsolete. Besides the information provided by the manufacturer was not updated. Finally, it was decided to try the ESP32 devices from another manufacturer and worked perfectly.

The process of creating the database required some additional effort due to the following reasons. The Raspbian operating system of the Raspberry Pi has its own limitations, it does not offer the same processing power, memory and storage capacity as for example desktop computers. In some cases the libraries needed, to install certain databases, do not have their own specific version for the Raspbian operating system. This has made the creation of the database process more difficult. Specifically, in this project it was initially attempted to implement a MongoDB database, but due to incompatibilities it could not be carried out. As for the database used, PostgreSQL, also meant an effort to develop it, due to the fact that the information on the installation of the Docker system was not focused on the specific installation on a Raspberry Pi. And not all the information was updated.

Chapter 5

Results

5.1 Plant Experiment

Throughout the work, experiments have been carried out. In order to make the tests the more realistic as possible, a pot with a home-grown pepper plant was used.
Figure 5.1 shows the pot used, where the temperature, air humidity and soil moisture sensors have been placed. As shown, the sensors are connected to an ESP32 device which acts as a sender.

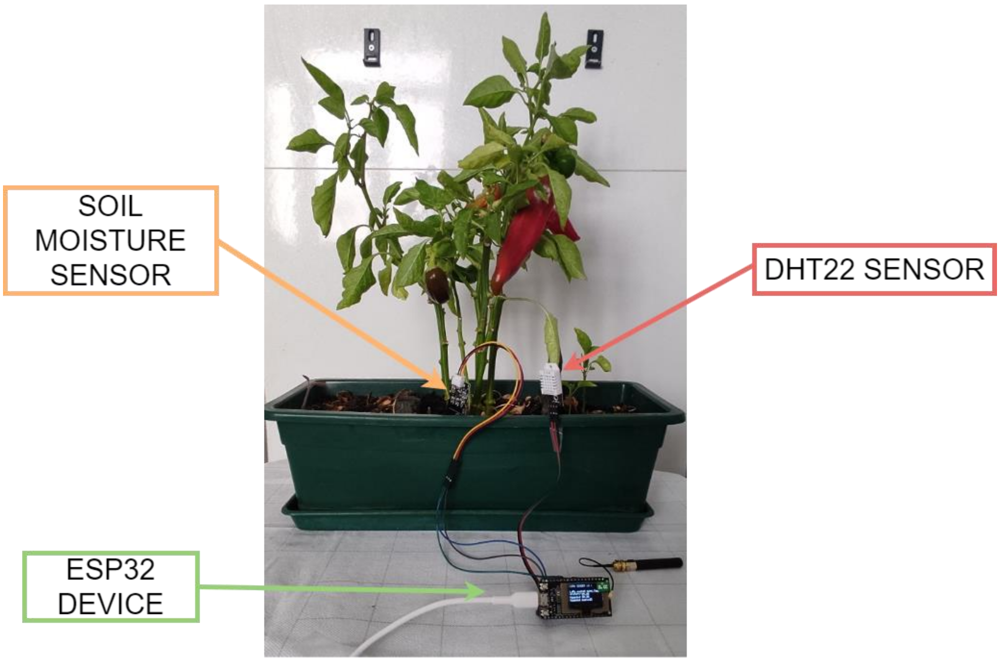

Figure 5.1: Homegrown pepper pot and deployed sender node

5.2 Ubidots Results

The final results can be found in the Ubidots application. The user can access it from his personal account and observe the collected data. Specifically in this work the user will find the real time values of temperature, air humidity and soil moisture measured by each device.

The system has been designed so that the farmer only has to switch on the devices that make up the project, i.e. connect them to a voltage source or battery. Once switched on, the data is updated on the Ubidots platform every one-minute period. In addition, it is possible to show the evolution of the data over a certain period of time, such as the last year, the last 7 days or the last hour.

Figure 5.2 corresponds with a window of the Ubidots application, where the real-time measures can be observed.

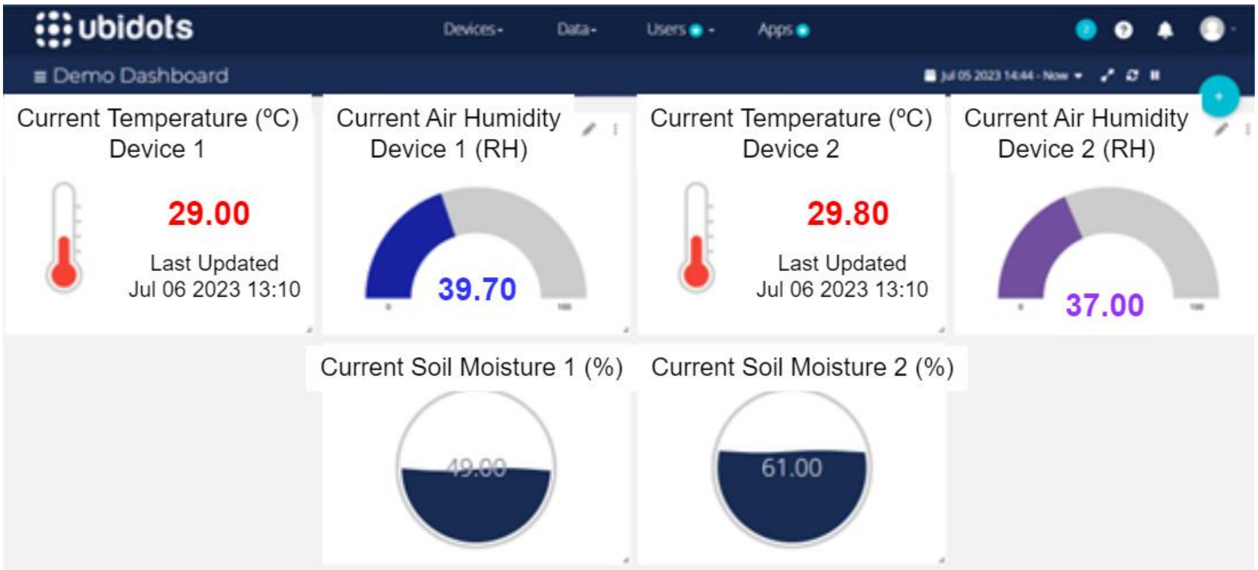

Figure 5.2: Real-time values measured by devices 1 and 2

The application also provides graphs to see the evolution of the measurements. For example, the following figures show the data collected for air humidity and temperature over a two-hour period. In this case the data is updated every minute.

Figure 5.3 and 5.4 correspond to air humidity graphs for devices (sender node) 1 and 2 respectively.

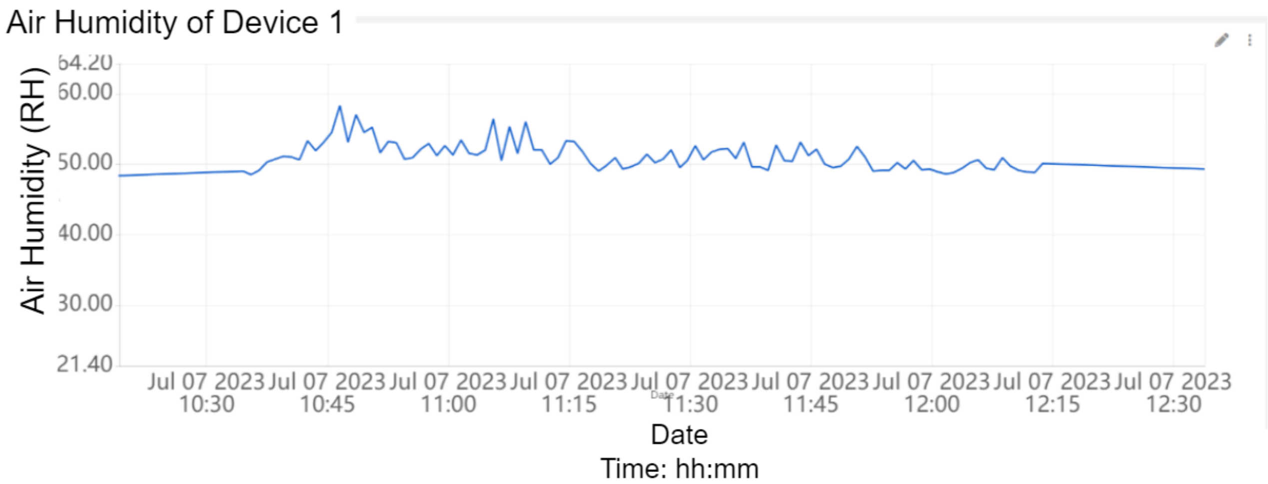

Figure 5.3: Line chart of air humidity measured by device 1

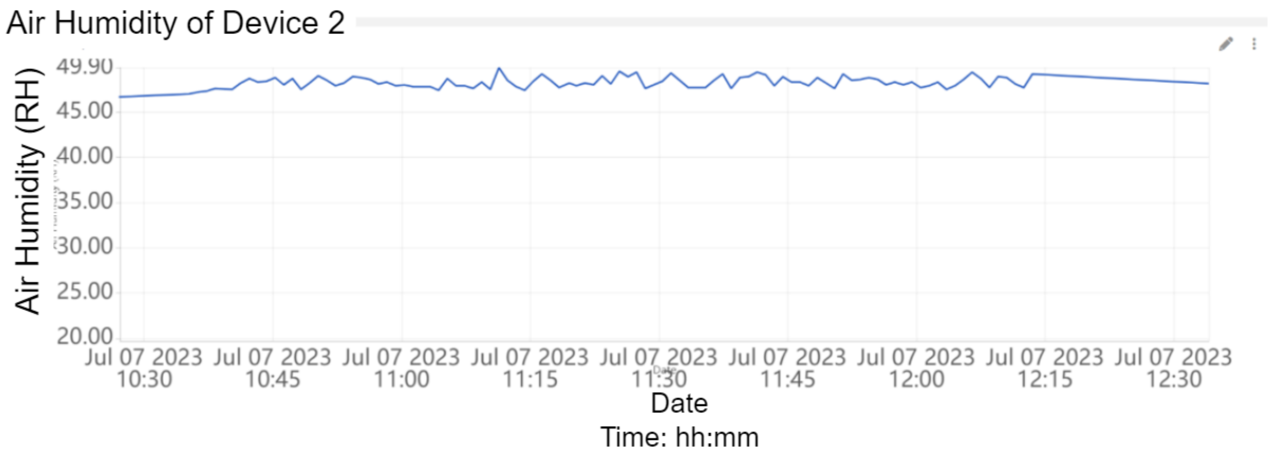

Figure 5.4: Line chart of air humidity measured by device 2

As can be seen in the graphs, during the two-hour period the humidity of air above

the plants is around 50 percent (Relative Humidity). The second device is slightly below (47 RH). These values are neutral, neither too high, meaning high humidity, nor too low. These values are acceptable, but when the humidity reaches values around 30 and 40 RH, it would be convenient to activate the irrigation system to cool the crop area.
Figure 5.5 and 5.6 correspond to air temperature graphs for devices (sender node) 1 and 2 respectively.

Figure 5.5: Line chart of temperature measured by device 1

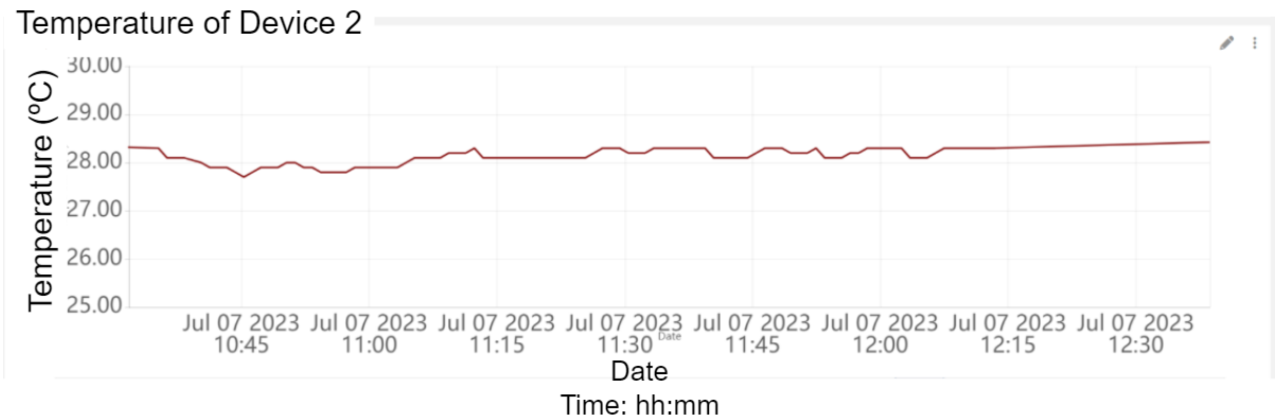

Figure 5.6: Line chart of temperature measured by device 2

In the case of temperature graphs, the values are around 28ºC. It should be taken into account that the values shown were taken in the summer season and between 10:45-12:45 am. Given these circumstances, it is expected that afternoon temperatures will be higher.

If the farmer feels that the air temperature over his crops is high and they are very exposed to the sun, the farmer could activate for example a motorised extendable awnings that provide shade and reduce the temperature.
It is also interesting to analyse these measures over a full day. Where in would be clearly seen a gradual decrease in the temperature values when the night appears and a gradual increase of the temperatures when the day begins.

5.3 Data Storage

In addition to the Ubidots platform, it was considered important to store the data on the Raspberry Pi.
In order to transmit the data from the Gateway to Ubidots, the Raspberry Pi needs to be connected to WiFi, so if there is no WiFi, the data will be lost.
To prevent this from happening, a database has also been created in the Gateway, it stores the data received without the need to connect to WiFi.

The data is stored in a table that has been created in the database. This table consists of six columns, each column corresponds to a variable.
These variables are temperature, air humidity, soil moisture (percent), sender node ID (sensor) and Timestamp.

Figure 5.7 shows a screenshot of the table storing the three measurements, the sensor ID and the date-time.
It is relevant to note that the number of rows can be infinite, since a new row is created each time data is stored, and that rows with the same sensor ID and timestamp cannot be repeated simultaneously.

temperature	humidity	soilmoisture	sensor	timestamp
30.70000076	26.20000076	56	2	2023-07-07 19:48:03.123461
31.20000076	26.79999924	49	1	2023-07-07 19:48:17.604372
30.70000076	26.29999924	56	2	2023-07-07 19:49:03.284967
31.20000076	26.70000076	50	1	2023-07-07 19:49:17.767912
30.70000076	26.29999924	57	2	2023-07-07 19:50:03.453113
31.20000076	26.89999962	50	1	2023-07-07 19:50:17.93416
30.70000076	26.29999924	58	2	2023-07-07 19:51:03.617654
31.20000076	26.70000076	48	1	2023-07-07 19:51:18.098836
30.60000038	26.39999962	60	2	2023-07-07 19:52:03.782125
31.10000038	26.70000076	47	1	2023-07-07 19:52:18.263749
30.60000038	26.5	56	2	2023-07-07 19:53:03.929061
31.10000038	26.79999924	49	1	2023-07-07 19:53:18.428971
30.60000038	26.5	59	2	2023-07-07 19:54:04.083994
31.10000038	26.89999962	48	1	2023-07-07 19:54:18.59395
30.60000038	26.70000076	59	2	2023-07-07 19:55:04.257124
31.10000038	26.89999962	48	1	2023-07-07 19:55:18.731593
30.60000038	26.60000038	58	2	2023-07-07 19:56:04.42186
31.10000038	27	48	1	2023-07-07 19:56:18.876241
30.60000038	26.5	55	2	2023-07-07 19:57:04.568098
31.10000038	26.89999962	48	1	2023-07-07 19:57:19.05178
30.60000038	26.5	56	2	2023-07-07 19:58:04.722793

--More--

Figure 5.7: Collected data in the database

Chapter 6

Global cost project considerations

6.1 Cost Analysis

As in every project the financial part is an important key for deciding whether the project is feasible.
A breakdown of the costs of the project is given below:

1) Material costs:

- ESP32 (DollaTek LORA32 868Mhz ESP32):
  Number of units needed: 3
  Unit price: 30 €
  Total cost: 90 €

- Raspberry Pi 4B 2GB:
  Number of units needed: 1
  Unit price: 99 €
  Total cost: 99 €

- DHT22 sensor (AZDelivery DHT22 AM2302):
  Number of units needed: 2
  Unit price: 9.50 €
  Total cost: 19 €

- Capacitive soil moisture sensor (TECNOIOT 2pcs):
  Number of units needed: 2
  Unit price : 4.24 €
  Total cost: 8.48 €

- Battery (EEMB Batería 3.7V Litio):
    Number of units needed: 2
    Unit price: 15 €
    Total cost: 30 €

- Greenhouse (Susany Invernadero Portátil de Jardín):
    Number of units needed: 1
    Unit price: 144 €
    Total cost: 144 €

- LED Grow Light for Indoor Plants (Sondiko LED Grow Light):
    Number of units needed: 3
    Unit price: 15.96 €
    Total cost: 47.88 €

==

Total cost of the material products: 438.36 €

2) Human personal costs:

One engineer is considered for undertaking all the work required for the development and implementation of this project.

-Number of working hours: 220 hours
    Price per working hour: 30 €

Total human personal costs: 6,600 €

3) Other miscellaneous costs:

- Costs per month: 20 €
    Months: 2.5

Total other miscellaneous costs: 50 €

Final considerations:

The global total cost of the project would be 7,088.36 €.
This project intends to be a low-cost project.
In this case, the final total cost is a bit high.
The human personal cost particularly increases the price of the project.

The hours estimated for the project's development is 220 hours, considering that it was developed by a recently graduated engineer.

If this work would be developed by a long experience professional specialized in this IoT field, the hours worked on could be reduced to 110 hours, however the price per hour worked is much higher. And so, the project's total cost would be 3,788.36 € if the price per hour worked is maintained (30 €/hour).

Chapter 7

Final conclusions and future work

7.1 Conclusions

Internet of Things (IoT) projects, such as the one developed in this work, can positively contribute to people's daily lives.

In this case the aim of the project is to provide crop care related information to the farmers. As explained along this memory, the user (farmer) access the Ubidots platform and can view real-time data on temperature, air humidity and soil moisture from there. In addition, with the graphics provided by the application, the farmer can make an analysis of how these parameters change over time.

In view of this, it can be concluded that IoT technology is an interesting tool that, when used wisely, can bring considerable improvements to our society, particularly to farmers requirements.

Besides, this project aims to promote traditional and sustainable farming methods while implementing new IoT technologies that can bring improvements in crop care. IoT technology is a key tool that collects information from an object of study, for example data related to crop care, which can be useful to predict situations, automate processes and even improve activities.

The IoT tool is very broad and allows a large variety of projects to be realised. In particular, projects that connect agricultural processes with technology can make an important contribution to facing humanity problems such as lack of resources and global warming.

This project is seen as contributing to the implementation of new technologies and infrastructure in unpopulated and less accessible areas. It also provides a solid tool to control consumption and production of scarce resources, such as water, on farming processes.

Regarding to the technical development of the project, the LoRa network protocol used must be particularly highlighted. LoRa has been a major tool for carrying out this work and the corresponding achievements. It was chosen for its long-range capacity and low power consumption. These are relevant and necessary network protocol characteristics to develop an IoT project in areas such as the countryside.

Also two hardware elements, that have been used in this project, that must be particularly highlighted are:

1) ESP32 modules, it is important to mention their easy handling and the possibility for connecting to the sensors of temperature, humidity and soil moisture. They also receive and send information correctly through LoRa.

2) Raspberry Pi, it is a mini-computer. This device acts as the Gateway of the system. Its functions consist of receiving via LoRa the data collected from the field, storing it in a database and transmitting it via HTTP to a web platform, in this case Ubidots.

Personal conclusions,

This work has allowed me to broaden my knowledge and to get acquainted with technology tools such as IoT. Specifically related to the LoRa network protocol. In addition it has allowed me to get deeper into the programming field in C and Python, and working closely with devices such as ESP32 modules, Raspberry Pi and sensors.

Challenges have also been appearing during the development of the project that have gradually been solved by looking for and identifying alternatives and improving processes.
Working in this project has been a great challenge for me and I have been able to learn new skills useful for my professional future.

In addition to the technical content that this project has given me, I would like to include the importance of evaluating whether the results make sense and the continuous learning of interesting new concepts, specially related to software development.

7.2 Future work

This project is very expandable in my opinion. As already mentioned in the beginning this project aims to be implemented on a large scale in a field. But due to reasonable reasons it will be implemented in a greenhouse with two shelves.

If implemented in the field, the project could be extended to be as self-sufficient power as possible, by setting up solar panels placed in the field.

Another interesting extension would be to automate a care system based on the measured parameters. For instance, an automatic watering system would be activated if the soil moisture is below a minimum value.

In this project three environmental parameters have been measured. This could be very extensible to many more measurements. For example light sensors that measure the solar radiation, CO_2 in the environment, or wind speed.

In relation to the user's application web, it would be possible to create a server with all the user accounts, this would complement and perhaps avoid the use of others applications such as Ubidots.

Appendix A

Sustainable Development Goals

IoT-based agriculture contributes to some of the goals set by the United Nations to be achieved by 2030. The first goal to which this type of systems can be related is number 9: "Industry, innovation and infrastructure". The combination of traditional agriculture with IoT technology gives rise to a new type of innovative agricultural activity that enables, for instance, food production to be more efficient and productive. In addition, it brings and implements new technologies in a more consolidated way to areas such as the countryside where they have low connectivity and infrastructure.

This project is also considered to contribute to the goal number 12: "Responsible, consumption and production". It is considered to contribute to this goal by improving both consumption and production activities.
On the consumption aspect, in agricultural activities farmers use fertiliser and pesticide products, which are useful for crop growth but harmful to the ecosystem. With an IoT system based on smart agriculture, the consumption of these products could be controlled and reduced. This would lead to a more sustainable agriculture. The same applies with water resource, these IoT smart systems can contribute to a more effective use of water. For example by automating irrigation processes only when necessary.
Concerning production activities, it can also be controlled. This could be done by using predictions based on IoT-data collected from previous processes. These analyses can contribute to efficient decision-making by farmers.

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