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Design of a beehive monitoring platform

Dissertation Submitted to the Department of Electronics in Partial Fulfillment of the Requirements for the Degree of Master

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Summary

In this work, we will create an internet-connected application to track the activity of the hives to facilitate the work of the beekeeper. Our work consists of two parts, the first part is the electronic system for each box, where sensors are placed on it to measure temperature, humidity, and weight to send these measurements to the station. The station receives these measurements and sends them to the cloud (Firebase) and then sends them to the second part of the system, which is an application that allows displaying the changes of the measurements in the form of graphical curves.

ملخص

في هذا العمل سنقوم بإنشاء تطبيق متصل بالأنترنت من اجل تتبع نشاط خلايا النحل وذلك لتسهيل عمل النحال. ويتكون عملنا من جزئين الجزء الاول وهو النظام الالكتروني الخاص بكل صندوق حيث يوضع عليه حساسات لقياس درجة الحرارة ونسبة الرطوبة وكذلك الوزن ليرسل هذه القياسات الى المحطة. تستقبل المحطة هذه القياسات وترسلها إلى سحابة (فايربيس) ثم يرسلها إلى الجزء الثاني من النظام وهو تطبيق يسمح بعرض تغيرات القياسات على واجهة التطبيق.

Résumé

Dans ce travail, nous allons créer une application connectée à internet pour suivre l'activité des ruches afin de faciliter le travail de l'apiculteur. Notre travail se compose de deux parties, la première partie est le système électronique pour chaque boîte, où des capteurs sont placés sur celle-ci pour mesurer la température, l'humidité, et le poids afin d'envoyer ces mesures à la station. La station reçoit ces mesures et les envoie au nuage (Firebase) puis les envoie à la deuxième partie du système, qui est une application permettant d'afficher les changements des mesures sous forme de courbes graphiques.

Thanks

Allah said: "By the grace of Allah and by His mercy, so let them rejoice, it is better than what they gather".

We thank God for giving us the courage and the will to develop our project.

This work would not have been possible without the moral support of our families. May this work be a token of our gratitude to them.

We would also like to thank our supervisor BENHAMADOUCHE who accompanied us since the beginning of this project.

The project we would also like to express our sincere thanks to the members of the jury who did us the honor of judging our work.

Without forgetting to thank all the people who contributed in any way to the realization of this project.

Dedication

Praise be to Allah, Beginning and End. Now, to begin:

I dedicate my success to everyone who proudly bears my name, to those who cleared the thorns from my path, giving me the time to pursue knowledge, which became the backbone of my journey. My father, may Allah protect and watch over you, you remain my unwavering support. To those whose prayers were the secret of my success, to those who wove threads of happiness from their hearts, to those who gave without expecting anything in return, to my angels in life, to those who sacrificed themselves, their time, their efforts, and all they have for us to reach higher levels, to my queen, my Mother. To my brother Mustafa, my sisters Khawla, Mona, Choroque and Ikrame Rhafe to the DEFFAF family,

To all the teachers and educators whose guidance led me to where I am now. To all my colleagues throughout my academic journey,

Deffaf Dounya

Dedication

Praise be to Allah, by whose grace all good deeds are completed. Peace and blessings be upon our Prophet Muhammad. I dedicate this message to my role model, the apple of my eye, my revered father, who crafted my personality and nurtured my ambitions with his tireless dedication and sacrificial love. To my dear mother, the light of my life, whose prayers were the essence of my strength and steadfastness. To my beloved siblings, my companions on the journey, whose unwavering support and encouragement were my rock and refuge in every storm.

I express my deep gratitude to my esteemed teacher, Mr. BENHAMADOUCHE Abdelouahab, whose profound wisdom and steadfast faith in my abilities, and guidance played a role in shaping my intellectual growth and academic aspirations. To all my teachers, to whom I owe much, and to all my dear friends, whose laughter, intimate friendship, and shared experiences added color and depth to my journey.

To everyone who contributed to my success, whether near or far, I ask Allah to make your efforts count in your favor.

Belayali Haroune

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General introduction

Bees, along with other pollinators, are essential to the proper functioning of the ecosystem. If these species are threatened by the effects of human misbehavior, the whole ecosystem is seriously affected. Physicist Albert Einstein once said, "If all the bees were to disappear from this world, man would have only four years to live.

Protecting bees is therefore essential to human survival. Protecting bees involves monitoring them, their habitat and changes in their environment. Researchers are developing technological solutions for remote monitoring of bees, hives, etc. using IoT technology.

IoT is the domain of the network in relation to consequences, results and actions via the internet enabling them to send and receive data. Here, things are linked together without human intervention for automatic identification of planned activities. The IoT helps to share sensor information via the wireless network, to identify and exchange information in an open IT network, and to manage the system seamlessly.

The final aim of our project is to design a beekeeping monitoring platform that enables beekeepers to monitor, evaluate and control their hives remotely in real time from a smartphone, while preserving biodiversity. This platform contains the following parts: a subsystem connected to each hive to measure temperature, humidity and weight, another system to manage the measured data and retrieve them via an internet server and send them to the android application.

This dissertation is divided into four chapters, through which we describe the work involved in designing and building our system: the first chapter presents definitions of the various beekeeping terms, the problems associated with the daily work of beekeepers, and existing solutions for monitoring hives. The second chapter presents the analysis of the system, showing the general concept as well as the concept of the specifications by enriching them with different diagrams. The third chapter presents the hardware and the software used for the project, detailing the operation and characteristics of each component. The fourth chapter provides methodological details for the design and realization of our system. We will present the tests and measurements carried out experimentally.

Finally, we'll end this dissertation with a general conclusion outlining the contribution of our achievement, and the future prospects of our work.

Chapter 1
Beekeeping Overview

1. Introduction

Beekeeping is a branch of agriculture that consists of raising honeybees for the utilization of hive products, mainly honey. The beekeeper must provide the bees with shelter, care and attention to their environment.

This chapter is devoted to a brief overview of the beekeeping sector and methods of hive protection. In addition, we will a slight survey on electronic and connected hives, including some commercial examples and projects currently available for hive monitoring, then we will enumerate their characteristics and advantages.

2. Beehives

2.1. Definition

A beehive is an enclosed structure in which some honey bee species live and raise their young. Though the word beehive is used to describe the nest of any bee colony, scientific and professional literature distinguishes nest from hive. Nest is used to discuss colonies that house themselves in natural or artificial cavities or are hanging and exposed. The term hive is used to describe an artificial/man-made structure to house a honey bee nest. The nest's internal structure is a densely packed group of hexagonal prismatic cells made of beeswax, called a honeycomb. The bees use the cells to store food (honey and pollen) and to house the brood (eggs, larvae, and pupae), Beehives serve several purposes, these include the production of honey, pollination of nearby crops. In America, hives are commonly transported so bees can pollinate crops elsewhere. [1]

2.2. The different types of hives

Beekeepers use several types of hives, which differ depending on the breeding technique and the region of implantation of the bee breeder [2]:

- ✓ Natural hives: Horizontal hives that do not use prefabricated frames or wax. Insects produce and build everything they need in this type of hive.
- ✓ Traditional beehives: Natural, sustainable, economical and easy to use. This type of hive includes straw hives, stem hives, Kenyan hives and Alsatian hives. Alsatian beehive
- ✓ Modern hives: also known as vertical frame hives Are the most common type of beehive used in beekeeping today. This category includes the Dadant hive, a modern standard. Then there's the Warre hive, better known as the popular hive, a device that helps make the beekeeper's job easier.

2.3. Parts of a modern Beehive

1. Hive Stand
2. Bottom Board
2a. (Alternative) Screened Bottom Board
3. Hive Body (AKA Brood Chamber, Brood Nest, Brood Box, Deep Super)
4. Queen Excluder
5. Honey Supers (AKA Shallow Super)
6. Inner Cover
7.Outer Cover

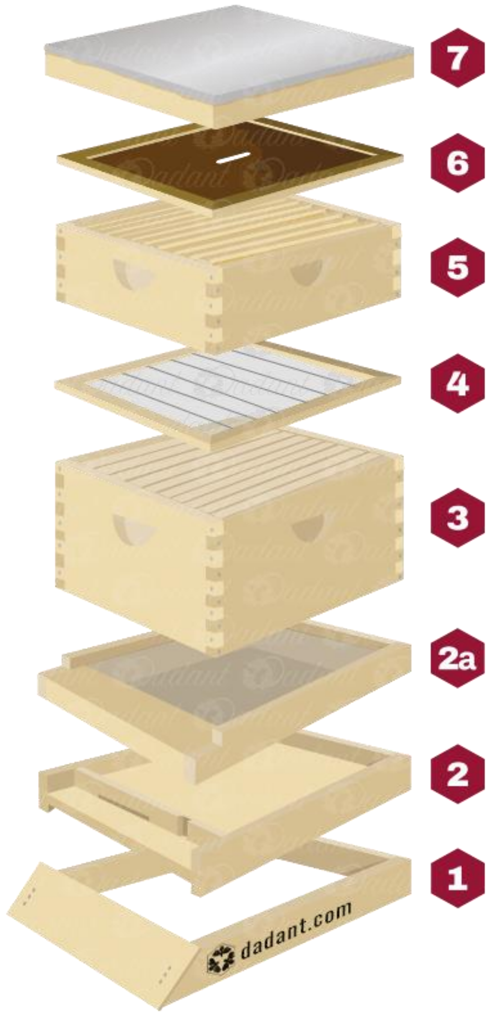

Figure 1.The components of a beehive.

3. Bee health and care

3.1. Location of the apiary

An apiary is a location where beehives are kept. Apiaries come in many sizes and can be rural or urban depending. The location chosen for the apiary must fulfil certain criteria:

- Quiet and away from any source of chemical contamination.
- Free of shrubs, Well-lit.
- Sunny but protected from excessive heat.
- Protected from wind and air currents (natural obstacles).
- Dry and away from moisture.
- Close to plants, trees and vegetable flowers and plant some of them if necessary.
- With a wide range of plants nearby to ensure flowering all year round.
- Near a water source.
- Away from other apiaries on the same farm.

3.2. Optimal hive parameters

Bee are a fragile creature; their health remains delicate and their existence depend significantly on environmental factors and climate variation. Below we present the most important parameters that impact their life.

A) Ideal temperature: Regulating the temperature and relative humidity inside the hive around the optimum value is a critical function in maintaining the right conditions for rearing larvae and pupae. Larvae and pupae are said to be "stenothermic", because their survival and growth depend on maintaining the temperature within a low range (33-36°C), while adults can tolerate high temperature changes ("eurythermic"). Thermoregulation processes within the colony therefore require the ability to produce heat by grouping workers together and their muscle contractions, or reduce it by dispersing workers and evaporating water with their wing beats.

B) Ideal humidity: The relative humidity in the hive must be higher in temperate climates than in atmospheric conditions.

c) Perfect lighting: The hive should be placed in a sunny spot, because:

- Bees do not like extreme cold,
- Brood requires an internal temperature of 36 degrees centigrade,
- The sun helps to dry the flight board and faces in the hive,

Bees also need shade:

- The wax must remain firm, otherwise the hives will become deformed. At high temperatures (60°C), the wax melts.
- The workers need to ventilate the hive.

3.3. Bee diseases and care

The World Organization for Animal Health “WOAH” lists six diseases in the category of bee diseases [3]:

- **Acarapiosis**

Caused by a microscopic mite, called a tracheal mite, which is an internal parasite of the adult bee's respiratory system, which feeds on the hemolymph. The infection is spread by direct contact, and newly hatched bees are the most susceptible. The diagnosis is made by visualizing the mites in the trachea.

Care: Do not introduce the parasite into an apiary via purchased colonies or queens. Purchased queens. There is no vaccine against the disease.

- **American foulbrood**

Is a serious disease of honey bees. It is caused by a spore-forming bacterium bacteria and is present throughout the world. The bacteria kill the larvae in the brood cell. In infected honey bees, the colony has a mottled appearance due to empty cells, American foulbrood is spread by bacterial spores formed inside infected larvae, which are very resistant and can survive for many years, the spores spread the disease through the transfer of wax, queens, or exchange of combs or by contaminated honey. Diagnosis is confirmed by identification of the bacteria using molecular techniques, culture or microscopic examination.

Treatment: Antibiotic treatment destroys the vegetative forms of the bacteria but does not kill the spores, leading to a recurrence of the disease.

Kill the spores, leading to a recurrence of the disease. Consequently, it is often recommended to burn the hive and equipment, which is sometimes the only way to destroy the spores.

Below are other diseases that can affect bees but are less aggressive:

- European foulbrood
- Small hive beetle infestation
- Tropilaelaps
- Varroosis

3.4. Enemies of bees

Bees have no shortage of sworn enemies. There are currently around thirty pathogens, predators and parasites that attack bee hives, the most common of them are:

- Hiver aiders.
- Diseases: Viruses, bacteria and even fungi attack bees.
- Parasites: Among the parasites, spiders (8 legs) are the most common, but there are also insects (6 legs) such as the bee louse (or bee mite).
- Solutions
- A biological weapon: Cold and heat and humidity.
- A surveillance system to monitor activity in the hive.
- Spy cameras and GPS beacons.
- Reducing the size of hive entrances.

4. Existing connected hives [4]

This is a hive equipped to monitor the behavior and health of the colony that it. It is equipped with a battery of sensors, recorders and transmitters linked to an on-board microprocessor an on-board microprocessor. Many solutions exist in literature and others available on the market, with several companies offering diverse electronic systems to help beekeepers in their work.

4.1. Hive scale

Hive scales can be removable or permanent, they are easy to use and can be adapted to the size of the hives. Depending on the model, they can measure hives weighing up to 100 kg. Prices range from €40 to €100. However, beekeepers should consult them on site to measure the weight of their hives.

Figure 2.Non-connected beehive scales.

4.2. VILKO model

The ALYA company offers the VILKO product (Figure 3), which contains the electronics needed to measure the weight of the hive and some meteorological parameters. The device then transmits data via GSM.

Figure 3. Hive placed on an ALYA weighting system.

Features :

- Basic measurements: weight, temperature, battery status, accelerometer.
- Battery powered.
- Advanced measurements: temperature and external humidity.
- Data sent by SMS or internet.
- Adjustable operation:
  - Number of SMS messages/24hours.
  - Set alarm conditions.
  - Set telephone number (5 numbers max).

Technical parameters:

- Maximum weight: 200 Kg with an accuracy of 0.1 Kg.
- Operating temperature - 10 to + 50°C.
- 6V battery supply voltage.
- Battery capacity 3-4 months (at 2 SMS / day).

4.3. Bee Online model

Bee Online offers several types of simple connected measuring station, differentiated by the number of sensors built into them.

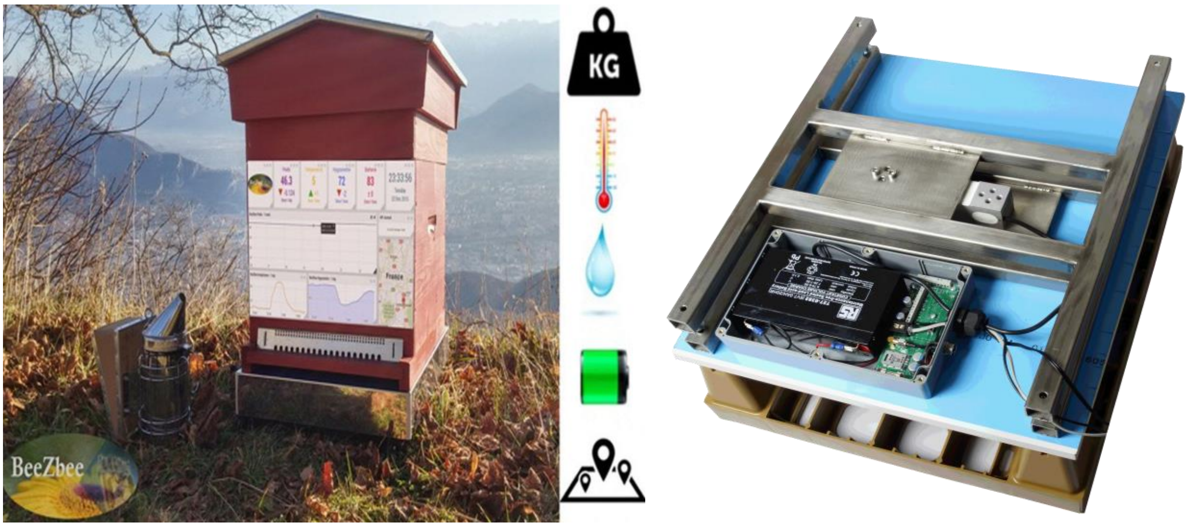

Figure 4.Bee Online connected measuring station for beehives.

Features :

- Quick and easy to install.
- Identify colony status.
- Online monitoring of readings: simple, intuitive interface.
- Access via mobile phone, daily readings, configuration via Internet or Smartphone, SMS alert in the event of theft or fall.
- Remote management of Bee online measurement stations using proprietary software.
- Data backup on a server (10 daily measurements).
- 2 years of measurements and communication without recharging.

Technical parameters:

- Weight measurement: from 0 to 100 kg with 100 g accuracy.
- Temperature measurement: internal/external from -20° +50°C - accuracy 0.1°C.
- Rainfall measurement: in mm/m² with an accuracy of 0.2 mm.
- Humidity measurement: internal/external from 0 to 100% - accuracy 0.1%.

Price: From €420 (depending on model)

4.4. Bee label

The Label Abeille connected hive (Figure 5) is designed to simplify the operation of a hive, make it easier to maintain the swarm and protect the species. A scale placed under the hive provides access to information such as light, temperature, mass, humidity, atmospheric pressure and orientation. In the event of theft, it is also equipped with a geolocation system.

Figure 5.The Label Abeille connected hive

Features:

- Batteries rechargeable.
- Geolocation.
- Anti-theft system.
- Setting alert thresholds.
- Receive alerts by email or SMS.
- Activation of anti-theft and power management alerts.
- Parameter measured :
  - Mass: up to 500 kg with an accuracy of 1g.
  - Temperature.
  - Orientation.
  - Brightness.
  - Humidity.
  - Atmospheric pressure.
- Selectable data reading frequency: every hour, every 2 hours, 6 times a day or 2 times a day.
- Transmission mode selection: GSM or LoRa.

Price: EUR 420 (depending on the model)

4.5. Modèle CAPAZ GSM200

The GSM200 scale automatically takes electronic readings of a wide range of data: hive weight, temperature, rainfall, humidity and brood temperature, humidity and brood temperature. The data collected is transmitted daily by mobile phone by SMS or e-mail or to the CAPAZ Direct server. Telemetry is based on SMS technology, so even a weak signal is enough to send an SMS. There is a hive alarm (abnormal weight loss, vandalism, theft).

They are made up of two parts, the station itself and the laptop, which can be detached from the structure.

Figure 6.The CAPAZ GSM200 connected beehive.

Features :

- Basic measurements: weight, temperature, humidity.
- Rain gauge (optional).
- Transfer via GSM by SMS or E-Mail.
- 7 or 9 measurements per record.
- Software as standard equipment, database, graphical evaluation.
- Security / access protection / alarms (abnormal weight loss).

Technical parameters :

- Maximum weight up to 200 kg with 100 g accuracy.
- Temperature sensor in hive body +/- 0.5° C accuracy (optional).
- Extension cable, portable distance and scale up to 50 m (optional).
- Internal memory 1700 measurements.

- RS232 interface for downloading.
- Battery life up to 200 days, rechargeable battery 12V, 7.2 AH.
- Operating range -10° C - +45° C.

Price: From €1,300 (depending on option).

4.6. OpenHiveScale station

The OpenHiveScale station is an open-source electronic/mechanical system for remote monitoring of your hives that is robust, easy to use and adaptable. Based on the principle of the Roman balance, a motor moves the counterweight and an optical sensor detects the balance of the load to deduce the weight of the hive.

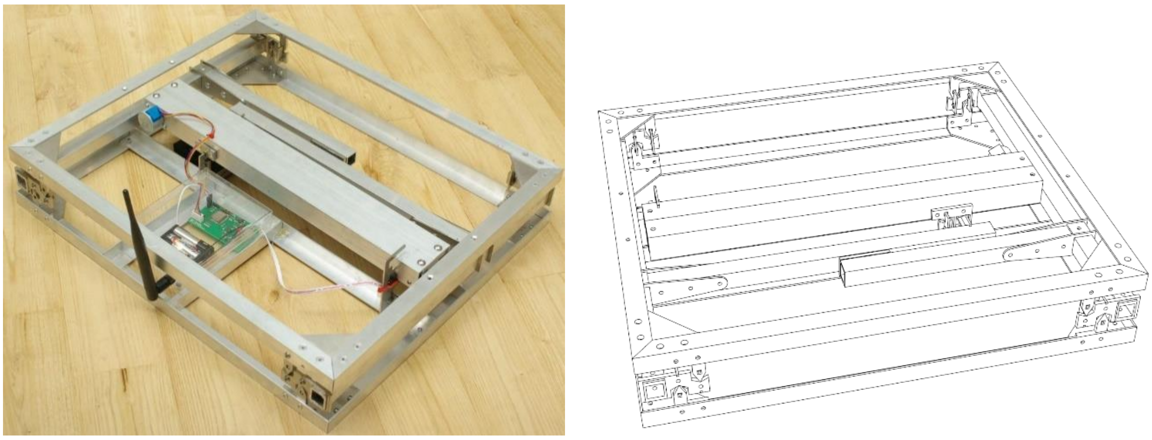

Figure 7. OpenHiveScale open source station

All the mechanical drawings, electronic diagrams, typon and software sources are available on GitHub. The software used is all free and/or open source.

Features :

- Connectivity: Wi-Fi, Sigfox, GSM.
- Battery life: 2 to 5 years with 3 AA alkaline batteries (depending on the number of measurements per day) autonomy of 1325 measurements.
- 125 kg standard version with 30g accuracy.
- Weight variation alarm (+/-).
- Designed for professional palletised beekeeping, affordable for hobbyists, reliable data for researchers.
- Number of data transmissions can be set manually or automatically according to weight variation.
- Ultra-upgradeable thanks to the Wifi module available on all versions, enabling you to add the sensors of your choice wirelessly.

5. Conclusion

In this chapter, we explained the framework and general background of the project in two parts. In the first part, we touched on beekeeping, hives, their components, organisation and ideal standards, we also discussed ways to protect the hives and emphasised the role of bees in influencing the climate. In the second part, we introduced mesh hives and some of the systems available on the market and their characteristics and advantages, and in the next chapter we will study and present the methods and equipment used in our project.

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CHAPTER 2
TECHNOLOGICAL REQUIREMENTS

1. Introduction

After presenting briefly beehive monitoring systems in the previous chapter, in this chapter we will analyze the needs of our system by identifying most important requirements as well as the design constraints. This analysis will allow us to take into consideration all facets of our system from the start of the design, it will also allow us to think about the way in which our system will interact with its environment as well as with the user.

In a such design, the interaction between the system and its environment is a critical issue in the elaboration process, for that reason we will discuss in detail the possible communication solution that could be applied in this kind of system.

2. System analysis

The aim of our project is to design a beekeeping monitoring platform for beekeepers, which will save them a great deal of time and effort. Our work concerns improving the capabilities of beehives for monitoring need by equipping them with a set of instruments and sensors, which can also be used to monitor the apiary remotely and in real time. This is done using an autonomous system that collects the necessary data and communicates it to a smartphone via an internet connection.

Basically, this system is divided into three parts:

- ✓ An electronic board including a processing unit with embedded firmware;
- ✓ A communication interface to connect the hardware board to the Internet;
- ✓ An Android application for distant monitoring associated with a cloud server services.

2.1. Simple system sketch

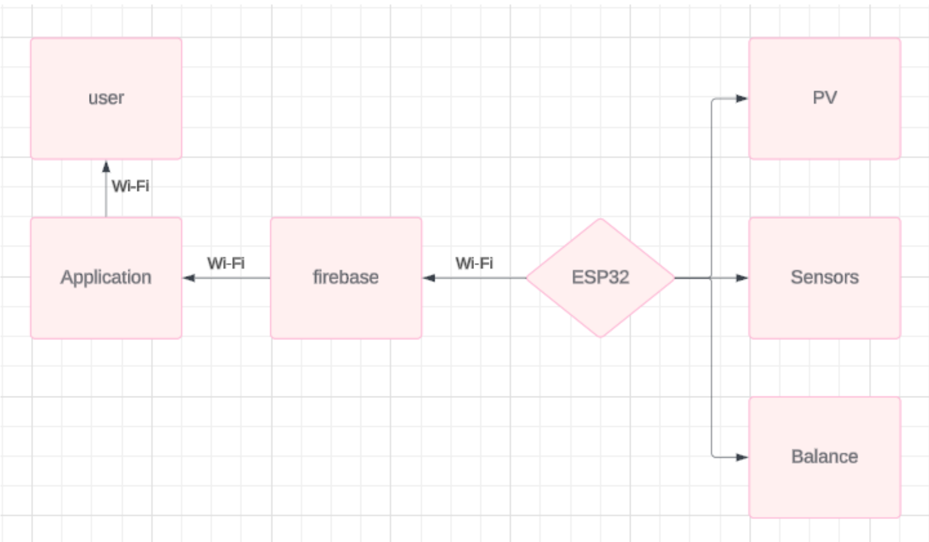

Figure 1 : Diagram of a simple system model

2.2. Reconfigurable design

Our project aims to develop an integrated system that combines multiple technologies to fulfil diverse customer needs. The project can include collecting data from multiple sensors, sending data to a cloud database, and providing a user interface for customer interaction. The choice of technology depends on specific customer needs such as communication range, power consumption, data speed, and security.

By selecting the right technology based on project needs (range, power consumption, transmission speed, etc.), efficient performance and user experience can be achieved. GSM, LoRa, NRF24, Wi-Fi, Bluetooth and ZigBee all have their own distinct uses, and the choice of cloud platform between AWS, Google Cloud and Azure depends on the requirements for analysis, storage and integration with other tools.

3. Communication interface solutions

The most critical choice for our system design is the communication interfaces, this choice depends in diverse considerations including the apiculture needs, in this section we present different means of communication such as GSM, Lora, Wi-Fi, Bluetooth and NRF 24.

3.1. GSM (Global Mobile Network)

GSM (Global System for Mobile communication) is a digital mobile network that is widely used by mobile phone users in Europe and other parts of the world. GSM uses a variation of time division multiple access (TDMA) and is the most widely used of the three digital wireless telephony technologies: TDMA, GSM and code-division multiple access (CDMA). GSM digitizes and compresses data, then sends it down a channel with two other streams of user data, each in its own time slot. It operates at either the 900 MHz or 1,800 MHz frequency band. [1]

3.2. LoRa (Long-Range)

LoRa (Long Range) is an emerging wireless communication technology developed by US Semtech, an ultra-long-distance wireless transmission scheme based on spread spectrum technology. Lora changes the previous way of thinking about the compromise between transmission distance and power consumption. Provide users with a simple wireless communication solution that can achieve long distance, long battery life and large capacity. [2]

3.3. NRF 24 (Wireless Communication Module)

The nRF24L01 is a 2Mbps ultra-low power (ULP) RF transceiver IC for the 2.4GHz ISM (industrial, scientific and medical) band. With peak RX / TX currents of less than 14 mA, a sub-µA power-down mode, advanced power management and a 1.9 to 3.6 V supply range, the nRF24L01 provides a true ULP solution that delivers months, even years, of battery life when operating on AA / AAA batteries. The Shock Burst™ hardware protocol accelerator also enhances the time-critical protocol functions of the application microcontroller enabling the implementation of advanced and robust wireless connectivity with low-cost third-party microcontrollers. [3]

3.4. Wi-Fi

Wi-Fi, short for Wireless Fidelity, provides high-speed wireless internet and network access using radio waves. It operates on both 2.4GHz and 5GHz radio bands and can achieve much higher data transfer speeds than Bluetooth.

With a wireless router or access point, Wi-Fi is used for convenient wireless internet access up to 50 meters. With no line-of-sight required, Wi-Fi is convenient for connecting the Internet and other devices through access points that create wireless local area networks (WLANs). Wi-Fi excels at portable wireless internet access and ad hoc networking. [4]

3.5. Bluetooth

Bluetooth is a short-range wireless standard for connecting mobile and fixed devices over 10 meters or less. It uses frequency-hopping spread spectrum technology in the 2.4GHz band to avoid interference and fading.

Bluetooth is designed for robust, low power, low cost wireless connections. It has evolved through several versions improving data rates up to 3 Mbps. Bluetooth Low Energy (BLE) provides ultra-low power consumption for IoT devices. Overall, Bluetooth excels at short-range wireless connections between devices for audio, data transfer, and control functions. [4]

3.6. ZigBee

ZigBee is a low power, low data rate protocol. Based on the IEEE 802.15.4 standard, ZigBee focuses on simple, self-organizing mesh networks between low battery-powered devices. Operating in various unlicensed radio bands including 2.4 GHz, ZigBee uses Direct Sequence Spread Spectrum modulation to provide reliable data transmission up to 100 meters away.

With data rates up to 250 kbps, ZigBee is suited for periodic or intermittent transmission of small data packets. Common ZigBee applications include smart lighting, thermostats, security systems and other simple IoT devices that do not require high bandwidth. ZigBee is optimized for low-power device networking. [4]

4. Local connections

4.1. Deference between Communication protocols

	Bluetooth	**Wi-Fi**	**ZigBee**
Specification authority	Bluetooth Special Interest Group (SIG)	IEEE Standards Association	ZigBee Alliance
Standard	802.15.1	802.11	802.15.4
Frequency band	2.4 GHz	2.4 GHz and 5GHz	2.4 GHz, 850 – 930 MHz
Data rate	1-3 Mbps	10-100+ Mbps	20-250 Kbps
Transmission range	Up to 100m	Up to 100m	Up to 100m
Power consumption	Very low	High	Low
Network topology	Ad hoc, point to point, sta	Point to hub, ad-hoc	Mesh, star, tree, ad-hoc
Security	62 bit, 128 bit	Authentication service set ID (SSID)	128 bit AES and application layer user defined
Complexity	Very complex	Complex	Simple
Cost	Medium	Low	High
Application	Wireless audio streaming and data transfer, smart wearables and fitness trackers, beacon networks	Wireless local area network connection, broadband Internet access	Home automation and control, industrial monitoring sensor network

Table 1 : Difference between communication protocols

4.2. Pros and cons of wifi, Bluetooth, and ZigBee

Bluetooth	Pro	Low power consumption: Bluetooth devices operate on batteries for longer periods due to lower energy use compared to Wi-Fi.	Secure transmission: Bluetooth employs data encryption protocols to securely transmit information between devices.	Wide compatibility: Bluetooth is supported on many types of devices like phones, speakers, headphones making it easy to connect.
	Cons	Limited range: The typical 10-100 meters range of Bluetooth restricts its uses to short distance connections.	Speed limitations: Data transfer speeds are much slower over Bluetooth compared to Wi-Fi.	Interference prone: Bluetooth is susceptible to interference from other Bluetooth devices as well as some electronics.
Wi-Fi	Pro	High-speed data transfer: Wi-Fi, with its high bandwidth, enables fast downloads streaming and network access.	Easy fault location: Faulty devices on a wireless network are easy to identify and replace to restore connectivity.	Easy to install: A local area network can be set up by installing one or more access points covering the whole area.
	Cons	Setup headaches: Wi-Fi networks require passwords, names, and configuring new devices, which can be cumbersome.	Power hungry: Wi-Fi uses more power compared to Bluetooth and ZigBee, which can drain batteries quicker.	Signal degradation: Walls and obstacles can weaken Wi-Fi signals reducing connectivity.
ZigBee	Pro	Extremely low power consumption: The optimized power consumption of ZigBee enables efficient transmission of small packets.	Built-in security: ZigBee includes encryption and authentication protocols to keep data secure during transmission.	Mesh network: ZigBee devices can transmit data over long distances through intermediate mesh network nodes.
	Cons	Smaller ecosystem: There are fewer compatible devices and platforms that work with ZigBee compared to the others.	Low data rates: ZigBee has much lower maximum data transfer speeds compared to Wi-Fi and Bluetooth.	

Table 2 : the pros and cons of Communication protocols

5. Cloud server

5.1. What is a cloud server?

A cloud server is a pooled, centralized server resource that is hosted and delivered over a network, typically the Internet, and accessed on demand by multiple users. Cloud servers can perform all the same functions of a traditional physical server, delivering processing power, storage and applications.

Cloud servers can be located anywhere in the world and deliver services remotely through a cloud computing environment. In contrast, traditional dedicated server hardware is typically set up on premises for exclusive use by one organization. [5]

In the next paragraphs, we introduce the major public cloud servers:

5.2. AWS

Amazon Web Services (AWS) is a subsidiary of Amazon.com, Inc. AWS is the leading provider of cloud computing platforms. AWS began as an internal cloud service in the early 2000s. Over the years, it has become the most mature, comprehensive, and widely adopted cloud platform, providing more than 200 fully functional services.

In 2021, AWS offers storage, computing, databases, application services, machine learning, deployment, and tools for mobile development and the Internet of Things (IoT), among others. AWS caters to any demand and serves millions of users: individual developers, large enterprises, and even governments.

5.3. Firebase

Google Cloud Platform (GCP) is a set of cloud computing services offered by Google. Started as an internal tool for Google projects in 2008, GCP was introduced to the public in 2011. Since then, both its popularity and its range of services have grown. Today, Google Cloud offers over 100 products to tens of thousands of customers worldwide.

GCP tools help resolve some of the toughest business challenges including the modernisation of infrastructure, data services management, the unification of data across a company, and more. Its key services include, but are not limited to data storage (Cloud Storage, Cloud Data store, Cloud Spanner), cloud-based artificial intelligence (Cloud Vision API, Cloud AutoML), big data (Big Query, Cloud Dataflow), networking, management, and so forth.

5.4. Azure

Azure is a Microsoft cloud platform that was introduced to the public in 2010. It's particularly relevant for enterprise customers as few companies offer the same enterprise background and level of support as Microsoft. Hybrid cloud is Azure’s real strength as the Azure team works hard to integrate with enterprises' data centers.

However, Azure has much to offer to young companies too. If you’re part of a startup, for instance, you can profit from a year of free cloud computing services — a great deal when you need to build and test your idea! The company’s services include storage (Table Service, Blob Service), communication, data management (Azure stream analytics, StorSimple, Cosmos DB), virtual machines, infrastructure as a service (IaaS), and more.

5.5. The difference between AWS, Azure, and Google Cloud

Even though the ‘big three’ offer the same cloud services, there are some differences between them. To see these, an AWS vs Google Cloud vs Azure comparison based on key characteristics is helpful: [6]

5.5.1. Computing resources

Compute Services		
AWS	Google Cloud	Microsoft Azure
EC2	Compute Engine	Virtual Machines
Elastic Container Service	Kubernetes	Virtual Machine Scale Sets
Elastic Container Service for Kubernetes	Functions	Azure Container Service
Elastic Container Registry	Container Security	Container Instances
Lightsail	Graphics Processing Unit (GPU)	Batch
Batch	App Engine	Service Fabric
Elastic Beanstalk	Knative	Cloud Services
Fargate		
Auto Scaling		
Elastic Load Balancing		
VMware Cloud on AWS		

Table 3 : Compute Services

5.5.2. Storage

The “Big 3” offer object, persistent block, and file storage services. In addition, each platform provides a hybrid storage environment and hardware devices that help organisations move petabytes of data locally if internet transfer isn't feasible. With regard to storage, we can conclude that AWS, GCP and Azure all offer the same services. Still, there is a difference. AWS has a Storage Gateway for backup and archive processes, while Azure and Google Cloud don't offer this. [6]

Service type		AWS	Azure	Google Cloud
Storage	Block storage	Amazon Elastic Block Store (EBS)	Azure Disk Storage	Persistent Disk
	File storage	Amazon Elastic File System (EFS)	Azure Disk Storage, Azure Files	Firestore
	Infrequently accessed object storage	Amazon S3 Glacier	Azure Archive Storage	Cloud Storage Archive
	Object storage	AWS Simple Storage Service (S3)	Azure Blob Storage	Cloud Storage
Backup Services	Archival	Glacier and Glacier deep archive	Archival storage	Nearline and Coldline
	Recovery		Recovery backups	
	Site Recovery		Site recovery	
Database	Document data storage	Amazon DocumentDB. AWS DynamoDB AWS AppSync	Azure Cosmos DB	Firestore
	In-memory data store	Amazon ElastiCache	Azure Cache	Memorystore
	NoSQL Indexed	Amazon DynamoDB	Azure Cosmos DB	Datastore
	NoSQL Key-value	Amazon DynamoDB	Azure Cosmos DB	Cloud Bigtable
	RDBMS	Amazon Aurora	Azure SQL Database	Cloud Spanner
	RDBMS	Amazon Relational Database Service (RDS). Amazon Aurora	Azure Database for MySQL and Azure Database for PostgreSQL	Cloud SQL
	Relational	Amazon RDS for Oracle	Azure Oracle Database Enterprise Edition	Bare Metal Solution

Table 4 : Types of Storage Services

5.5.3. Pricing

When you compare AWS vs Google Cloud vs Azure, you'll find that their prices are roughly equivalent. All of them provide pay-per-minute pricing at similar rates. Despite the close price points, it can be difficult to make a quick comparison between the three as they all offer different service packages, discounts, and promotions.

Machine Type	AWS	Azure	GCP
Smallest Instance	AWS charges roughly US$69 per month for a primary instance with two virtual CPUs and eight gigabytes of RAM.	In Azure, the same type of instance, i.e., an instance with 2 CPUs and 8 GB of RAM, will cost roughly US$70 per month.	Compared to AWS, GCP will supply you with the most basic instance, including two virtual CPUs and eight gigabytes of RAM, at a 25% lower cost. As a result, it will cost you around US$52 every month.
Largest Instance	The most expensive AWS instance, with 3.84 TB of RAM and 128 CPUs, will cost you roughly US$3.97/hour.	Azure's largest instance includes 3.89 TB of RAM and 128 CPUs. It costs about $6.79 per hour.	GCP leads the pack with its largest instance, 3.75 TB of RAM and 160 CPUs. It will cost you approximately US$5.32/hour.

Table 5 : The Price of services

5.5.4. Pros and cons

Here is a table with pros and cons for Azure, AWS, and Google Cloud:

	AWS
Pros	• **Vast service portfolio:** AWS is a leader in the number of solutions and services it offers to companies, including storage, analytics, ML and AI, and computing power. Essentially, it can meet any business needs. • **Global infrastructure:** AWS's data centers are scattered across the globe, allowing low-latency access and the ability to build and deploy apps close to their users, significantly improving user experience and overall performance. • **Security and compliance:** AWS provide various security features and compliance with the latest regulations. As a result, all data will be protected against breaches and leaks. • **Scalability:** Depending on business evolution, AWS allows to scale up or down quickly and select flexible computing power and network resources options.
Cons	• **Complexity:** The number of features and solutions offered by AWS can be overwhelming for those unfamiliar with the platform. Learning how to use them and manage everything can take some time, thus companies should invest in employee training if you decide to adopt AWS in your company. • **Vendor lock-ins:** It's a disadvantage of any cloud provider; migrating an apps to a new cloud platform can be burdensome. • **Pricing:** AWS's pricing models are pretty flexible, but the structure is still complex. If companies don't plan a budget or optimize costs, they can waste time and money. • **Limited support:** Here, the received support depends on the chosen plan. In some cases, the AWS support plans might not align with business requirements, so companies need to seek additional support elsewhere.
	AZURE
Pros	• **A lot of services:** Azure also impresses with its number of services. They include virtual machines, analytics, machine learning and artificial intelligence, and various databases. • **Integration with Microsoft ecosystem:** Azure is great for integration with other Microsoft products and services, such as Office 365, Windows Server, and others. • **Global presence:** Azure also distributes its services worldwide, just like AWS. • **Hybrid cloud:** This platform supports hybrid cloud deployments, so that companies can integrate on-premises infrastructure with the cloud.
Cons	• **Complexity:** Azure can also be complex for beginners, requiring learning and training. • **Documentation:** The platform offers extensive documentation, yet it can be too overwhelming. Moreover, Azure also has different support plans, and they may not suit your needs. • **Cost management:** Dynamic cloud makes managing and understanding costs challenging. You need to carefully monitor your spending or else you will be faced with unexpected expenses way over your budget. • **Service availability:** Azure offers high availability but doesn't guarantee disruptions and service outages. Yet, if you have a proper disaster recovery plan, you can take care of those problems.
	Google Cloud Platform (GCP)
Pros	• **Security:** Google's main priority is security and compliance with regulations, so all data and apps are highly protected. • **Scalability:** We can scale application resources up and down with GCP quickly. • **Global infrastructure:** GCP also offers a vast global network for potential clients worldwide. • **ML and Big Data:** GCP offers tools for big data processing, AI features, and machine learning for advanced analytics and more data-driven insights.
Cons	• **Competition:** GCP faces severe competition with Azure and AWS, often not being the first choice, so it's essential to evaluate all features and solutions wisely before making a choice. • **Cost:** Google hosting pricing has a lot of options for all types of businesses, but sometimes, the prices can rise depending on the chosen services. • **Support:** It seems to be the common disadvantage of cloud computing platforms, but GCP may not always meet needed support requirements. • **Service outages:** All cloud platforms can face service outages, so companies need to come prepared for that.

Table 6 : The pros and cons of each server

Based on all the precited features we can choose the right cloud server and the most adapted services that can fill the need of our system and application, in the present project, we opted for google cloud services.

5.6. Google cloud "Firebase" overview

Firebase is a comprehensive platform developed by Google for building mobile and web applications. It offers a wide range of features and services that help developers with tasks such as development, testing, and deployment. Here is an overview of some key components and functionalities of Firebase:

- Real time Database: Firebase provides a NoSQL cloud database to store and sync data in real time across clients. It's particularly useful for applications that require real-time updates and synchronization across multiple devices.
- Authentication: Firebase offers authentication services, allowing developers to easily integrate user authentication using email/password, phone number, social logins (Google, Facebook, etc.), and more.
- Cloud Fire store: Fire store is Firebase's newer, more scalable NoSQL database. It offers features like real-time synchronization, offline support, and more complex querying capabilities compared to the Real-time Database.
- Cloud Functions: Developers can write server-side logic using Node.js in response to Firebase events. These functions can be triggered by events in Firebase services like Fire store, Authentication, and Cloud Storage.
- Hosting: Firebase Hosting allows developers to deploy web apps quickly and securely. It offers features like SSL, CDN integration, and custom domain support.
- Cloud Storage: Firebase provides scalable cloud storage for user-generated content like images, videos, and other files. It integrates seamlessly with Firebase Authentication for access control.

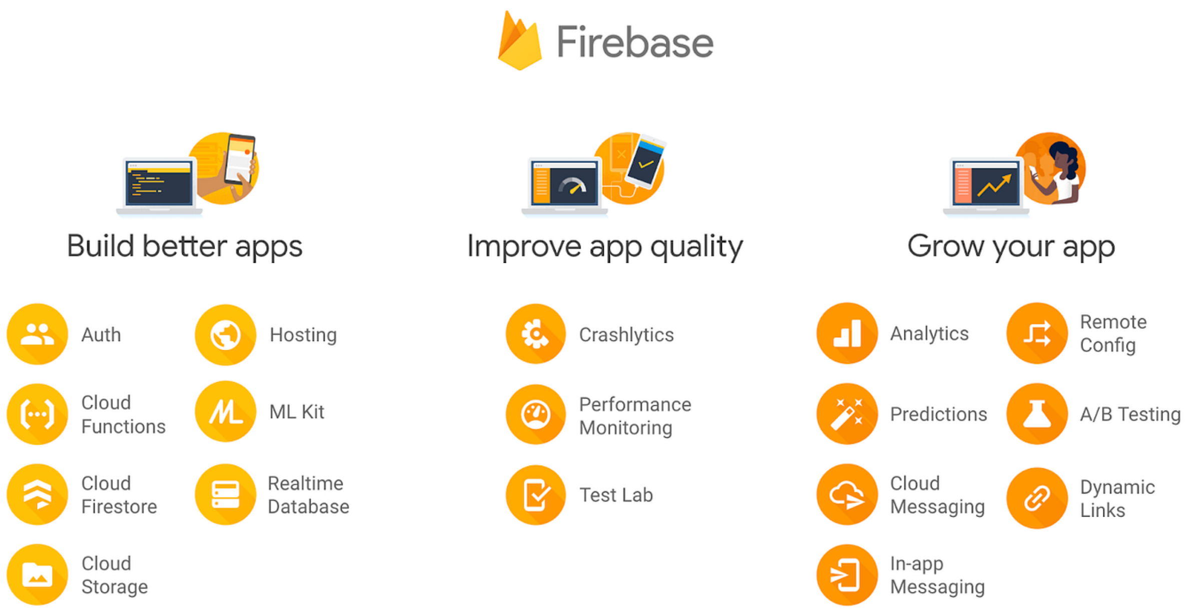

Figure 2 : Types of Firebase Services

- Machine Learning: Firebase ML Kit enables developers to easily integrate machine learning capabilities into their applications, such as image labeling, text recognition, face detection, and more.
- Analytics: Firebase Analytics provides insights into user behavior, app usage, and user engagement. It helps developers understand their audience and make data-driven decisions.
- Performance Monitoring: Firebase Performance Monitoring helps developers track app performance metrics such as app startup time, network latency, and more. This data helps in optimizing app performance.
- Remote Config: Firebase Remote Config allows developers to customize the behavior and appearance of their apps without deploying updates. It's useful for A/B testing, feature flagging, and targeted rollouts.
- Cloud Messaging: Firebase Cloud Messaging (FCM) enables developers to send notifications and messages to users across platforms (iOS, Android, and web). It supports various types of notifications, including data messages and notification messages.
- Crashlytics: Firebase Crashlytics helps developers track and prioritize app crashes and issues. It provides detailed crash reports, stack traces, and insights into the root causes of crashes.

6. Conclusion

In this chapter, we looked at the technical requirements for a beekeeping monitoring system. We began by analyzing the system requirements and design constraints, and emphasized the importance of communication solutions in such systems. We then discussed various communication interfaces, such as GSM, LoRa, NRF 24, Wi-Fi, Bluetooth, and ZigBee, and highlighted their features, advantages, and disadvantages. We then explored cloud server options, focusing on AWS, Google Cloud, and Azure, ultimately choosing Google Cloud's Firebase service because their comprehensive offerings fit the needs of our application. Firebase offers a range of services, including real-time database, authentication, cloud functions, hosting, machine learning, analytics, and more. Finally we outlined the functional architecture of the system and explained components such as the user interface, Firebase backend services, device communication protocols,

This thorough analysis and selection of technologies provides a solid foundation for the following chapters, where we will delve deeper into the implementation and testing phases of a beekeeping monitoring platform.

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CHAPTER 3

BASIC COMPONENTS FOR THE REALIZATION OF THE PROJECT

1. Introduction

In the previous chapter we talked about bees and their importance in environmental stability, in this chapter we will detail the structure of the system. It consists of two parts

The first part, we will describe the components of the different parts of the system that will be used in its implementation, especially the sensors and other equipment that connect the parts of the system to each other,

In the second part, the software, we will describe how the application communicates with the hardware.

2. Hardware Parts

The diagram in Figure 1 shows an overview of the key elements of our system as well as the planned functionalities of our implementation. The system consists of two parts:

- A management and communication station
- A set of beehives (apiary).

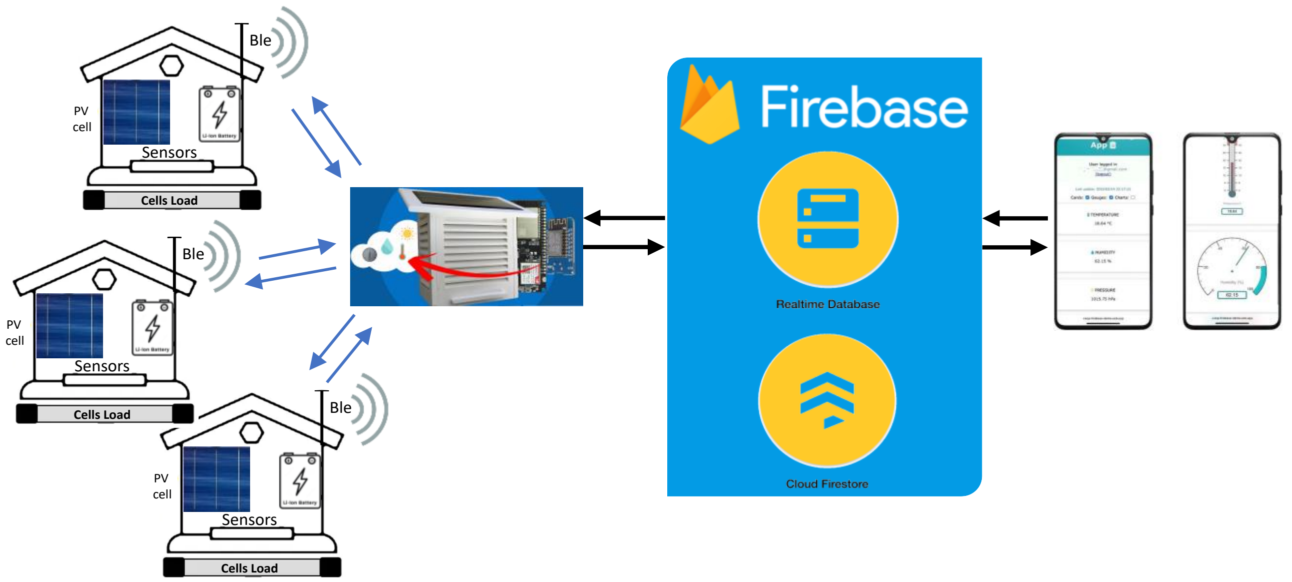

Figure 1 : Schématique diagram for the implementation of the project

The main components we will be using to build the hardware for our platform. We Will:

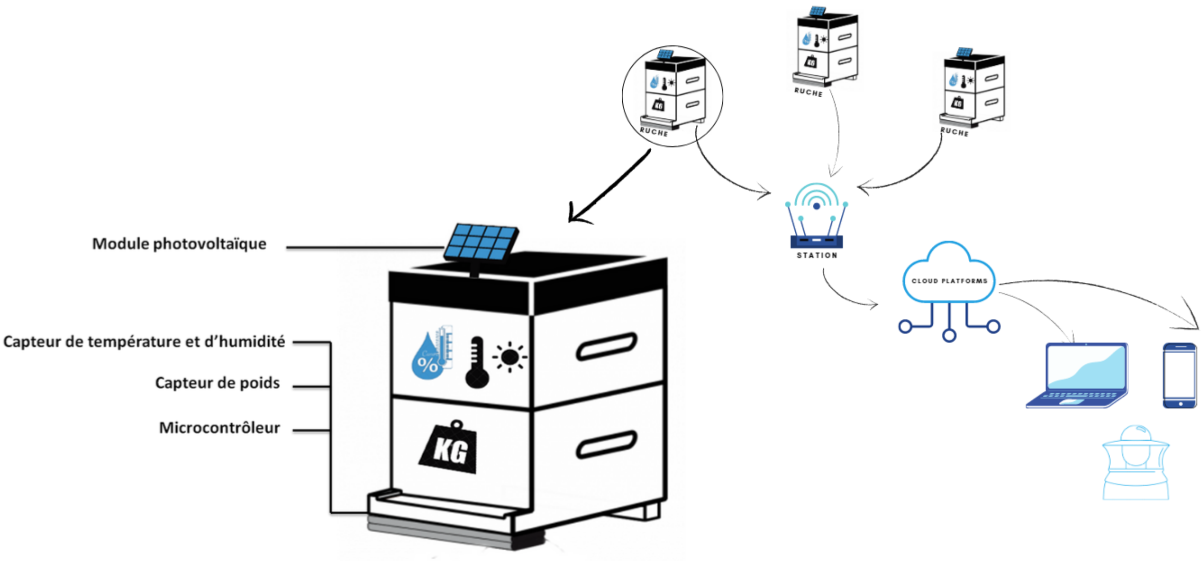

Figure 2 : System detail diagram

Figure .2 shows the essential elements of the system attached to a single hive. These elements are:

- A medium-performance microcontroller.
- Temperature and humidity sensors.
- Strain gages for weight measurement.
- Sensors for measuring atmospheric pressure and ambient temperature.

2.1. Microcontroller

We have defined a number of functionalities that the microcontroller must contain, which we summarize as follows:

- The microcontroller must be efficient.
- Must not consume a lot of power, and must contain standby modes.
- Must have a variety of communication interfaces such as: UART, SPI, I2C.
- Must support at least one type of wireless communication such as: Wi-Fi, Bluetooth.
- Must have analog inputs with analog-to-digital converter.
- Must have a high-performance hardware and software development platform.

A. The ESP32 module

ESP32 WROOM 32 is a small and powerful controller developed by Espressif Systems. It integrates the ESP32 module, which is considered part of the ESP family (Espressif Systems products). The WROOM 32 module is widely used in various embedded systems and Internet of Things (IoT) applications due to its advanced features and capabilities.

B. The LOLIN D32 card

LOLIN D32 is one of microcontroller development platform that very popular to be use in IoT [21], [22]. LOLIN D32 is a low-cost microcontroller development platform that based on

Espressif official ESP32-WROOM-32 module. It has Wi-Fi & Bluetooth networking capabilities that essential as a lot of things today need to be connected to the internet. ESP32 integrates an antenna switch, RF balun, power amplifier, low-noise receive amplifier, filters, and power management modules. ESP32-WROOM-32 module has wide operating voltage from 2.3 V to 3.6 V with power consumption for deep sleep mode at about 10 uA. In order to minimizing power consumption in ESP32-WROOM-32 module, the chip radio, CPU, and any other feature except RTC memory and RTC peripherals will be disable.[1]

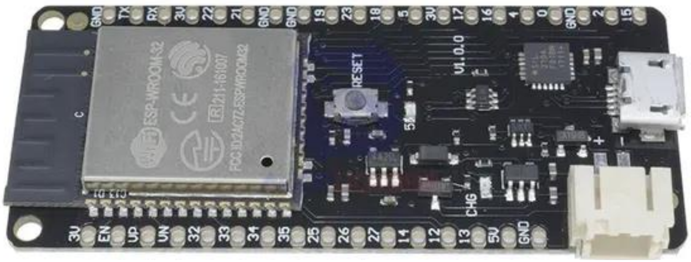

Figure 3 : System detail diagram

C. ESP32 technical specifications

Microprocessor	Tensilica Xtensa LX6
Supply voltage (USB)	5 V DC
Input/output voltage	3.3 V DC
Processor	Dual-Core Tensilica Xtensa LX6 (32-bit)
Clock frequency	up to 240 MHz
SoM	ESP-WROOM-32 (Espressive)
SoC	ESP32 (ESP32-D0WDQ6)
Digital GPIO pins	24 (some input pins only)
Bluetooth	v4.2 BR/EDR and Bluetooth Low Energy (BLE)
Wi-Fi	v4.2 BR/EDR and Bluetooth Low Energy (BLE): 802.11 b/g/n/e/i (802.11n @ 2.4 GHz up to 150 Mbit/s)
Memory	448 Ko ROM520 Ko SRAM 16 Ko SRAM in RTC
PWM pins	16

Table 1 : The technical specifications of the ESP32 card.

D. Power supply

There are three different ways to power an ESP32 card

- Micro-USB socket: By connecting the mini-USB socket to a phone charger or computer via a cable, it will draw the power needed to operate the board;
- 5V pin: The 5V pin can be supplied with a regulated 5V, this voltage will be regulated back to 3.3V via the integrated voltage regulator, as the ESP32 module only works with 3.3V;
- 3.3 V pin: If a regulated 3.3 V power supply is available, it can be connected directly to the ESP32's 3.3 V pin.

2.2. DHT21

DHT21, also known as AM2301, is a digital temperature and humidity sensor. It is part of the DHT sensor series and is widely used in various projects where accurate temperature and humidity measurement is required. The sensor features a temperature sensing element and a capacitive sensor for measuring relative humidity. The DHT21 uses a single-wire digital interface to communicate with microcontrollers or other electronic devices, making it easy to integrate into a variety of electronic projects. It provides temperature readings with a typical accuracy of ±0.5°C and humidity readings with a typical accuracy of ±3 %.[2]

Figure 4 : Schematic diagram of the sensor

A. Pin identification and configuration

The table below shows the pin identification and configuration of the DHT21 module.

Réf	Spindle name	Description
1	VDD	Power (3,3-5,2 V)
2	SDA	Serial data, dual- port
3	GAND	Ground
4	NC	Empty

Table 2 : Shows the pin identification and configuration of the DHT21 module.

B. Specifications

- Power source: DC 3.5~5.5V
- Humidity range: 0~100%RH
- Temperature range: -40~80'C
- Precision: ±3%RH / ±0.5'C
- Monobus digital output.

2.3. Weight sensor

Hive weight is an important indicator for beekeepers, as it shows whether or not the hive is in good health, as well as the ideal time to harvest honey. In winter, it can be used to check whether food reserves are sufficient. For weight measurement, we used 4 load cells of 50kg each. |3]

A. Load cell

Load cells (Figure 5) are specially-shaped metal parts to which strain gauges to which strain gages are attached. Strain gauges are resistors that change resistors that change their resistance when bent. When the metal part bends, the resistance of the load cell changes. We also used an HX711 signal amplifier to amplify and digitize the.

Figure 5 : Strain gage

digitize the output signal of the 4 strain gages required

B. HX711- Analog-to-digital converter (ADC)

HX711 is a 24-bit analog-to-digital converter (ADC) integrated circuit. It is an integrated preamplifier used to amplify low-voltage signals. The HX711 chip takes voltage signals as input and provides digital values. The preamplifier handles low voltages. It features an on-chip power regulator that provides analog power, so you don't need an external power regulator. You can interface directly with a bridge sensor. This chip has two analog channels, A and B. We can program the gain of channel "A" to either 128 or 64. On the other hand, channel B has a constant gain of 32.chip, making it suitable for such applications.

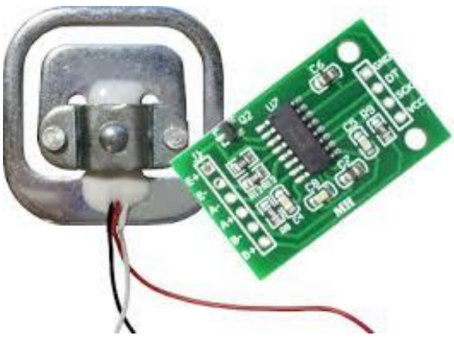

Figure 6 : The HX711 converter

C. HX711 features and specifications

- Automatic reset circuit on power-up
- Simple digital control and serial communication: all controlled by input pins, chip records without programming
- Selectable 10Hz or 80Hz output data rate
- Simultaneous rejection of 50Hz and 60Hz power interference
- Power consumption (including supply circuit): typical operating current: <1.7 ma, switch-off current: <1 µa
- Operating voltage range: 2.6 ~ 5.5V
- Operating temperature range: -20 ~ + 85 ℃
- Easy-to-use serial interface without programming;
- 2 input channels;
- Output data speed selectable as 10SPS or 80SPS

D. Wiring load cells and HX711

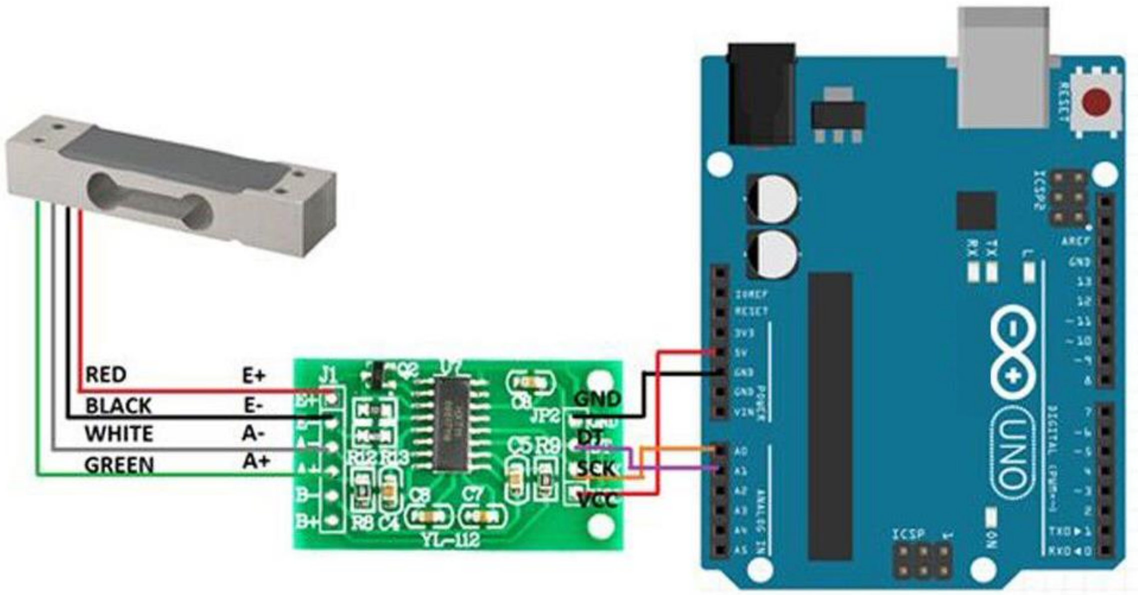

Figure 7 : Load cell wiring diagram with HX711

2.4. Pressure sensor

The BMP280 is a small, low-power, high-precision pressure sensor for use in mobile devices. Its performance, the lowest absolute accuracy down to 0.2 Pa and its low power consumption, only 2.7 µA. The BMP280 uses a powerful 8-pin ceramic lead-free chip carrier (LCC). This device can be SPI-connected and also I2C-connected. It doesn't use a 5V power supply, so you'll need to run it from your Arduino's 3.3V pin.[4]

Figure 8 : Pinout of the GY-BMP280 module

A. Pin configuration

Name of pin	**Pin description**
VCC	Alimentation (3.6V max)
G ND	Masse
SDI	Data. To be connected to SDA in the case of the I2C bus
SCK	Clock. To be connected to SCL in the case of the I2C bus
CSB	is used to switch from SPI mode to I2C mode. By default, CSB=1 means I2C mode. If CSB=0 at start-up, then SPI mode is used.
SD0	choice of I2C address. If SD0=0, then the address is 0x76, if SD0=1, then the address is 0x77.

Table 3 : Pin configuration

B. Characteristics

- Interfaces: I2C and SPI for simple communication.
- Versatility: Suitable for a variety of Arduino projects.
- Compact: Small, for space-saving mounting.
- This precision sensor is the best low-cost precision sensing solution for measuring barometric pressure with an absolute accuracy of ± 1 hPa and temperature with an accuracy of ± 1.0°C. Because pressure changes with altitude

and pressure measurements are so good, you can also use it as an altimeter with an accuracy of ± 1 meter.

- This sensor is ideal for all kinds of weather detection and can even be used with both I2C and SPI.

C. Electrical specifications of the BMP280 module

- Model: GY-BMP280-3.3.
- Chip: BMP280.
- Power supply: 3V/3.3V DC.
- Peak current: 1.12mA.
- Atmospheric pressure: 300-1100hPa (equivalent to +9000...-500m above sea level).
- Temperature range: -40 ... +85 °C.
- Digital interfaces: I²C (up to 3.4 MHz) and SPI (3 and 4-wire, up to 10 MHz).
- BMP280 current consumption: 2.7µA at 1Hz sampling rate.

2.5. Power supply with photovoltaic module

For this purpose, we have chosen the configuration shown in the figure below. This configuration allows the use and charging of a lithium battery through the use of a photovoltaic module.

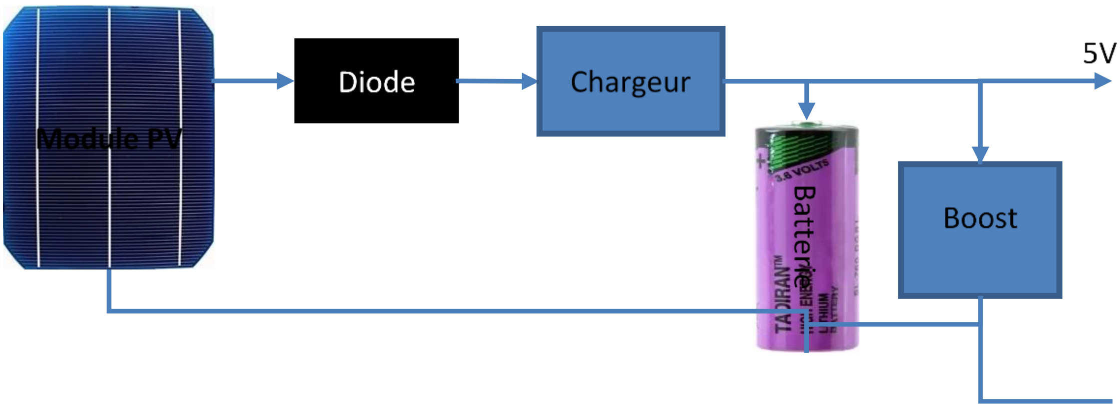

Figure 9 : System power supply configuration

A. Battery charger

We have chosen the TP4056 battery charger, which is the most widely used for embedded systems, and is shown in the figure below.[5]

Figure 10 : Li-Ion battery charger TP4056

The P4056 module is a linear charger for lithium-ion and LIPO batteries. This module can charge batteries made up of a single cell. Its ability to supply 4.2V makes it ideal for charging 18650 cells and other 3.7V batteries. The charger can be powered by a USB source, a wall adapter or any other 5V and 1A source.

Thermal feedback automatically adjusts the charging current to limit chip temperature. The charge voltage is fixed at 4.2V, and the charge current.

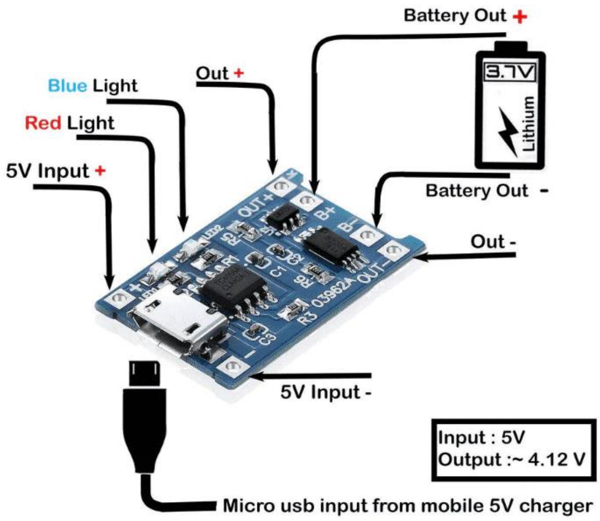

Figure 11 : counted battery charger TP4056

B. Boost converter

We've chosen to use a Boost DC/DC converter which supplies a voltage of 5V. Integrated modules such as the one shown in the figure below are available for sale:[6]

Figure 12 : USB 5V boost module

C. Choosing Li-Ion batteries

If the system is powered solely by a Li-Ion battery, rigorous calculations will enable us to calculate the system's consumption over a long period (several months), and thus deduce the size of the battery.

Alternatively, in the case of a solar module power supply, we can use 1300mAh batteries, which will be more than sufficient to run the system, especially in the absence of sunlight.

D. Choice of PV module

The main power source for the collector module is the solar panel. It must therefore be able to provide the current to power the system, as well as the current to recharge the battery during the day. [7]

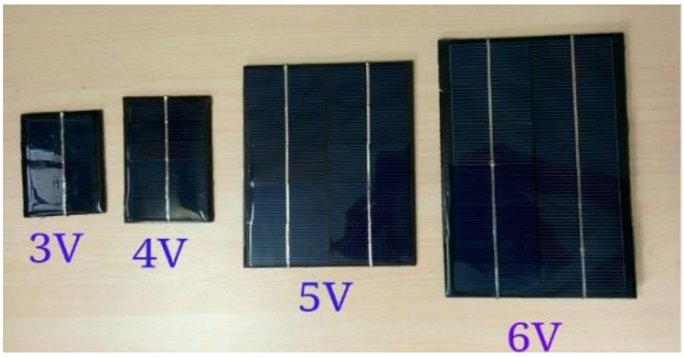

Figure 13 : Photovoltaic module

To choose the most suitable module for our application, we need to make a compromise, and follow these rules of thumb:

- Voltage: Choose a voltage 1.5 times the battery voltage.
- Current: The current drawn by the system + a current sufficient to charge the battery.

There are also rules of thumb for associating battery type with module type.

Battery	PV module
1.2V	2V ~ 2.5V
2.4V	3.5V ~ 4V
3.6V	5V ~ 6V
6V	7.5V ~ 9V
12V	15V ~ 18V

Table 4 : Relationship between battery voltage and PV module voltage

We will therefore choose a photovoltaic module that generates a voltage of 6V with a power of 3W, which gives us a maximum current of 600mA.

Figure 14 : Selected photovoltaic module

3. Software section

Our project is based on an application built in *Dart language* and the *Flutter framework*, where our application connects to the cloud receives data from the ESP32 board and display changes in the hive parameters. Below are the main steps to get the app up and running:

- ***Setting up Firebase:***

  The work begins by creating a new Firebase project and setting up a real-time database to store the cell changes data. Access to the database (read, write, allowed paths, etc.) is determined by the configuration.

- ***Configuring the application in Flutter:***

  The Firebase SDK library is added to the Flutter project to communicate with the Firebase real-time database. An attractive and user-friendly user interface is created to display the bee change data.

- ***Connection to ESP32:***

  The ESP32 module connects to the cloud using wireless technology (Wi-Fi). To ensure the confidentiality of data sent from the ESP32 to Firebase, secure communication protocols such as HTTPS are added.

- ***Programming with ESP32***

  The ESP32 is programmed to read bee data from sensors such as temperature, humidity, and hive weight. The data read from the ESP32 is sent to the Firebase database in real-time via a Wi-Fi connection.

- ***Database updates***

When the ESP32 sends bee data to Firebase, the values in the database are continuously updated in real time. Firebase data is organized so that each hive has its own dedicated path containing its own data.

- ***Displaying data in the app***

The Flutter app uses the Firebase SDK to retrieve bee change data from the real-time database. The data is appropriately formatted and displayed in the user interface, including graphs and descriptive text.

- ***The data is continuously updated***

We add code to our application to continuously and automatically update the data in the Firebase Real-time database. New data and changes are immediately displayed to the user without having to reload the app.

- ***Security and protection***

Flutter apps have additional security and identity verification features to ensure data is sent and received securely. Encryption features are used to protect data and privacy during transmission between the app and the cloud.

With the above steps, a Flutter app connected to Firebase and ESP32 can be developed to directly and effectively monitor and manage bee health and activity by effectively and securely displaying changes within the hive.

3.1. Description of the application

The mobile application that we project to implement is based on the internet of Object infrastructure, it is constructed on the around the Realtime firebase service. The structure of the different page involved in the application is described in the figure below, the figure illustrate the expected design and the link between the different pages.

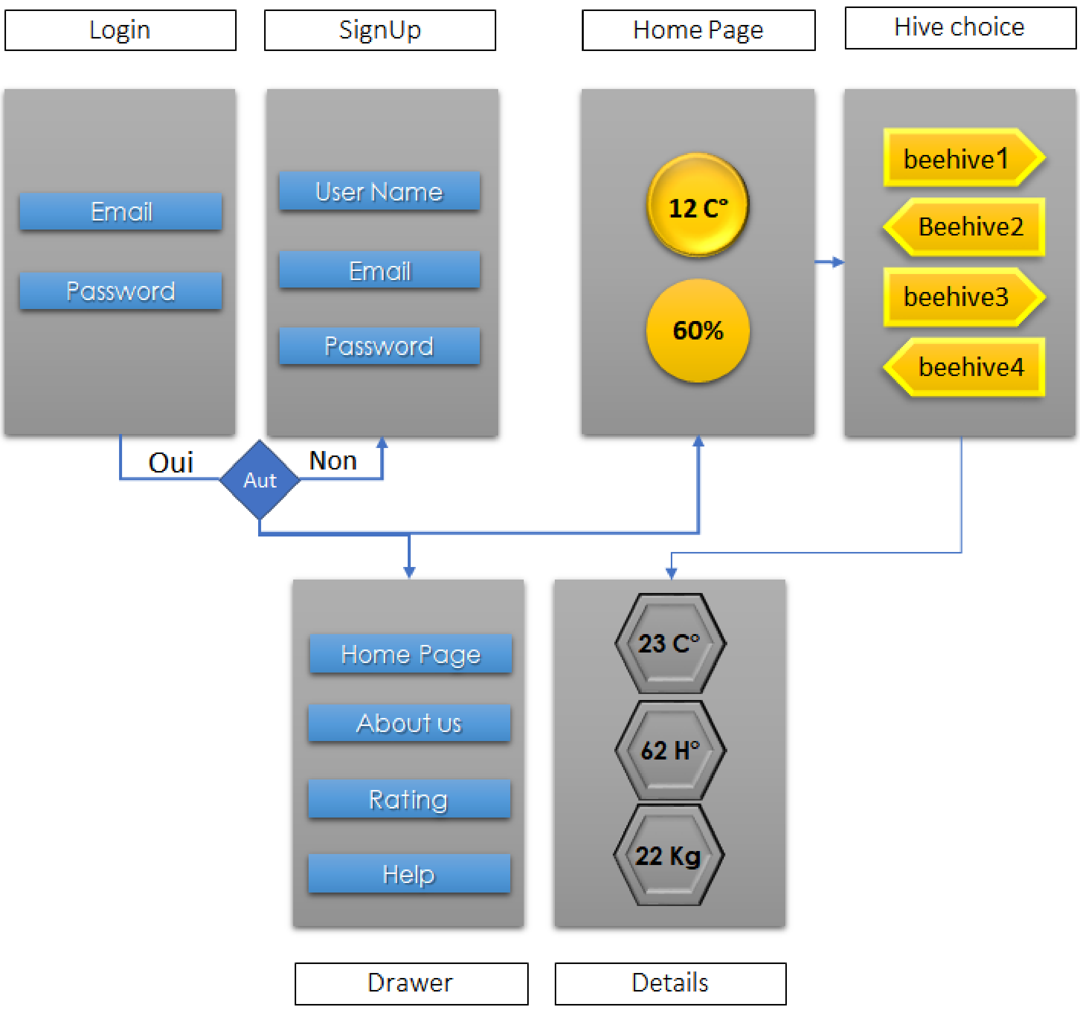

Figure 15 : Structure of the project mobile application

3.2. Architecture of the Internet of Things for the project

- The physical layer consists of the devices that need to be controlled. Sensors to detect environmental conditions are also connected to this layer.
- The data link layer consists of the IoT gateway router, device manager, and various communication protocols. This layer connects the devices to the web server or cloud via a Wi-Fi connection.
- Firebase is used as a private server to store the sensor data and sends the data to the end users when they access the app.
- In this system, Firebase falls under the database/server layer. Application layer and web protocol rendering.
- This layer involves either designing a web page to access the devices connected to the perception layer via a PC or laptop, or building an Android or iOS mobile application if the devices are to be controlled and monitored via smartphones.

The IoT layers of the proposed system are shown below:

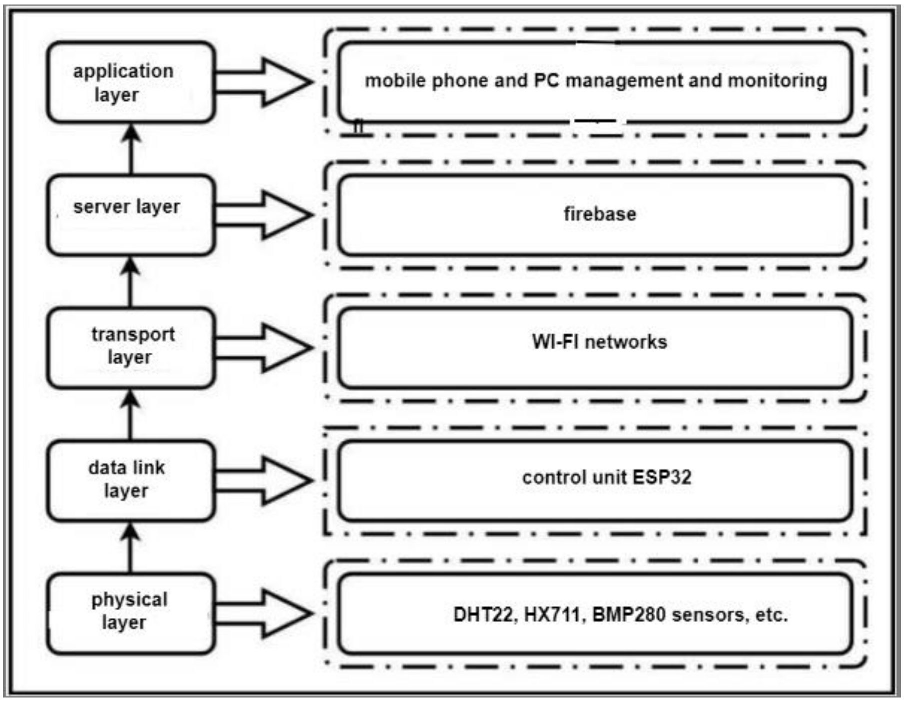

Figure 16 : IoT architecture

3.3. Programming Languages Supported by Firebase

Firebase supports multiple programming languages for app development, depending on the specific Firebase service you're using. Here's a list of common languages that can be used with Firebase:

- JavaScript: You can use JavaScript with Firebase for web app development using Firebase Hosting, Firebase Real-time Database, Firebase Authentication, and other services.
- Node.js: You can use Node.js with Firebase to write Cloud Functions using Firebase Cloud Functions and interact with Fire store database and other services.
- Java/Kotlin: For Android app development, you can use Java or Kotlin with Firebase to utilize Firebase Real-time Database, Firebase Authentication, Firebase Cloud Messaging, and more.
- Swift/Objective-C: For iOS app development, you can use Swift or Objective-C with Firebase to utilize Firebase Real-time Database, Firebase Authentication, Firebase Cloud Messaging, and more.
- Python: You can use Python with Firebase to interact with Firebase Real-time Database, Firebase Authentication, Firebase Cloud Functions, and other services.
- C++: Firebase supports some C++ libraries that can be used to interact with Firebase Real-time Database, Firebase Authentication, and other services.

- Unity (C#): For game development using Unity, you can use C# with Firebase to interact with Firebase Real-time Database, Firebase Authentication, Firebase Cloud Messaging, and other services.

4. Conclusion

In this chapter, we reviewed the components of the hive monitoring system and how to implement it, and divided it into two main sections:

Hardware: We covered hardware components such as the ESP32 microcontroller, temperature and humidity sensors, weight sensors, pressure sensors, and power supplies. These components play an important role in monitoring and collecting data about the condition of the hive to ensure its health and optimise honey production.

The software: We developed a Firebase-connected application using the Dart language and the Flutter framework to receive data from the ESP32 and display hive information.

By integrating hardware with an app, our systems provide beekeepers with a reliable solution to effectively monitor and manage hive conditions, optimising hive health and productivity.

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CHAPTER 4
SYSTEM IMPLEMENTATION

1. Introduction

The previous chapter enabled us to show the various components involved in implementing the system, as well as their characteristics, which helps us to better understand how they work, and how we would program them.

In this chapter, we will describe the various stages in the project's implementation, as well as presenting the tests carried out on the system's components and the final results of the system's functional validation.

2. Detailed system structure

The aim of our work is above all to propose an evolvable architecture that is customized to the needs of the customer, in particular beekeepers. three architecture options are available, as shown in figures 1, 2 and 3.

A. 1st configuration

In the first configuration, there tow hardware parts of the system, a set of beehives and base station. The base station collects periodically the information from all the hives connected with it through Bluetooth interface, and send the all data packet to the firebase server. The base station is connected to internet through WIFI interface.

B. 2nd configuration

This configuration is essentially similar to the first one, the principal difference is the use of a GSM module, this module allows the base station to connect to the internet and then send the data to the firebase server.

C. 3rd configuration

In this third configuration, a connected hive is in a standalone mode, the system is based in a one hardware part that connect directly to the internet through a WIFI connection. It is the simplest configuration for prototyping.

Other configuration can be proposed, the choice of configuration depends on a number of parameters, including the customer's preferences, the price of the system, and the location of the apiary. We choose the 3rd configuration for our first prototype because of the availability and affordability of the electronic components, on the one hand, and the robustness and efficiency of the chosen architecture, on the other.

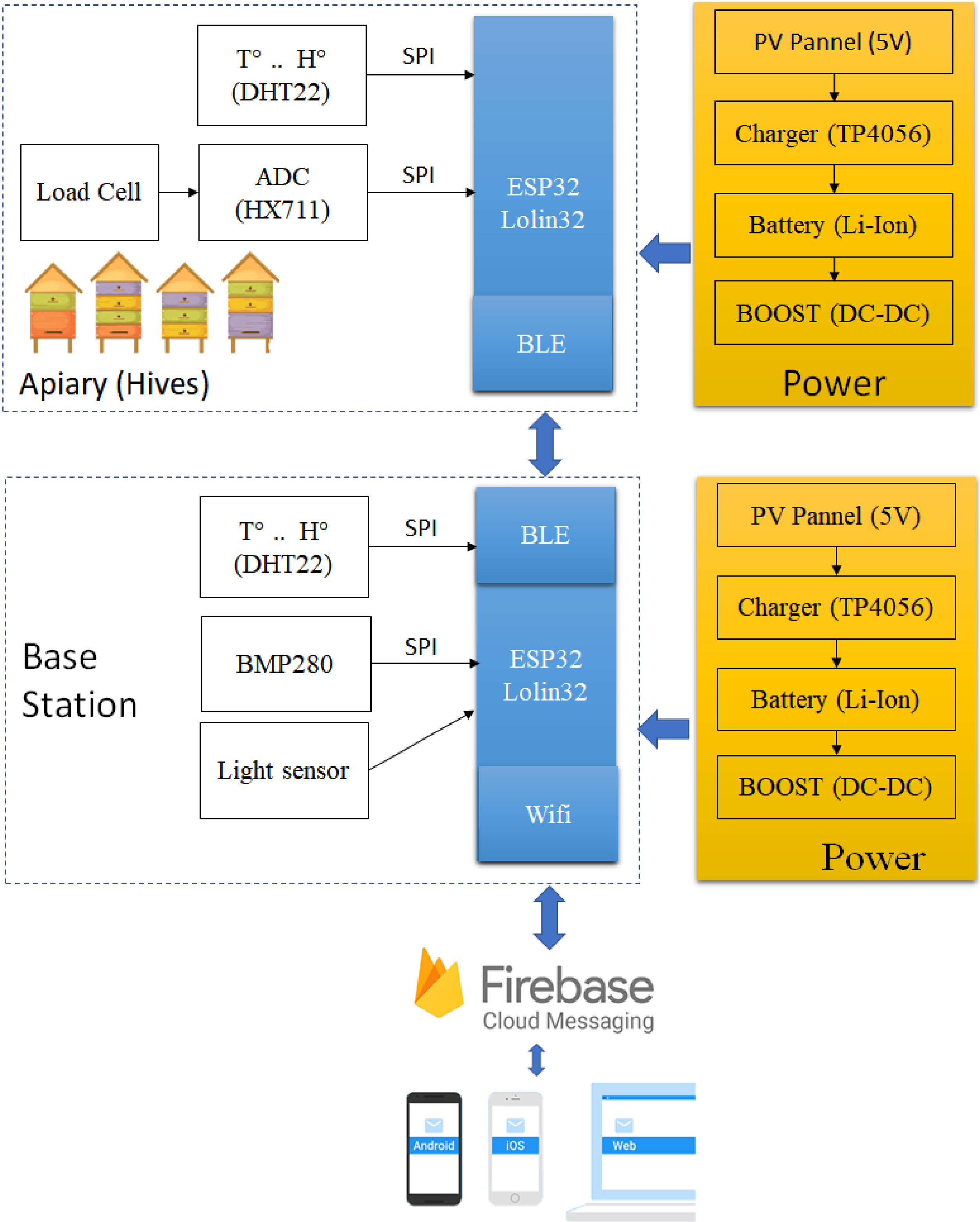

Figure 1. 1st configuration (1 apiary, 1 base station, WIFI connection)

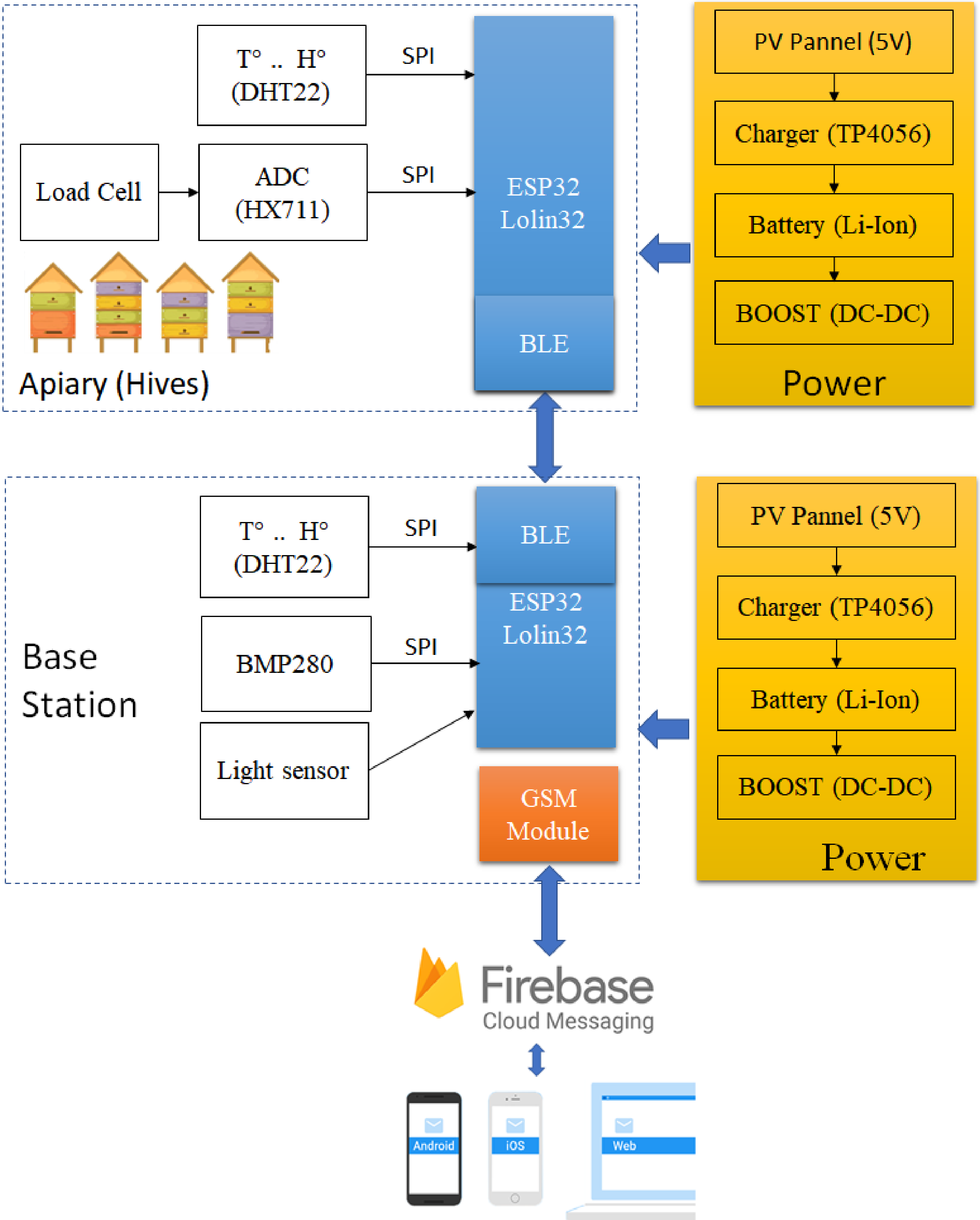

Figure 2. 2nd configuration (1 apiary, 1 base station, GSM connection)

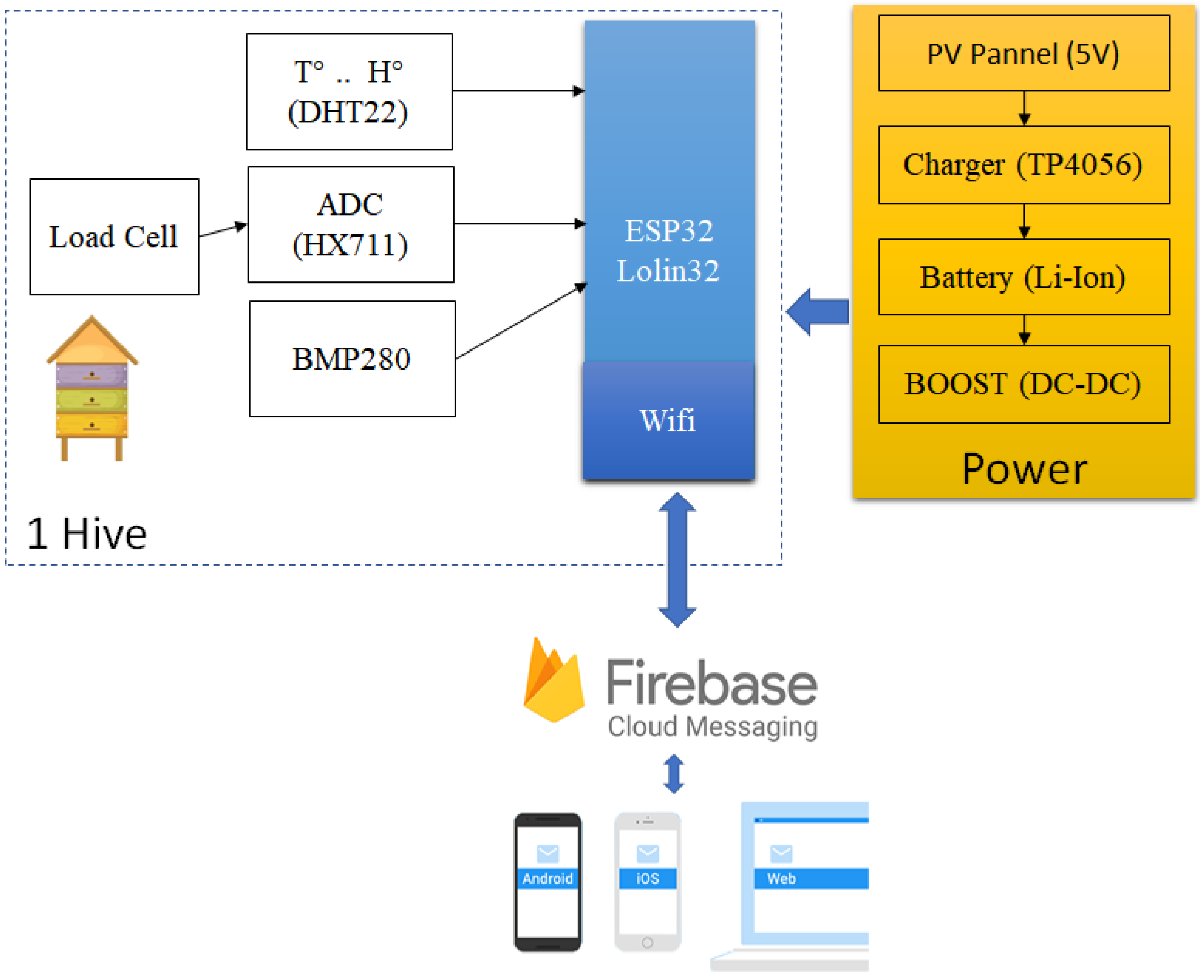

Figure 3. 3rd configuration "standalone" (1 Hive, WIFI connection)

Figure 3 shows a detailed view of all the elements required to build a prototype system. Three parts are essential for its operation.

- ➢ The first part concerns the realization of the hive's electronic system. This part contains an ESP32 board, a DHT22 sensor to measure temperature and humidity, strain gauges to measure weight. The ESP32 board include a WIFI module that allow to connect directly to the internet.
- ➢ The power supply system consisting mainly of a photovoltaic module, a battery, a TP4056 charger and a boost converter.
- ➢ The third part concerns a mobile application connected to the electronic hive through the firebase server.

3. System design and construction

3.1. Configuring the ESP32 card with sensors

A. Interfacing the ESP32 card with the DHT22 module

To measure temperature and humidity, we use the DHT22 sensor, to do this we need to connect this module to the microcontroller board, the connection of the DHT22 sensor to the ESP32 is defined as follows:

- Putting ESP32 on the card.
- Sensor and ESP32 Installation.
- Connect the sensor's VCC pin to the ESP32‘s 3.3 V pin and the sensor's GND to the ESP32’s GND. of the sensor to the GND of the ESP32.
- Also, connect the sensor data pin to pin D4 of the ESP32.
- Place a resistor between VCC and the data line.

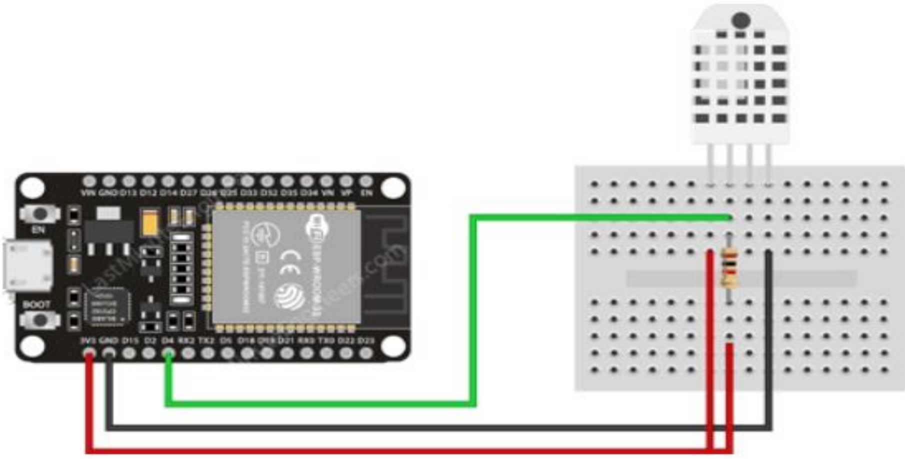

Figure 4. Mounting the ESP32 with DHT22

B. Interfacing the ESP32 card with the HX711 and strain gauges

To measure the weights of the hives we use a balance made up of 4 load cells of 50kg each, these cells are connected to the ESP32 card via an HX711 module to digitise the measured signal.

HX711 - input (strain gauge side):

- Upper left load cell signal => HX711 E- pin.
- Lower left load cell signal => HX711 A+ pin.
- Upper right load cell signal => HX711 A- pin.
- Lower right load cell signal => HX711 E+ pin.

HX711 - output (ESP32 card side):

- HX711 Vcc pin => ESP32 3.3V pin.

- HX711 GND pin => ESP32 GND pin.
- HX711 SCK pin => ESP32 GPIO 2 pin.
- HX711 DT pin => ESP32 GPIO 5 pin.

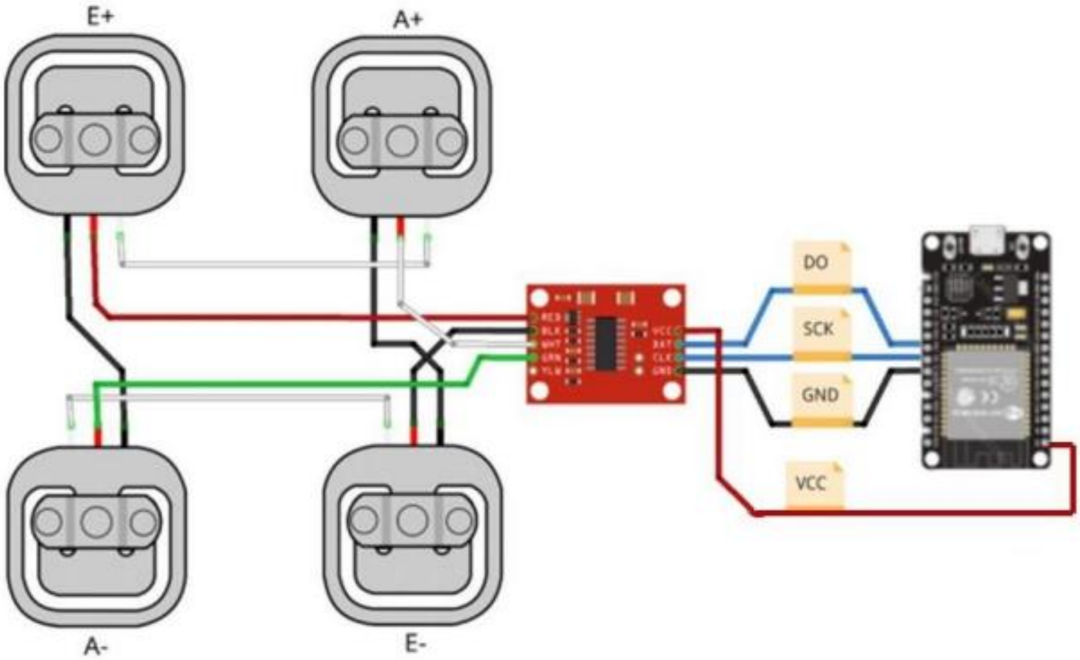

Figure 5. Connecting the HX711 with ESP32

C. Interfacing the ESP32 with the BMP280 module

We use the BMP280 sensor to measure atmospheric pressure.

The connections are described as follows:

- Connect the VIN pin to the 3.3V output of the ESP32;
- Connect GND to ground;
- Connect the SCL pin to pin D22 of the ESP32 I2C clock;
- Connect the SDA pin-to-pin D21 of the ESP32 I2C data.

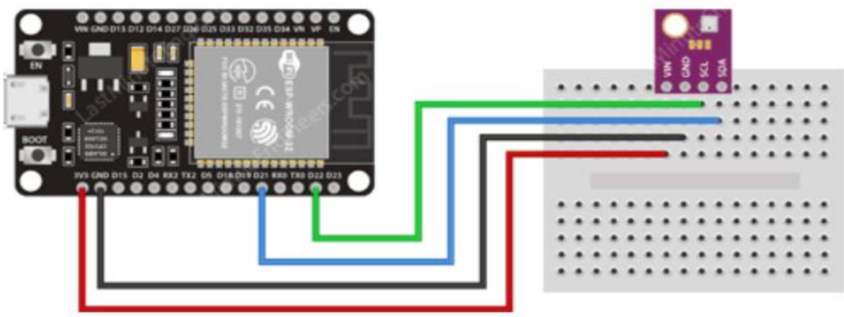

Figure 6.Mounting the ESP32 with BMP280.

3.2. Hardware implementation

For the implementation of the proposed prototype we use the following structure, this structure is the simplest one to test the most important issues in the system design. The expected can become, essentially, from the power supply and from the microcontroller board. We made this first structure to bring out the most important functional tasks with minimum hardware components.

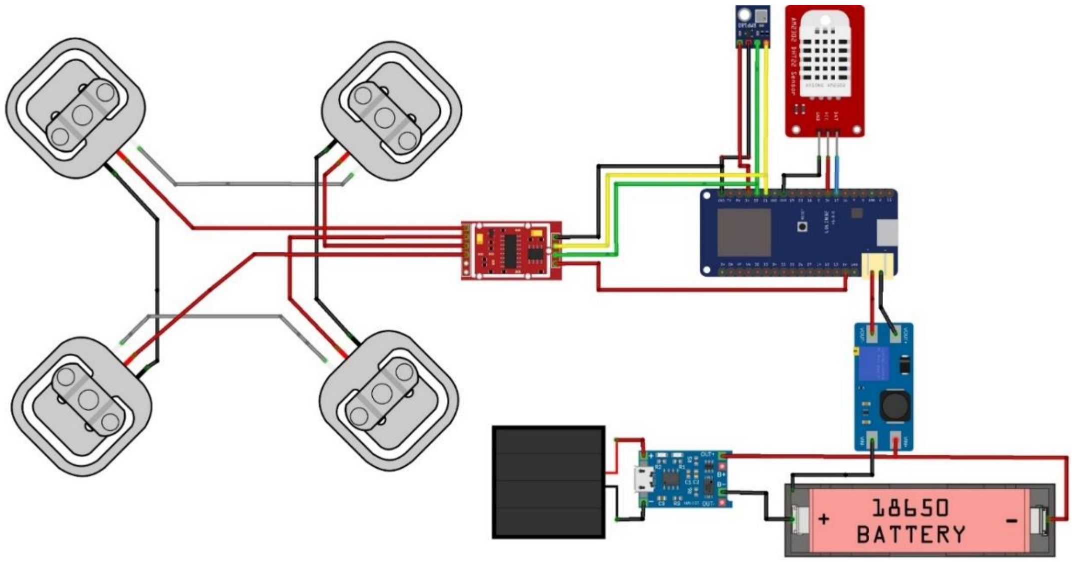

Figure 7. Simplest structure for the realization of the first prototype.

3.3. Firmware implementation

A basic firmware example is given in the figure bellow:

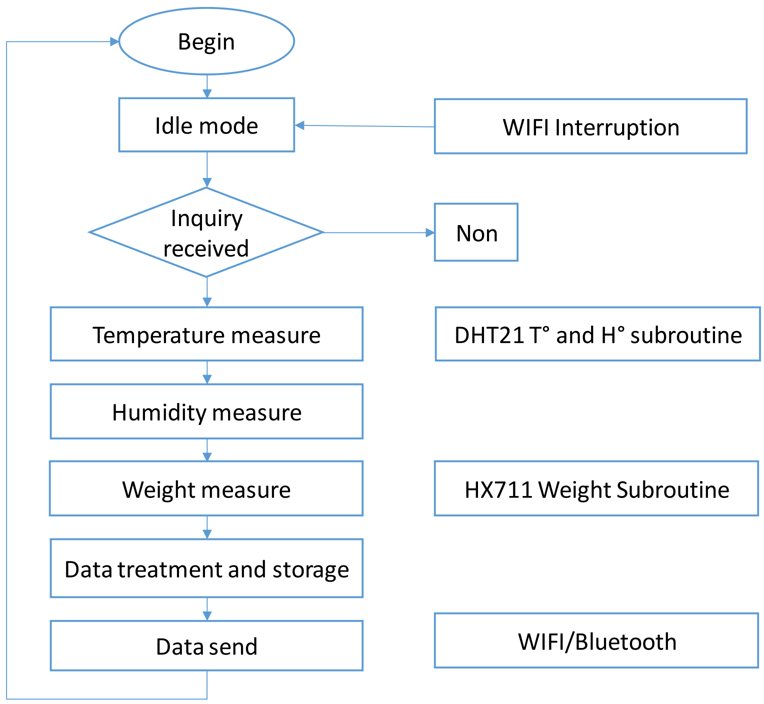

Figure 8. Basic algorithm for the firmware implementation.

4. Mobile Interface

The most important part of our project is to build a mobile application to monitor the different information of the whole hives in an apiary.

Our application is a collection of pages for displaying data and information and the following are the most important pages

4.1. Login and account creation pages

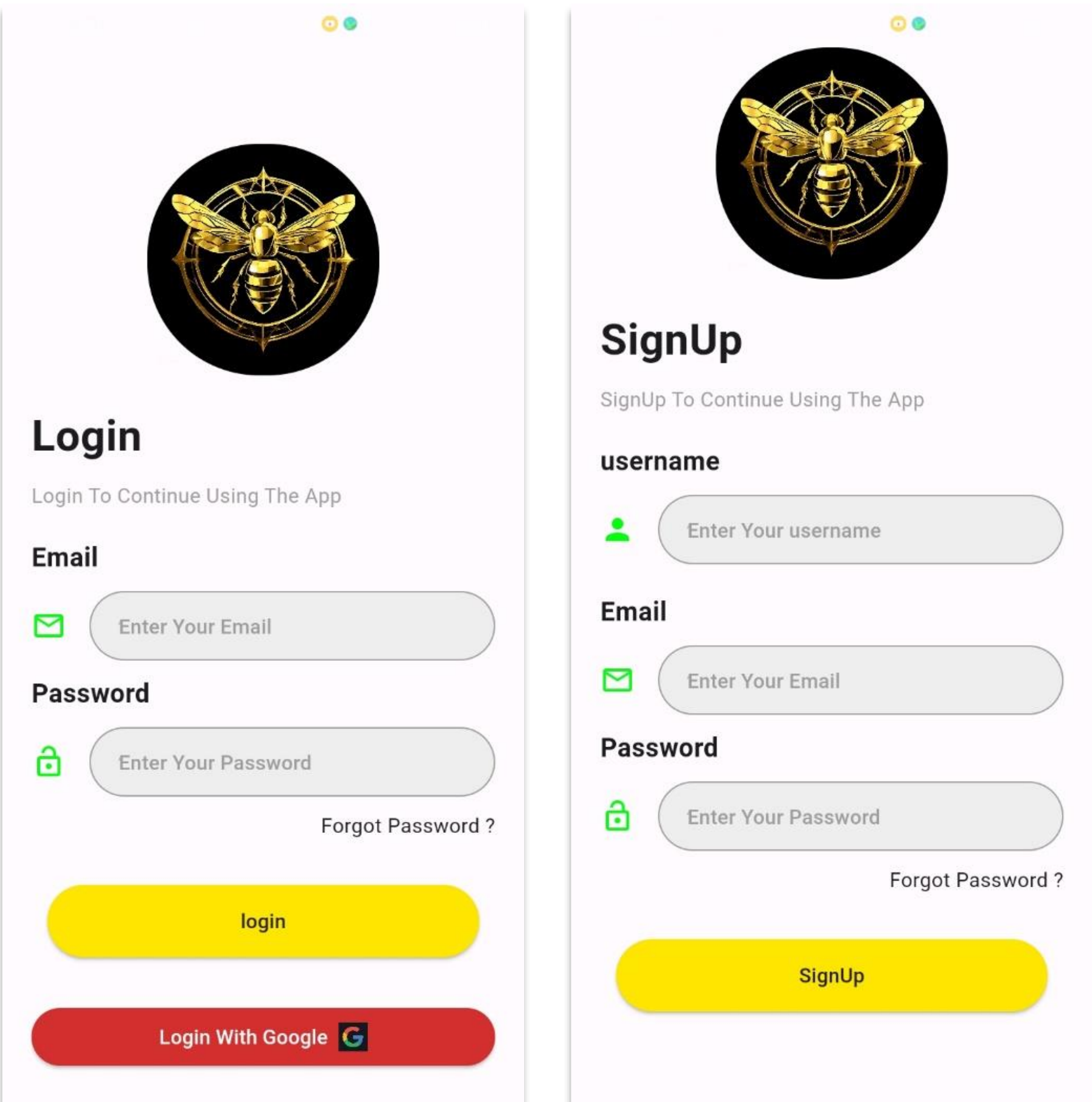

Figure 9. Login and SignUp pages

4.2. Home Page

It is a collection of abbreviations, the most prominent of which are

- Drawer
- Message showing the status of the application with the database
- Temperature and humidity changes in the atmosphere
- Archive
- Detail

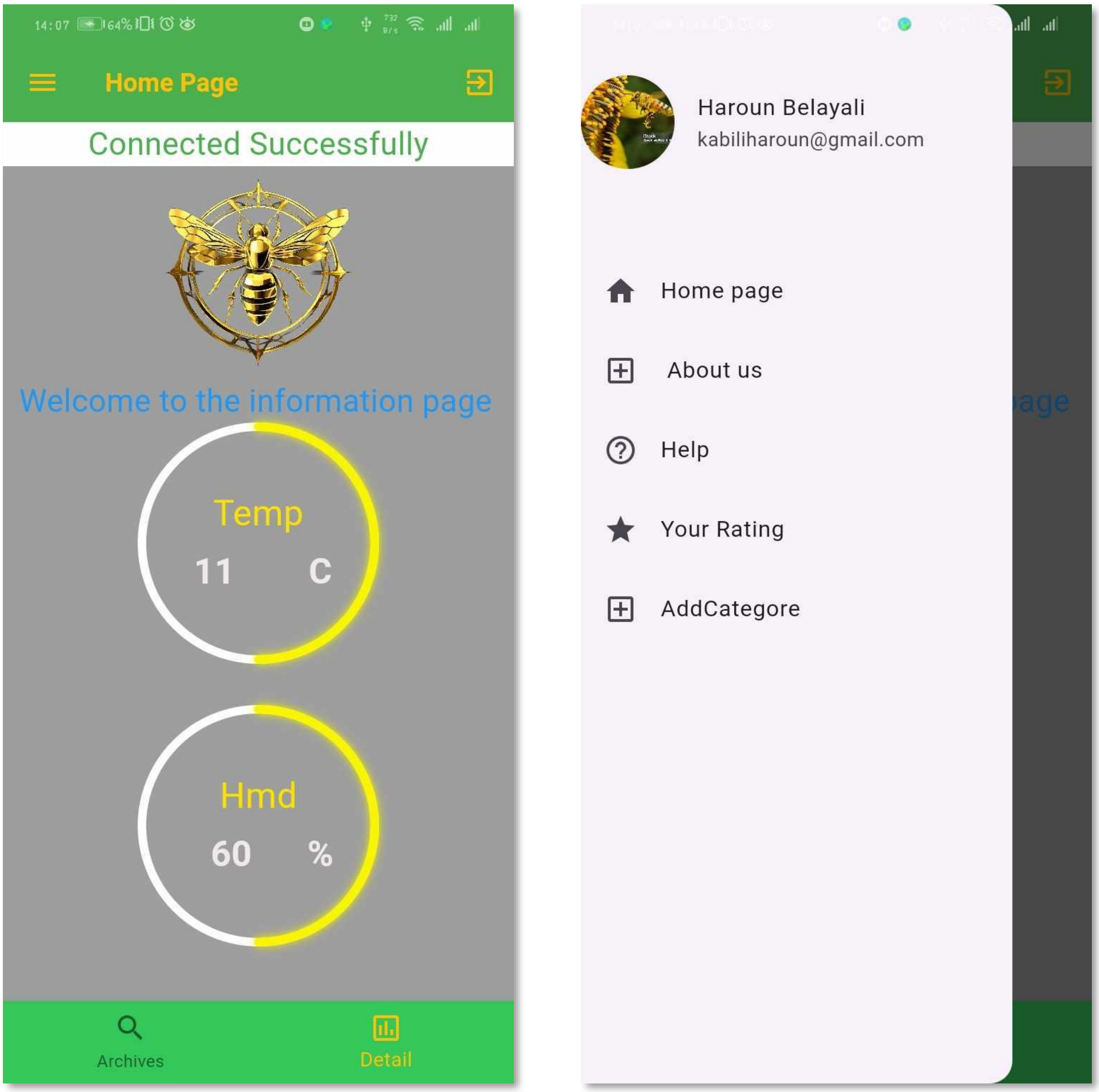

Figure 10. Home Page and Drawer Menu

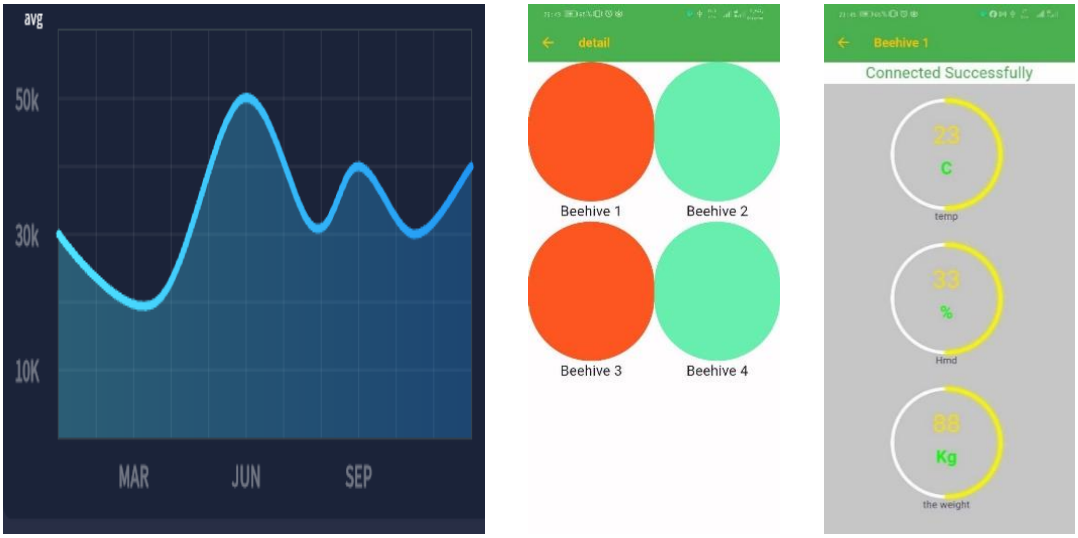

Figure 11. Archive and Detail pages

4.3. ESP32 / mobile phone interface

The software interface that link between the ESP32 firmware and the Firebase database in illustrated in the figure below:

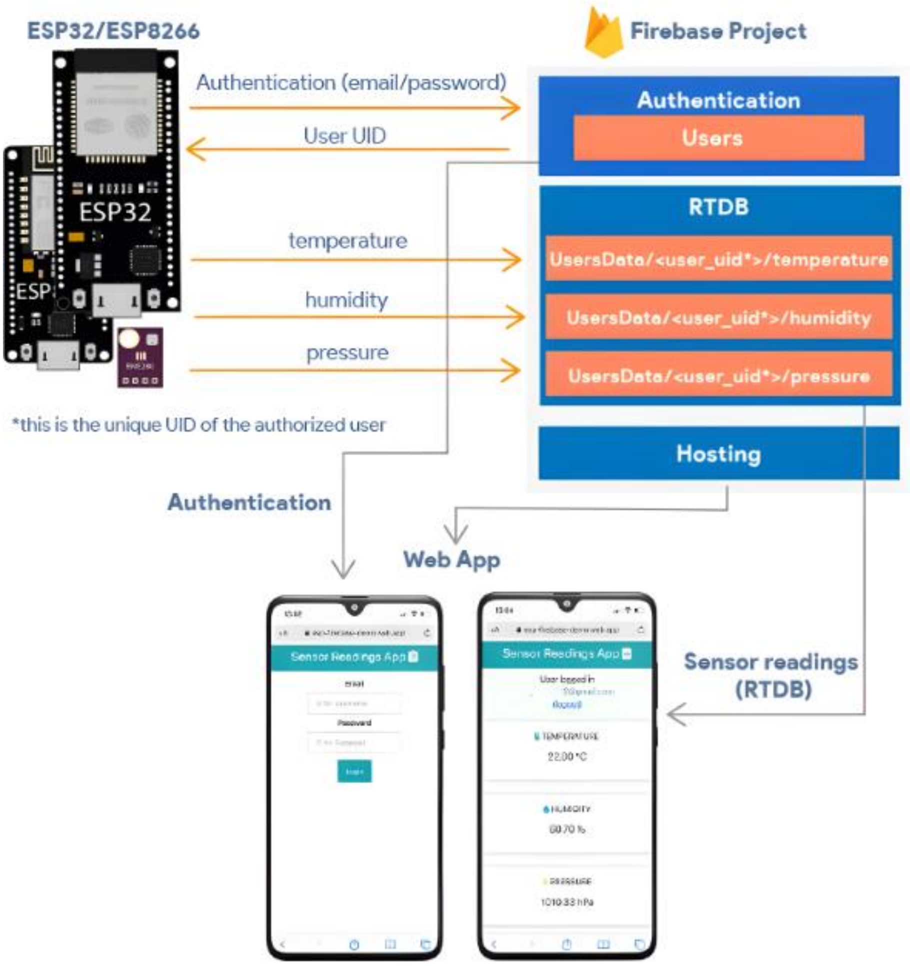

Figure 12. ESP32 / mobile phone interface

5. . Production and testing

During the development of our system, we carried out a number of tests to check and validate the operation of each component and then of the platform as a whole. In the following paragraphs, we will present the main points of the tests carried out.

5.1. Power supply test

A. Testing the photovoltaic module

The test verified the PV module's output voltage, which is essential for the system's power supply to function. essential for the operation of the system's power supply. A voltage of 6.4V will charge the battery and power the whole system.

B. Testing the battery charger

In this test, we checked the operation of the battery charging module by connecting it to the PV module. The PV panel voltage is sufficient to attain the requirement for the charger functioning.

C. Battery recharge test

The output voltage of the battery charger is recorded as 4.4V max, this value enables the battery to be charged efficiently.

5.2. Assembling and testing the system hardware

After testing the hardware part of the system, we were able to assemble all the components to check the system's functionality. Figure 9 shows the assembly of the hardware part of the final system.

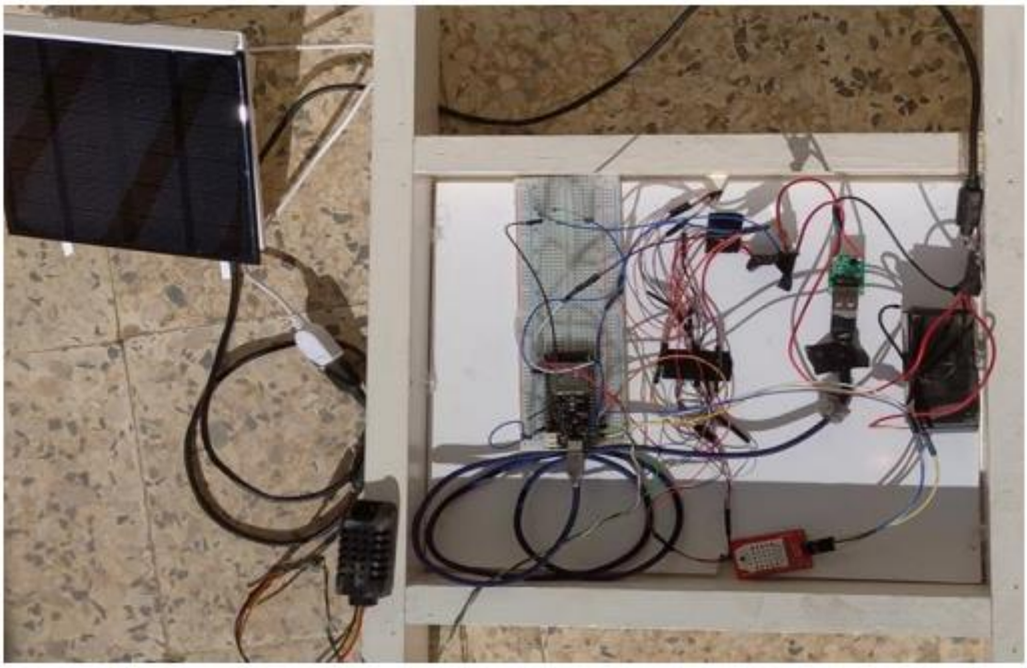

Figure 13.Assembling and testing the hardware part of the system

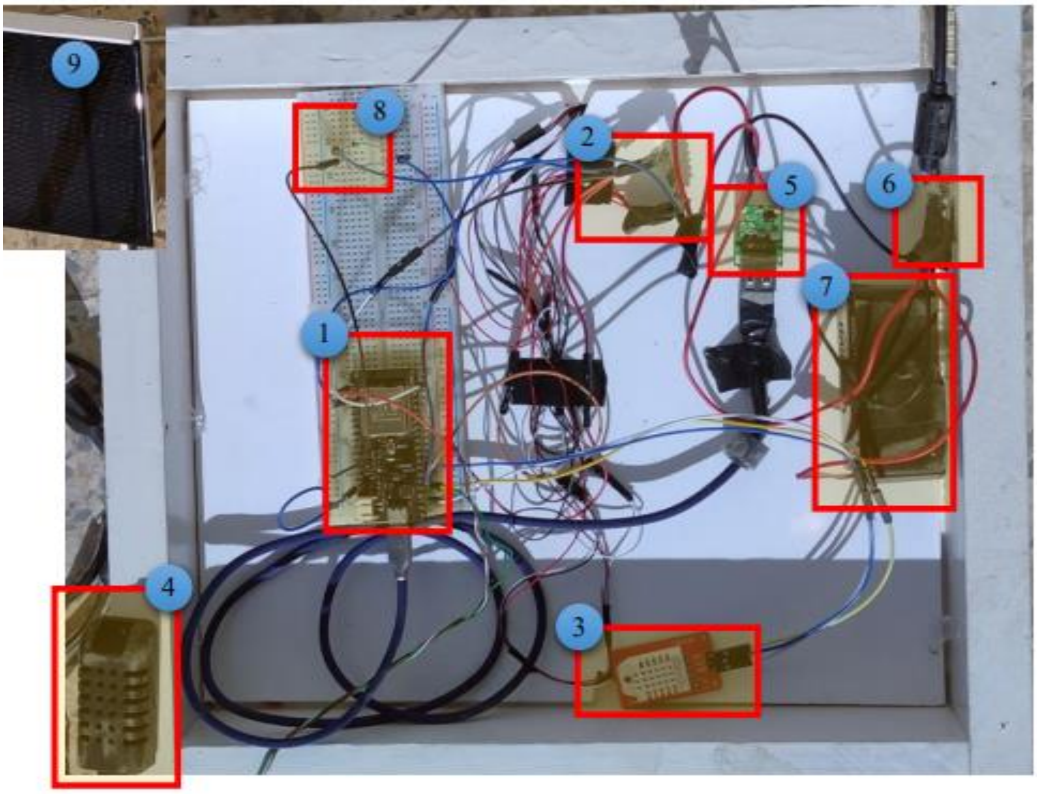

Figure 14. Final assembly of the system with marking of each component

The different numbers shown in Figure 13 represent the following elements of the system:

1. ESP32 module
2. HX711 module
3. DHT22 sensor
4. DHT21 sensor
5. Boost converter module
6. TP4045 battery charger
7. Battery Li-ion
8. Voltage divider for measuring battery charge
9. 6V 4W PV module

5.3. Test the program

Figure 11 shows a screenshot of the serial interface, showing details of the initialization and operation of the system during the test. This enables the following operating points to be checked:

- Connect to the Internet via a Wi-Fi.
- Connect to the Firebase server.

5.4. Results

Once we had assembled a test prototype of our project, we were able to run a number of different tests to verify that the system was working as we had originally intended. Figure 12 shows the results of humidity, temperature, and weight measurements for each hive.

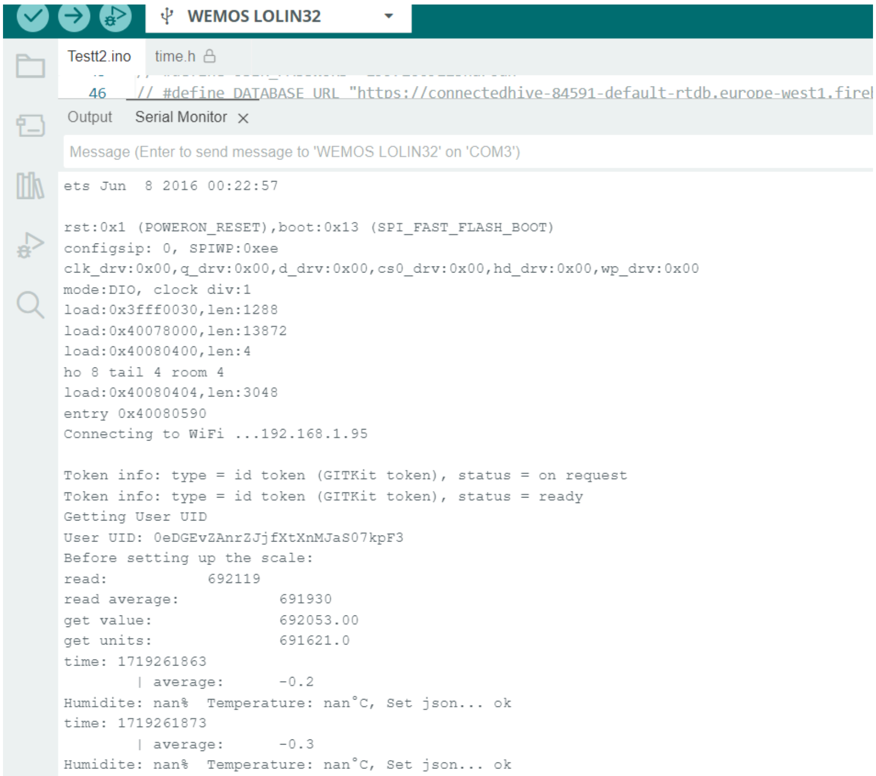

Figure 15. Firmware test.

Figure 16. Screenshot of the mobile application during test.

6. Conclusion

In this chapter, we produced the final system with its various functional components, as well as the various tests required to validate it.

The hardware part of our project was implemented using an ESP32 card and a set of sensor modules including a firmware to handle all the needed functionality. And a mobile application to allow user to monitor distantly beehive in real-time.

During the project, we performed different tests to validate each task and function of the system, including software and hardware functionality and specification.

General conclusion

The final year project involves designing a platform that provides continuous monitoring at all times, based on the Internet of Things (IoT) technology. This platform enables beekeepers to check climatic parameters as well as hive parameters such as weight, then process them and send them to a web server, where they can be displayed in an Android app.

To do this, we used one of our methodologies to design an embedded system project. In order to be able to implement this system, we had to follow the following steps:

The first step was to understand the field of beekeeping and the difficulties associated with it, by researching the connected beehive technologies already on the market. This helped us get an initial idea of the functionality required for our system.

The second step was to develop a system specification, where we defined the overall concept, specifications (requirements and constraints) and functional design. This gave us a better idea of the functions of the system and how they interact.

The third Step is to consider the choice of components used, both on the hardware side (ESP32 microcontroller, DHT22 sensor, HX711 sensor, BMP280 sensor, etc.) and on the software side (Arduino IDE, application). Another essential choice for the operation of the system concerns the power source, where we chose a PV module with a battery, which is managed through the power inverter modules.

The fourth step consists of the implementation of the complete project. After testing and checking each component individually, we started by designing the basic electronic system with its control software. Then we verified that all the requirements were met, and finally we validated the trial run of the system.