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Topic: Development of a connected BeeHive

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شهادة الترخيص لإيداع مذكرة الماستر

انا الأستاذ(ة): بوسيف شمس الدين

المشرف على اعداد مذكرة الماستر الموسومة بـــ :

Devlopment of a connected Beehive

من انجاز الطالبين:

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أشهد ان الطلبة قد قاموا بالتعديلات والتصحيحات المطلوبة من طرف لجنة التقييم/المناقشة وبإمكانهم ايداع النسخ الورقية والاليكترونية على مستوى المكتبة المركزية للجامعة

امضاء المشرف | امضاء رئيس اللجنة

عين تموشنت في: ....

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إن رئيس اللجنة الوطنية لمنح علامة "مؤسسة ناشئة" و "مشروع مبتكر" و حاضنة أعمال"،

- بمقتضى المرسوم الرئاسي رقم 21-281 المؤرخ في 26 ذي القعدة عام 1442 الموافق 7 يوليو سنة 2021 والمتضمن تعيين أعضاء الحكومة ، المعدل والمتمم.
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- بمقتضى المرسوم التنفيذي رقم 20–254 المؤرخ في 27 محرم عام 1422 الموافق 15 سبتمبر سنة 2020 والمتضمن إنشاء لجنة وطنية لمنح علامة "مؤسسة ناشئة" و"مشروع مبتكر" و"حاضنة أعمال" وتحديد مهامها وتشكيلتها وسيرها، المعدل و المتمم.
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إلى المشروع : BEEGUARD

صاحب \ أصحاب المشروع : LOURMIL SOUMIA

BOUZID DAHO RANIA HADJAR / MILOUD ABID AHLEM SABRINE

BEMMOUSSAT CHEMS EDDINE

المادة الثانية:

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حرر بالجزائر في:...24 أفريل 2025

وزارة اقتصاد المعرفة والمؤسسات الناشئة والمؤسسات المصغرة
اللجنة الوطنية لمنح العلامة
"مؤسسة ناشئة" "مشروع مبتكر"
و"حاضنة أعمال"

رئيس اللجنة الوطنية

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There is gratitude. There is friendship. There is a bond that time will never break.

Dedication

With a heart full of gratitude, I dedicate this work to the people who mean everything to me

To my dearest parents, you have been my quiet heroes.

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And finally, to anyone who dares to dream of making a difference
This is for you. Keep building, keep believing.

LOURMIL Soumia

Dedication

بسم الله الرحمان الرحيم

With a heart full of gratitude and humility, I dedicate this humble work:

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Dedication

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And finally, I dedicate this work to **Palestine** to its blessed land, to its resilient and dignified people, whose cause lives in every free heart.
May God grant them victory and honor us all with a prayer in Al-Aqsa, in peace and in freedom.

MILOUD ABID Ahlem Sabrine

Table of Contents

الـخلاصة

يهدف هذا المشروع إلى تصميم وتنفيذ **خلية نحل ذكية** قادرة على **مراقبة وتنظيم درجة الحرارة تلقائيًا** داخل الخلية، بهدف تحسين ظروف عيش النحل وزيادة إنتاج العسل. يعتمد النظام على متحكم دقيق المرتبط بحساس لقياس درجة الحرارة والرطوبة.

عند ارتفاع درجة الحرارة داخل الخلية فوق 35 درجة مئوية يتم تشغيل **مروحة تبريد** تلقائيًا لتخفيض الحرارة وضمان بيئة مناسبة للنحل. تم تزويد النظام بـشاحن متنقل لتأمين الطاقة بشكل مستقل دون الحاجة إلى مصدر كهربائي خارجي. كما يمكن لمربي النحل **مراقبة الخلية والتحكم بها عن بُعد** عبر تطبيق (بلينك) على الهاتف المحمول، حيث تظهر البيانات البيئية في الوقت الحقيقي.

تُساهم هذه الحلّ في **تقليل التوتر الحراري على النحل**، وتحسين صحته، مما يؤدي إلى **زيادة في إنتاج العسل** وتقليل الخسائر الناتجة عن التغيرات المناخية. ويمثّل هذا المشروع خطوة مهمة نحو إدخال **التقنيات الذكية في مجال تربية النحل الحديثة.**

ABSTRACT

This project introduces an innovative **smart beehive system** designed to improve bee colony health and assist beekeepers in hive management. The system is built around an **ESP32 microcontroller**, connected to a **DHT11 sensor** that monitors internal temperature and humidity. When the temperature exceeds a critical threshold of **35°C**, a **cooling fan** is automatically activated to **regulate the internal environment** and **prevent heat stress** on the bees.

The system is powered by a **power bank**, ensuring autonomous operation without dependence on external power sources. Additionally, it features a **remote monitoring interface** through the **Blynk mobile application**, allowing the beekeeper to **track and control** hive conditions in real-time using a Smartphone.

This smart solution contributes to **better colony welfare**, **reduces risks** related to temperature fluctuations, and **boosts honey production**. It represents a significant step toward integrating smart technologies into modern beekeeping practices.

Résumé

Ce projet propose une **solution innovante de ruche intelligente** destinée à améliorer les conditions de vie des abeilles et à faciliter le travail des apiculteurs. Le système est basé sur un microcontrôleur **ESP32**, couplé à un capteur **DHT11** pour mesurer la température et l'humidité à l'intérieur de la ruche. Lorsque la température dépasse le seuil critique de **35°C**, une **ventilateur** se déclenche automatiquement afin de **réguler la température interne** et ainsi **prévenir le stress thermique** des abeilles.

L'alimentation est assurée par un **power Bank**, garantissant un fonctionnement autonome même en absence de courant. De plus, une interface connectée via l'application **Blynk** permet à l'apiculteur de **suivre à distance** les données environnementales de la ruche et d'intervenir si nécessaire, depuis son Smartphone.

Cette solution contribue à **renforcer la santé de la colonie**, à **réduire les pertes** dues aux conditions climatiques extrêmes, et à **augmenter la productivité en miel**. Elle offre un premier pas vers l'intégration des technologies intelligentes dans l'apiculture moderne **de miel**.

List of Figures

Chapter I

Chapter II

List of Tables

Chapter I

Chapter II

List of Acronyms

AI: Artificial Intelligence

BLE: Bluetooth Low Energy

CFM: Cubic Feet per Minute

dB : Decibal

DIY: Do It Yourself

ESP32: Espressif Systems Protocol 32-bit

GPIO: General Purpose Input/output

GND: Ground

HR: Humidity Relative

IOS: IPhone Operating System

IOT: Internet of Things

MQTT: Message Queuing Telemetry Transport

RAM: Random Access Memory

RPM: Revolution Per Minute

RTOS: Real-time Operating System

SRAM: Static Random Access Memory

VCC: Voltage at the Common Collector

WIFI: Wireless Fidelity

General Introduction

General Introduction

Bees are a crucial component of our ecosystem. Through their role in pollination, they significantly contribute to plant reproduction and agricultural productivity. However, in recent years, beekeepers have faced numerous challenges, particularly those related to climate change and its impact on bee colonies. One of the major issues is the excessive rise in temperature inside the hive**,** which can disrupt bee behavior, impair the queen's egg-laying process, weaken the colony, and reduce honey production.

In response to this challenge, it is essential to develop innovative solution that allow for the monitoring and regulation of internal hive conditions-especially temperature and humidity.

This is the aim of our project, which focuses on designing a Smart Beehive capable of detecting environmental variations in real time and responding autonomously to maintain an optimal environment for the colony's development.

The main goal is to create an automated monitoring and regulation system based on connected technologies. This system will continuously track internal hive data, notify the beekeeper in case of anomalies, The objective is to maintain a stable climate within the hive, ensuring bee welfare and, consequently improving honey production.

The adopted methodology consists of several stages. An initial study phase defines the optimal thermal and hygrometric needs of the bees. This is followed by the design of embedded system that integrates sensors, data processing logic, remote communication and actuators. Finally, a Testing phase will asses and validate the system's performance in a controlled environment simulating real hive condition.

This project aims to bridge traditional beekeeping and modern technologies, promoting sustainability, efficiency, and respect for the apicultural ecosystem.

CHAPTER I

Towards Intelligent Beekeeping:

Challenges, Innovation &Prospects

I.1.Introduction

The protection of bees has become a global priority, at the intersection of environmental, agricultural, and economic concerns. Responsible for the pollination of nearly 80% of flowering plant species, bees play an irreplaceable role in preserving biodiversity and ensuring food security. Yet, their population is in alarming decline due to multiple factors, with climate-related disruptions being a major contributor.

In this context, the chapter aims to explore the scientific and technical foundations related to our research topic. It is structured around five complementary themes: we begin with an overview of the essential role bees play in ecological balance, followed by an examination of the effects of climate change on beekeeping activity. We then present the shift toward modernized practices in apiculture, along with a review of emerging technologies in the field of connected hives. Finally, special attention will be given to the influence of internal climatic conditions particularly temperature and humidity on bee behavior and the quality of honey production.

I.2.The importance of bees in the ecosystem

Beekeeping is important because bees play a vital role in the reproduction of many plants and in food security, poverty reduction, health, and environmental protection. Their disappearance would therefore have major repercussions on plant diversity and global food security, as they contribute significantly to the production of most of the plants we consume. Indeed, more than 75% of food crops depend, in part or in full, on pollinators, with bees being among the most important because they play a crucial role in the production of fruits, vegetables, coffee, cocoa, and almonds. They also play a vital role in maintaining biodiversity, as evidenced by the positive correlation between plant diversity and pollinator diversity. The abundance and variety of pollinator species in a given environment are considered key indicators of the health of that ecosystem and according to experts from the Food and Agriculture Organization of the United Nations; about a third of global food production depends directly on the work of bees. (1)

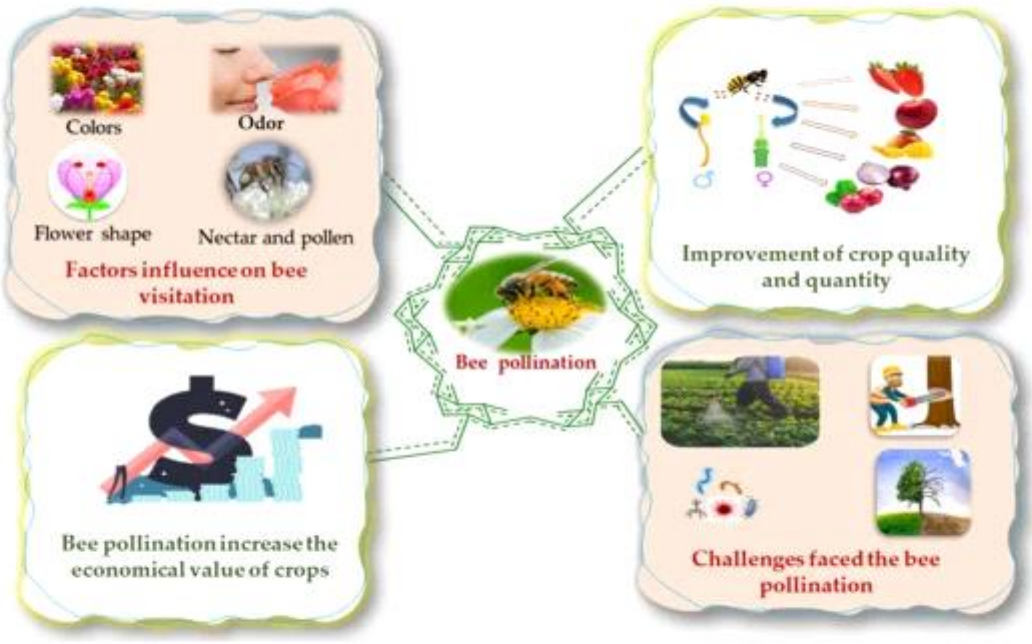

Figure I.1: Bee Pollination (2)

I.3.Beekeeping in the context of climate change

Beekeeping will be no exception whereby climate change will inevitably have consequences for bees and beekeeping thereby impacting the key ecosystem service of pollination and honey harvesting. (2)

I.3.1.Observed impacts

- Increased bee feeding to compensate for the lack of available nutrients in the environment.
- Addition of waterers in apiaries to compensate for water shortages.
- Changes to the beekeeping calendar (colony start-up, queen availability, syrup preparation, transhumance dates, harvest of certain honey flows, apiary visits, final harvest, wintering, etc.)
- Anticipation of hive preparation and keeping hives ready to respond to climate variability.
- Changes to the transhumance plan (modification of routes, schedule, health measures, etc.) and increased travel to find available nutrients in the environment.
- Increased vigilance and observation of external phenomena.
- Increased arduousness and working hours (workload, stress), leading to psychological fatigue for beekeepers.
- Variability in honey quality and quantity.
- Increased costs (transhumance, feeding, equipment, etc.) (3)

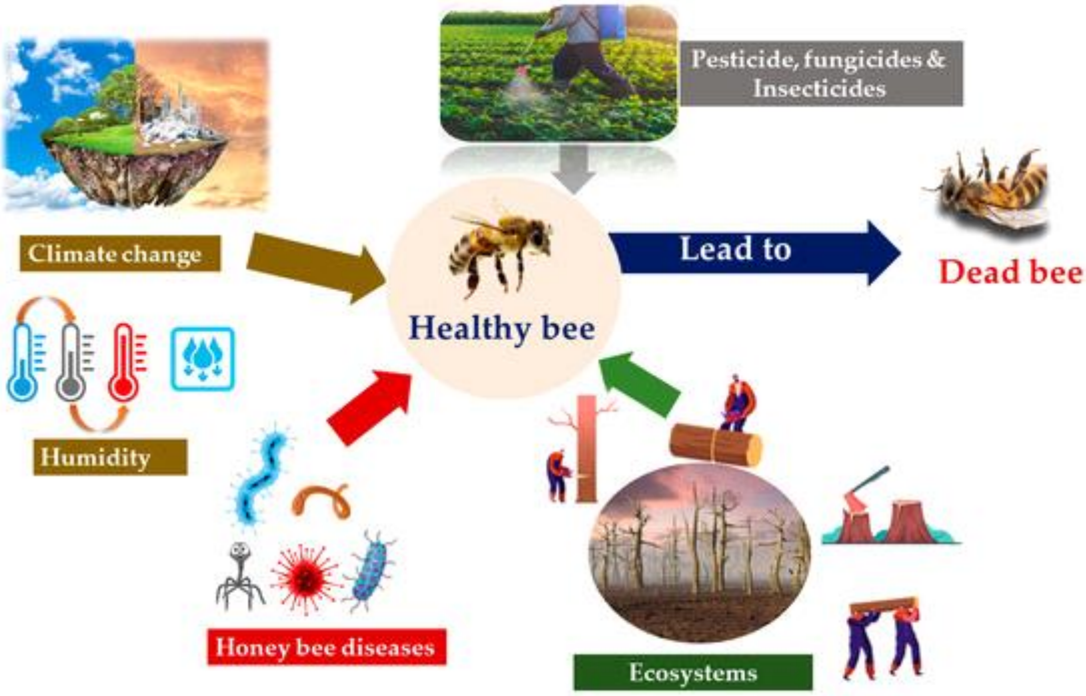

Figure I.2: Healthy Bee (2)

I.4.Presentation of modern Beekeeping

Modern beekeeping plays a crucial role in bee conservation and sustainable agriculture. With technological advancements, beekeepers can now remotely monitor their hives, analyze real-time data, and make informed decisions. Connected devices track hive conditions without disturbing the bees, reducing colony stress. In urban areas, smart hives are increasingly installed to raise awareness about pollinators' importance. This modern approach makes beekeeping more efficient, accessible, and better suited to current environmental challenges (4).

I.4.1. Use of Technology

Modern beekeepers use smart sensors to monitor hive conditions like temperature, humidity, and hive weight. Tools like microcontrollers, applications, and IoT systems help beekeepers receive real-time data and alerts. (5)

I.4.2. Bee Health Monitoring

Technologies such as thermal cameras, AI image analysis, and remote sensors help detect diseases, parasites , or stress in bees early. (6)

I.4.3. Sustainable Practices

Modern beekeeping emphasizes environmental care. Beekeepers use natural treatments, avoid harmful chemicals, and plant pollinator-friendly flowers to support bee populations. (7)

I.4.4. Urban and Smart Beekeeping

Urban beekeeping is growing in cities, often using smart hives that connect to mobile apps. These systems allow hobbyists and professionals to monitor their bees without frequent interference. (8)

Modern beekeeping blends tradition with innovation. By using technology and eco-friendly methods, it helps protect bees and ensures better honey production and pollination.

I.5. Technologies used in connected Beekeeping

Connected beekeeping, has evolved significantly with the integration of advanced technologies. Recent innovations have introduced systems that combine Internet of Things devices, artificial intelligence, and machine learning.

I.5.1. IoT-Enabled hive monitoring Systems

Internets of things devices are becoming more and more important in modern beekeeping as they provide real-time data on hive conditions. For example, early illness identification and proactive hive management are made possible by the Hive link system's integration of sensors that track temperature, humidity, hive weight, and diurnal cycles. By giving beekeepers useful information, this method reduces the need for manual checks and encourages sustainable practices. (9)
Similarly, Bee sage provides smart beehive scales that monitor weight variations, ambient temperature, and GPS positions. This technology notifies beekeepers of crucial events. (10)

I.5.2. Artificial Intelligence and Machine Learning applications

Complex hive data analysis now heavily relies on ML and AI. The Intel beehive system uses machine learning and computer vision algorithms to track bee activity. It offers non-intrusive, real-time data by placing cameras at hive entrances, which makes it easier to comprehend and control hive health.
Additionally, an Attention-based Multimodal Neural Network (AMNN) AI-based integrated system has been created to evaluate bee health by examining both acoustic and visual information. With an overall accuracy of 92.61%, our all-encompassing method outperformed conventional single-signal models and provided a more effective, non-invasive method for early disease identification. (9)

I.5.3. Robotic Beekeeping Innovations

Robotics is transforming modern apiculture by automating essential hive management processes.

Beewise's Beehome is a robotic beehive that combines AI and robotics to perform regular maintenance, monitor environmental conditions, and detect diseases. Operated using solar power, this system minimizes the necessity for frequent human intervention, which helps reduce stress on the colony and enhances productivity. (11)

I.5.4. Integrated environmental and security monitoring

Advanced monitoring systems now incorporate sensors for temperature, humidity, and GPS tracking, providing real-time alerts on hive conditions and unauthorized movements.

I.5.5. Data-driven decision making and predective analytics

Platforms like BeeSTAR empower beekeepers with precision sensing technology, enabling data-driven decision-making. By tracking hive performance and providing early warnings for potential issues, beekeepers can take proactive measures to maintain colony health. (12)

The integration of IoT, AI, robotics, and data analytics in connected beekeeping represents a transformative shift towards more efficient, sustainable, and resilient apiculture practices. As show in the figure bellow.

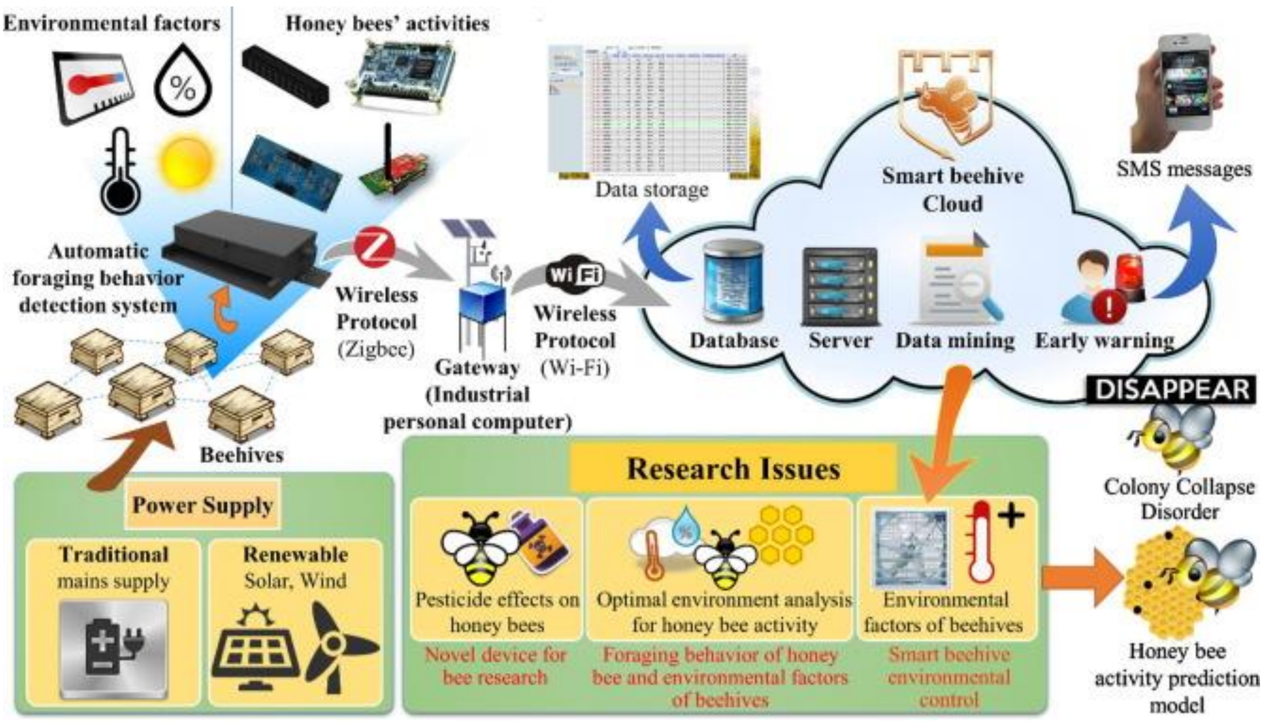

Figure I.3: Technologies utilized in connected Beekeeping Systems (13)

I.6. Impact of Temperature and Humidity on Honeybee Productivity

I.6.1. Impact of temperature

Temperature fluctuations significantly impact honeybee productivity, affecting their physiological function, behavior, and colony dynamics. Research has shown that optimal hive temperatures (33_36°C) are essential for maintaining colony efficiency, while deviations from this range lead to adverse effects.
High temperatures exceeding 36°C impose thermal stress on worker bees, increasing their energy consumption as they engage in thermoregulatory activities such as wing fanning and water collection (14). These behaviors divert resources from essential tasks like foraging and brood care, ultimately reducing honey production. Additionally, elevated temperatures decrease the efficiency of pheromone signaling, disrupting colony cohesion and potentially increasing swarming tendencies or stress responses in the hive. Prolonged exposure to excessive heat also heightens the risk of dehydration and weakens bees 'immune responses, making colonies more vulnerable to parasites such as Varroa destructor. (15) (16)

Conversely, temperatures below 33°C hinder larval development, slowing metabolic efficiency and leading to delayed growth and reduced adult bee populations (17). To compensate for heat loss, bees must consume more stored honey to generate warmth, depleting their reserves and increasing the risk of starvation, especially during prolonged cold periods. (18)

High temperature above 35°C also suppress foraging activity, as bees must return to the hive to assist in cooling efforts, reducing nectar and pollen collection. Studies using smart hive monitoring technology confirm that temperature instability correlates with reduced daily foraging rates and lower honey storage levels. (19) (20)

The table below shows the impact of temperature on honeybee productivity

Average temperature (°C)	Potential Honey Production (kg/ruche)
<20°	<10 Kg
25°-31°	20-30 Kg
32°-36° (ideal)	28-40 Kg
>40°	<10 Kg

Table I.1: The impact of temperature on honeybee productivity

I.6.2. Impact of humidity

Relative humidity plays a crucial role in maintaining colony homeostatic and influencing honey quality. Honeybees actively regulate hive humidity to sustain optimal brood-rearing conditions, which should ideally range between 50% and 70%. Deviations from this range can lead to detrimental effects on both the colony and honey production. (21)

When humidity levels exceed 70%, the evaporation rate of water from honey decreases, increasing its moisture content and making it more susceptible to fermentation and fungal infections, such as chalkbrood caused by Ascosphaera apis. Excessive moisture also compromises honey storage stability, requiring bees to invest additional energy in ventilation to maintain appropriate conditions. Conversely, low humidity levels below 40% can cause dehydration in developing larvae, leading to weakened adult bees or increased brood mortality. Additionally, reduced humidity effects the physical properties of beeswax, increasing its brittleness and making stored honey more vulnerable to contamination. (22) (23)

Humidity also influences nectar processing and honey ripening. If it’s too high, bees must spend more time drying nectar before capping honeycombs, delaying the honey maturation process. In contrast, when humidity levels are too low, nectar dries too quickly, potentially altering its sugar concentration and nutritional composition. Proper moisture regulation is essential to ensure honey maintains water content below 18%, preventing fermentation and preserving quality. Variability in humidity conditions can therefore impact not only colony health but also the market value of the harvested honey. (24)

Overall, maintaining optimal hive temperature and humidity is essential for the survival of honeybee colonies. As demonstrated in the following figure

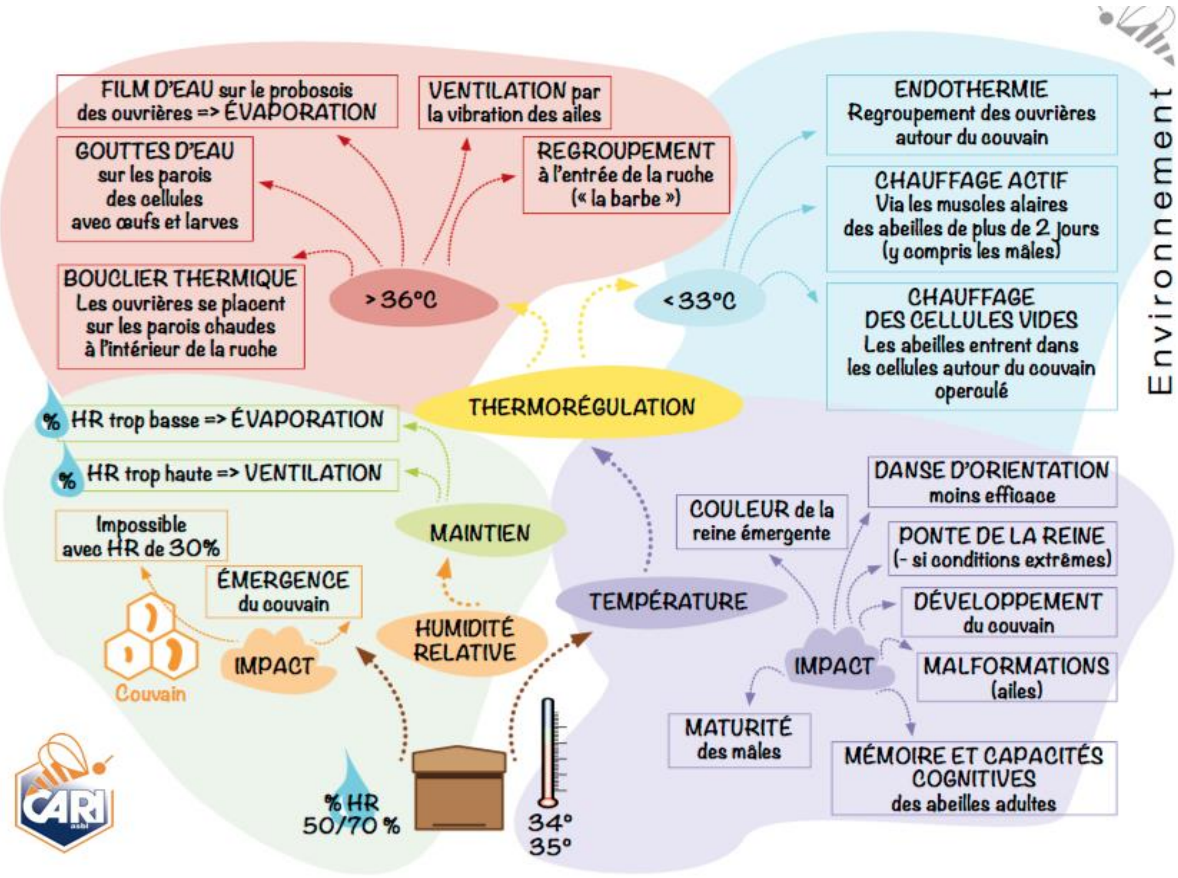

Figure I.4: Effects of Temperature and Humidity on Bee Productivity (26)

I.7.Comparison of international smart Beehive Projects

I.7.1. OSBeehives – BuzzBox (Spain / USA)

- Overview

OSBeehives is a startup founded in Denver, Colorado, with strong ties to the Fab Lab in Barcelona. They developed the BuzzBox, an IoT device designed to continuously monitor the health of beehives.

- Key Features

Acoustic Analysis: The BuzzBox records hive sounds to detect anomalies such as queen loss, swarming risk, or environmental stress.

Environmental Sensors: It measures temperature, humidity, barometric pressure, and local weather conditions.

Real-Time Alerts: Data is sent to a mobile app, allowing beekeepers to receive instant notifications when issues arise.

Solar-Powered: The device is equipped with solar panels for energy autonomy.

Easy Installation: It can be placed inside the hive frame or attached externally, and it's designed to be weather-resistant.

- Objectives

The main goal is to provide beekeepers with a non-intrusive monitoring tool, reducing the need for frequent hive openings and enabling rapid intervention when anomalies are detected. (25)

I.7.2. BeeHealthGuru (USA)

- Overview

BeeHealthGuru is a mobile application developed by Dr. Jerry Bromenshenk and his team at Bee Alert Technology, Inc. It uses artificial intelligence to analyze hive sounds and detect potential health issues.

- Key Features

AI-Based Sound Analysis: The app records hive audio and compare it with a sound database to identify signs of disease, stress, or queen loss.

Fast Diagnostics: Analyses are completed in under 15 seconds on modern smart phones.

Collaborative Learning: Users can submit their recordings and inspection reports to improve the detection algorithm.

Professional Version: An advanced version targets professional beekeepers, offering extra features like automatic alerts and regional reports.

- Objectives

BeeHealthGuru aims to provide a globally accessible tool for monitoring hive health using only a smart phone eliminating the need for costly equipment. (26)

I.7.3. SensorBee (Switzerland)

- Overview

SensorBee is a Swiss-based company specializing in environmental monitoring technologies. They offer smart, autonomous sensors specifically adapted for beehives to help beekeepers track key metrics effortlessly.

- Key Features

Multi-Parameter Sensors: Measure temperature, humidity, hive weight, and vibrations with high precision.

Wireless Connectivity: Data is transmitted in real time via LoRa or other low-power wireless technologies.

Plug-and-Play Setup: The system is easy to install and user-friendly, requiring minimal technical skill.

Durability: Designed for outdoor use in varied weather conditions.

Data Platform: Collected data is visualized through an intuitive dashboard.

- Objectives

SensorBee aims to simplify hive monitoring for both amateur and professional beekeepers. By offering accurate and real-time insights into hive conditions, the solution helps detect early warning signs of stress or disease, reducing hive losses and improving colony health. (27)

I.7.4. BeeScanning (Sweden)

- Overview

BeeScanning is a Swedish mobile app that leverages computer vision and AI to diagnose beehive health from simple photos. It was developed to help beekeepers detect parasites and diseases quickly and non-invasively.

- Key Features

AI-Powered Image Analysis: Detects the presence of Varroa mites and other abnormalities directly from Smartphone photos of brood frames.

Non-Intrusive: Eliminates the need for physical sampling or chemical tests.

Cloud-Based Processing: Photos are uploaded and analyzed in the cloud, with results sent back to the user.

User-Friendly App: Beekeepers simply snap photos with their phones and receive a full diagnostic report.

Disease Monitoring: Helps track and document the spread of parasites or infection over time.

- Objectives

BeeScanning's mission is to empower beekeepers with fast, reliable tools for disease detection. By minimizing the need to disturb hives and providing quick feedback, it improves hive management efficiency and supports sustainable beekeeping. (28)

I.8.Conclusion

The survival of bees today depends on the ability to adapt beekeeping practices to new environmental challenges. The integration of technological tools allows for a better understanding of colony needs and enables effective responses to climatic variations. By controlling key parameters such as temperature and humidity, modern beekeeping paves the way for smarter and more sustainable hive management, supporting both bee preservation and improved honey production.

CHAPTER II

BeeGuard: Smart Connected Hive System

Inspired by bees driving by technology!

II.1.Introduction

In the context of climate change and rising global temperatures, maintaining stable thermal conditions inside beehives has become a key challenge in modern beekeeping. Excessive heat can lead to significant stress on bee colonies, negatively impacting their health, behavior, and honey production. This chapter presents the development of an intelligent ventilation system designed to regulate the internal microclimate of the hive. The system operates autonomously and responds to thermal variations by activating a ventilation mechanism when necessary. It also includes a remote control function via a mobile application, allowing beekeepers to intervene manually when needed. By using this approach, it is possible to reduce the effects of thermal stress, improve bee comfort, and enhance overall hive performance within the framework of precision beekeeping.

II .2.Physical Design of the Hive

The physical design of the smart hive as illustrated in the image below is critical for both maintaining a healthy environment for the bee colony and ensuring the reliable functioning of the embedded monitoring system. The structure was conceived to integrate electronic components seamlessly while preserving optimal biological conditions. The hive was primarily built using natural, untreated wood, chosen for its excellent thermal insulation properties and its chemical neutrality, which helps avoid disturbing the bees or contaminating honey production.

Figure II.1: Physical Design of the Hive

II .2.1.Dual-Roof Smart Hive Design

The smart hive features an innovative dual-roof system specifically designed to optimize internal climate control and protect the integrated electronics. The outer roof serves as the primary barrier against external environmental factors such as rain, direct sunlight, and dust. It also functions as the technical platform, supporting a 5V exhaust fan and a weather-resistant enclosure that houses the electronic components.

Beneath the outer roof lies the inner roof, which plays a crucial role in regulating airflow into the hive. This inner structure is equipped with eight circular ventilation holes as can be seen in the image below, each with a diameter of 5 cm four located on the right side and four on the left. These holes are strategically positioned to allow the air pushed by the fan to enter the hive evenly, ensuring effective and balanced ventilation throughout the brood chamber. This airflow design helps prevent moisture accumulation and overheating, especially during hot weather conditions.

The dual-roof configuration not only enhances thermal insulation and air circulation but also creates a buffer zone between the external environment and the sensitive internal hive space. This separation ensures that the bees are not directly exposed to electronic components or air currents, maintaining colony comfort while allowing intelligent environmental regulation controlled by the embedded system.

Figure II.2: Dual-Roof Smart Hive Design

II .3.Initial Solution: Arduino Uno with DHT11 and Fan

At the beginning of the project, we developed a simple prototype using an Arduino Uno board, a DHT11 sensor for temperature and humidity measurement, and a fan that was automatically activated according to environmental readings.

The Arduino Uno is a widely used development board, particularly suited for beginners and simple electronic applications. However, the Arduino Uno does not have built-in wireless communication (Wi-Fi or Bluetooth), which is essential for remote monitoring and control in IoT applications. Implementing such features would require external modules like the ESP8266, which increases hardware complexity, power consumption, and the risk of instability.

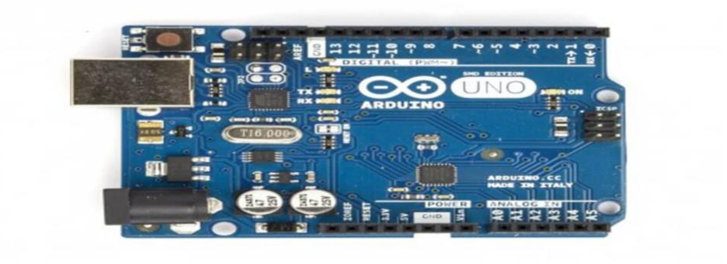

Figure II.3: Arduino UNO

II .3.1.Identified Limitations of the Arduino-Based System

Despite being user-friendly, the Arduino Uno presents several limitations:

- No native Wi-Fi or Bluetooth connectivity
- Limited memory and processing power
- Fewer available GPIO pins
- Additional components needed for IoT capabilities

These drawbacks make the Arduino Uno unsuitable for modern connected systems that require real-time data transmission and mobile monitoring.

II .3.2.Migration to ESP32:

To overcome these limitations, we transitioned to the ESP32, a more advanced microcontroller optimized for IoT applications. The ESP32 features a dual-core 32-bit processor (up to 240 MHz), integrated Wi-Fi and Bluetooth, up to 4 MB of flash memory, and 520 KB of SRAM.

Its main advantages include:

- Built-in wireless communication (Wi-Fi + Bluetooth)
- Higher processing capabilities and multitasking (FreeRTOS support)
- Low power consumption in deep sleep mode
- Wide compatibility with IoT platforms such as Blynk, and Firebase
- Greater number of GPIOs for enhanced expandability

With these features, the ESP32 enabled us to build a more intelligent, autonomous, and connected system, perfectly aligned with the needs of a smart agricultural environment like our IoT-based beehive.

II .4.Features Comparsion Table: Arduino Uno vs ESP32

Specification	Arduino Uno	ESP32
Microcontroller	ATmega328P	Xtensa dual-core 32-bit
Clock Speed	16MHZ	Up to 240 MHZ
Flash Memory	32KB	Up to 4MB
RAM(SRAM)	2KB	Up to 520KB
GPIO Pins	14 digital / 6 analog	30+ Configurable GPIOs
WIFI	Not integrated	Integrated(802.11)
Bluetooth	Not available	Integrated(Classic+BLE)
Processor Cores	Single-core	Dual-core
Operating Voltage	5V	3.3V
Power Consumption (Sleep Mode)	High	Very low (deep sleep supported)
Multitasking Support	No supported	Supported with FreeRTOS
IOT Connectivity	Requires external modules	Native support (wifi+Bluetooth)
IOT Platform Compatibility	Limited	Board (Blynk, MQTT, Firebase…)
Price	Lower(5-10)€	Slightly higher(8-15)€

Table II. 2:Arduino Uno VS ESP32 Features

II .5.System Architecture

The system architecture is designed to enable real-time environmental monitoring, intelligent response mechanisms, and remote access via a mobile platform. It consists of five major subsystems working in coordination:

II.5.1. Hardware Layer

At the physical level, the system integrates:

II.5.1.1.ESP32

The ESP32 as illustrated in the image below is a low-cost, low-power microcontroller with integrated Wi-Fi and Bluetooth, developed by Espressif Systems. It is widely used in Internet of Things (IoT) applications because it can collect data from sensors, process it, and send it wirelessly to other devices or cloud services. Its small size, energy efficiency, and versatility make it ideal for smart systems like connected beehives, smart homes, or environmental monitoring. (29)

Figure II.4: Microcontroller ESP32

II.5.1.2.DHT11

The DHT11 as presented in the image below is a basic digital sensor that measures both temperature and humidity. It is widely used in DIY electronics and IoT projects due to its low cost and ease of use. The sensor sends data in digital form, which can be read directly by microcontrollers like the ESP32. Though less accurate than more advanced sensors. (30)

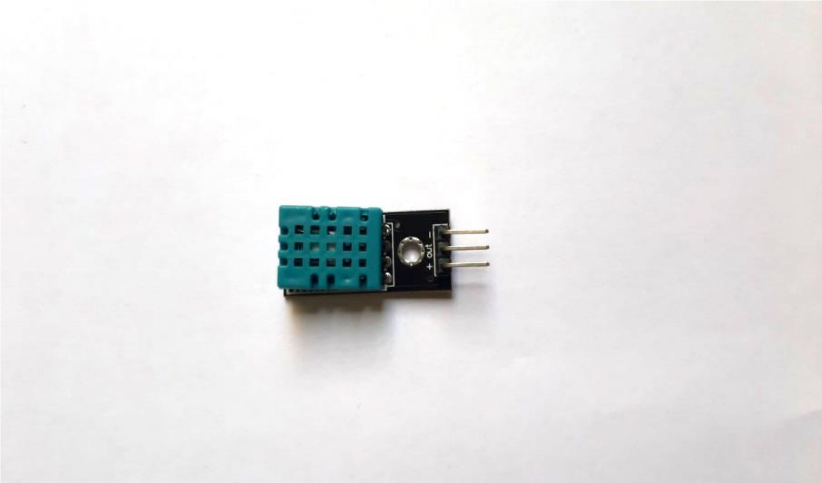

Figure II.5: Sensor DHT11

II.5.1.3.DHT11 Features:

Parameter	Specification
Sensor Type	Temperature and Humidity Sensor
Temperature Range	0°C to 50°C
Temperature Accuracy	±2°C
Humidity Range	20% to 90% HR
Humidity Accuracy	±5% HR
Operating Voltage	3.3V to 5V
Max Current Consumption	2.5 mA
Average Current	0.3 mA
Signal Output	Digital (single-bus protocol)
Sampling Rate	1 reading per second (1 Hz)
Response Time	< 5 seconds
Operating Temperature	0°C to 50°C
Operating Humidity	20% to 90% HR
Dimensions (module)	Approx. 23mm x 12mm x 5mm
Pins	VCC, GND, DATA
Recommended Pull-up Resistor	5kΩ to 10kΩ on DATA pin

Table II.2:DHT11 Features

II.5.1.4 Cooling Fan

A fan as can be seen in the image below is a mechanical device used to create airflow by rotating blades, usually powered by an electric motor. Fans are commonly used in ventilation, cooling, and climate control systems to move air and regulate temperature. In electronic or environmental systems such as a smart beehive a fan helps circulate air, preventing overheating and maintaining stable conditions.

Figure II.6: A 5V cooling Fan

II.5.1.5. Cooling Fan Features

Component	Specification	Details
Cooling Fan	Rated Voltage	5V
	Operating Current	100 mA – 300 mA (depends on model)
	Fan Speed	3000 mAh – 7000 RPM
	Air Flow	4-10 CFM
	Noise Level	20 – 30 dB(A)
	Typical Sizes	18.5 CM
	Usage	Cooling for electronics,

Table II.3: Cooling Fan Features

II.5.2. Control Layer

The ESP32 runs a firmware written in C++ using the Arduino framework. The firmware handles:

- ✓ Data acquisition fromes sensors.
- ✓ Local decision-making
- ✓ Communication tasks using Blynk

II.5.3. Communication Layer

Uses the built-in Wi-Fi module of the ESP32 to send data to the mobile app via the Blynk platform

II.5.4. Power Management Layer

The image below shows that the system is powered using a power bank wich is a portable battery device that stores electrical energy and supplies it to other devices via USB or similar connections. In the context of a smart beehive, a power bank can be used as an energy source to run small components like a fan, especially in remote areas where direct electricity is not available. It offers a simple, rechargeable solution for powering low-voltage devices like microcontrollers or cooling systems, helping to maintain a stable environment inside the hive.

Figure II.7: A Power Bank

II.5.4.1.Power Bank Features

Component	Specification	Details
Power Bank	Output Voltage	5V DC (USB standard)
	Output Current	1A – 2.1A
	Capacity	2000 mAh – 20000 mAh
	Battery Type	Lithium-ion / Lithium-Polymer
	Protection Features	Over charge, Overdischarge, Short Circuit
	Charging Interface	Micro-USB / USB-C (depends on model)
	Usage	Portable power for USB devices

Table II.4: Power Bank Features

Solar Panel (optional future addition): To enable autonomous outdoor operation.

II.5.5. Application Layer

Users interact with the system through a mobile application that displays data and allows real time control.
This modular architecture allows for easy upgrades and ensures energy-efficient, continuous monitoring of the system.

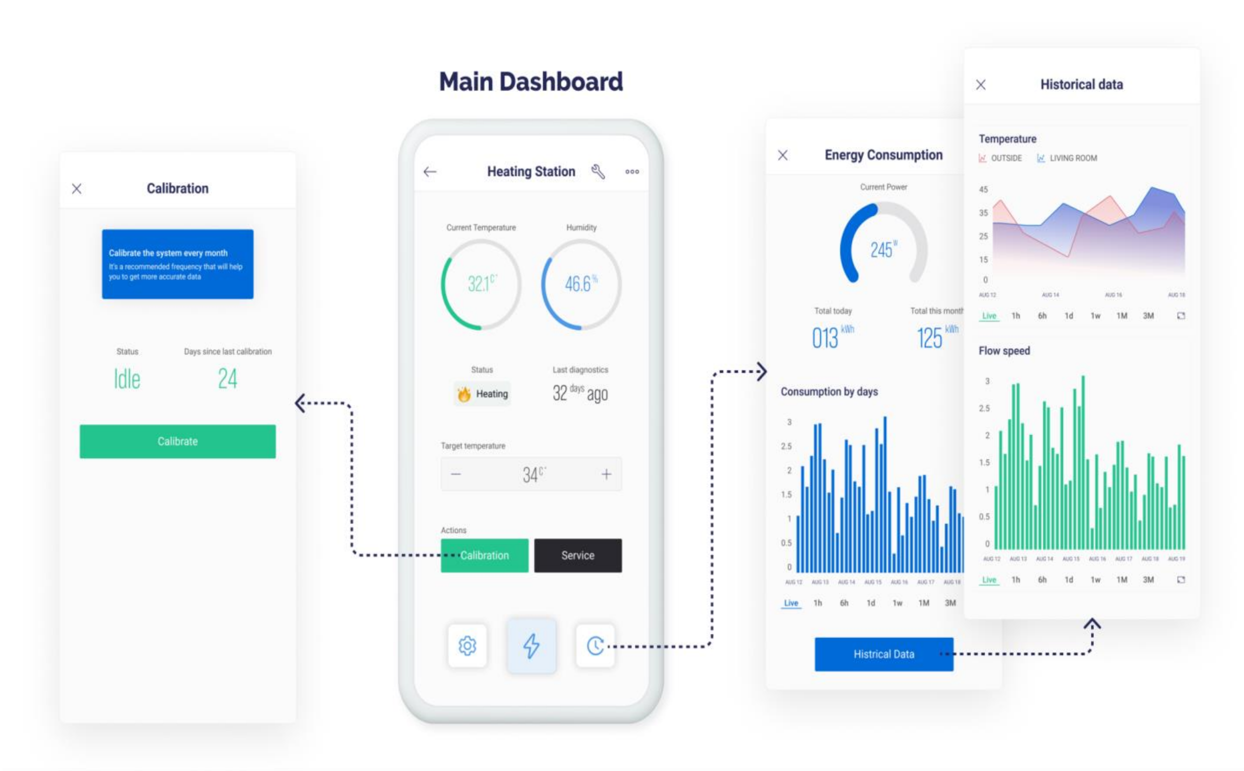

Figure II.8: Application Interface (31)

II.6.Electronic System Development

The development process began with a prototyping phase on a breadboard, which provided a flexible platform for assembling and testing the system's electronic components before permanent installation. This stage involved the individual testing of key components, including the ESP32 microcontroller**,** DHT11 temperature and humidity sensor**,** 5V ventilation fan, and a portable power source (power bank).

The objective of this phase was to ensure that each component functioned as expected and to debug any issues in isolation. The DHT11 sensor was tested for temperature and humidity accuracy, data stability, and response time under various environmental conditions. Simultaneously, the ability to reliably switch the fan ON and OFF based on digital signals from the ESP32 was evaluated, confirming safe operation at the desired current and voltage levels.

After successful individual validation, the components were connected together into an integrated circuit on the breadboard as shown bellow. The ESP32 was programmed to continuously read sensor values, process environmental data, and trigger the relay automatically when the temperature exceeded 35°C. This integration also included Blynk platform testing, where widgets such as gauges, buttons, and status indicators were configured and tested for real-time communication with the ESP32 via Wi-Fi.

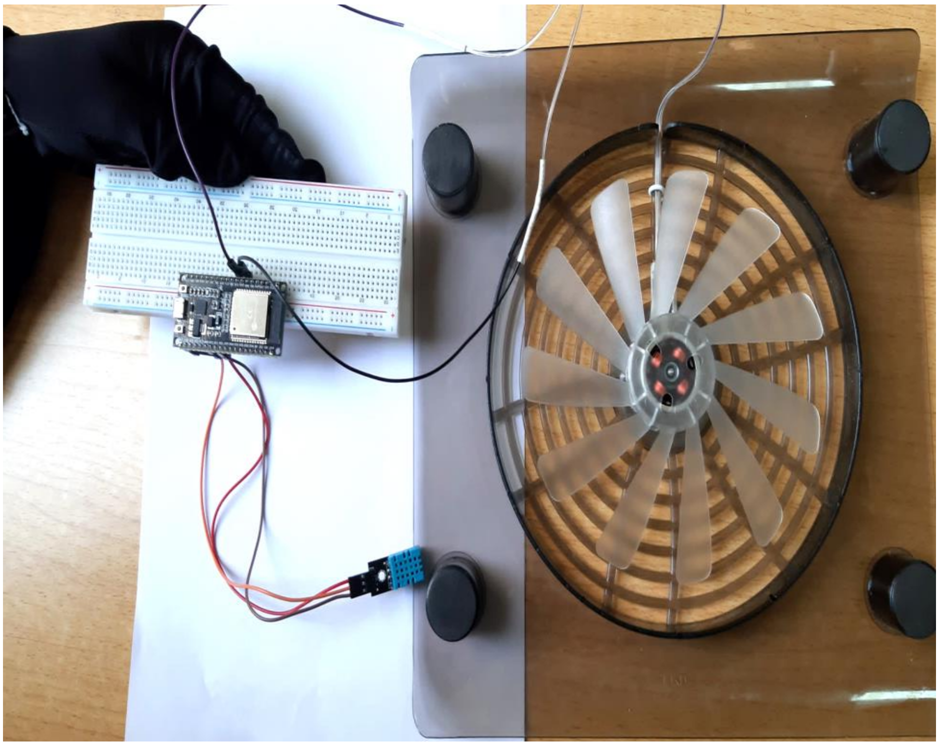

Figure II.9: Electronic System

II.7.Mobile Application Development

II.7.1. Platform Selection

Blynk was chosen for initial implementation due to:

- ✓ Easy integration with ESP32.
- ✓ Pre-built widgets (gauges, charts, and buttons).
- ✓ Cross-platform compatibility (IOS/Android).

II.7.2. Functional Features

II.7.2.1. Dashboard Widgets

The Blynk mobile application interface is designed to provide real-time monitoring and manual control functionalities for the connected smart beehive. It includes digital gauge widgets that display live readings of temperature and humidity, collected from the DHT11 sensor connected to the ESP32. These visual indicators allow the user to monitor the internal environment of the hive at any time via the internet.

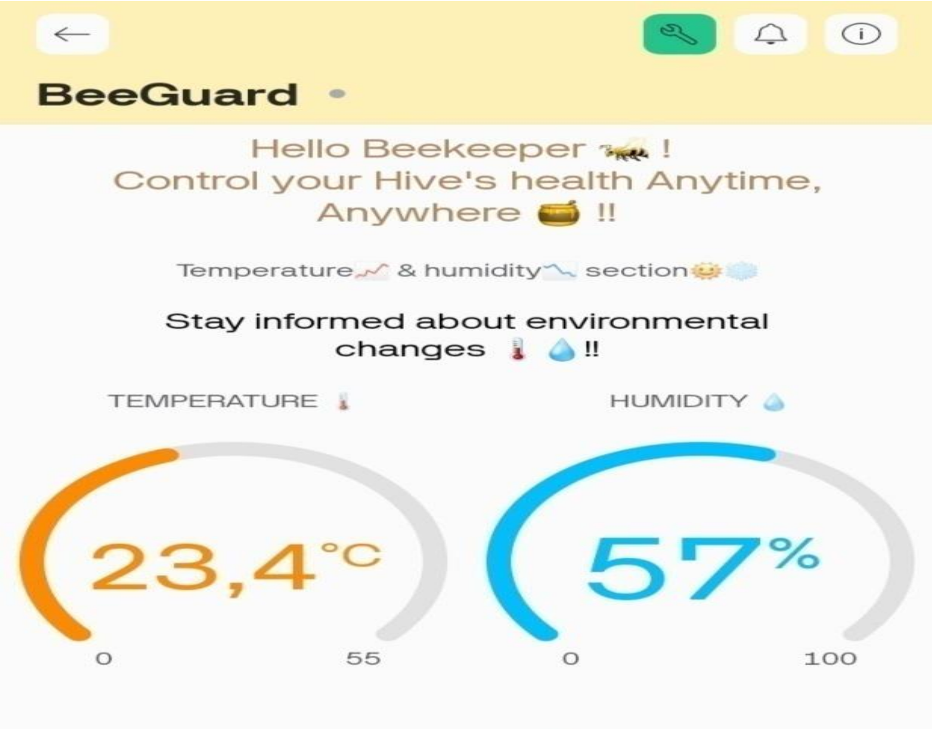

Figure II.10: The digital gauge widgets

In addition to monitoring, a button widget is implemented in the app to provide manual control over the ventilation fan. This feature allows the user to activate or deactivate the fan when necessary.

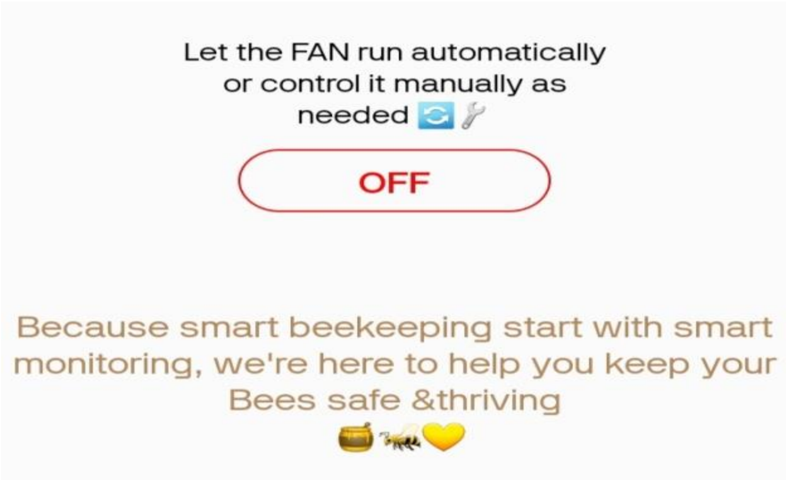

Figure II.11: The button widget

To enhance user feedback, a value display widget is also integrated into the interface. It shows the current status of the fan whether it is ON or OFF. This ensures transparency in the system's state and improves user interaction by confirming the fan's operational status in real time.

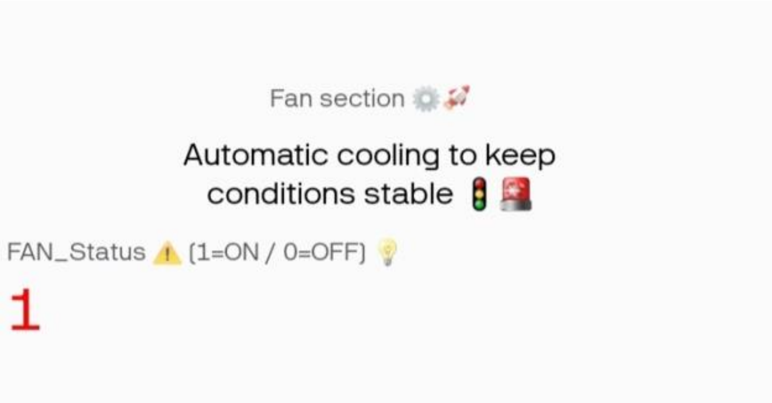

Figure II.12: The value display widget

II.7.2.2.Security

To enable secure and authenticated communication between the ESP32 and the Blynk mobile application, a unique authentication token (Auth Token) is generated by the Blynk platform when a new project is created in the app. This token serves as a digital key that links the ESP32 device to the user's Blynk account. The token is manually copied from the app and embedded into the ESP32's firmware by including it in the source code before uploading it to the board.

Once programmed, the ESP32 uses this token to connect to the Blynk cloud server over the internet. During each session, the Blynk server verifies the token to ensure the device is authorized. This approach prevents unauthorized devices from accessing the system and allows secure remote control and monitoring through the Blynk app

The mobile app enhances user experience by providing real-time access and control from any location, promoting proactive system management.

II.8.Perspective

In the future, The BeeGuard system has strong potential for development by adding:

- Add more sensors: such as: -Gas detector (for pollution)
  -Vibration detector (for hive disturbances)
  -Sound sensor (for stress level of bee activity)
- Use solar energy: to make the system autonomous and environmentally friendly.
- Create a mobile /web platform: to control and monitor multiple hives remotely in real time.

- Share data with researchers: to support studies on bee health, climate change and environmental protection.
- Support commercial use: by offering beekeepers a smart, affordable, and scalable solution for hive management.
- Adding a relay enables remote control of our connected devices

II.9.Conclusion

The implementation of an autonomous ventilation system for beehives represents a significant advancement in precision beekeeping. By dynamically responding to internal temperature changes, the system helps maintain optimal environmental conditions, reduces thermal stress on the bees, and supports improved honey production. The integration of remote control through a mobile application enhances flexibility and convenience, allowing real-time monitoring and manual intervention when necessary. This project demonstrates the value of applying smart technologies to traditional agricultural practices, improving efficiency and supporting the well-being of pollinators.

General Conclusion

General Conclusion

The rapid evolution of connected technologies is profoundly transforming the way we live, produce, and interacts with our environment. Among these innovations, the Internet of Things (IoT) plays a central role by bridging the physical and digital worlds. This technological revolution is now impacting various sectors such as healthcare, industry, transportation, and especially agriculture.

IoT provides intelligent solutions that improve efficiency, reduce costs, enhance safety, and support decision-making through real-time data analysis. In agriculture, its impact is particularly significant, enabling remote monitoring of crops, livestock, or beehives, automating repetitive tasks, and optimizing the use of natural resources such as water and energy. These technologies offer effective responses to major challenges related to productivity, sustainability, and food security.

Through this project, we have observed the relevance and importance of such tools in the context of digital transformation.

IoT is no longer a luxury or a convenience it has become a key driver in building a smarter, more sustainable, and more responsible future. This work represents a modest contribution to this global trend while opening the door to further innovations and improvements in the agricultural sector and beyond.

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Bibliographie

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People's Democratic Republic of Algeria

وزارة التعليـم العالي والبحـث العلـمي

Ministery of Higher Education and Scientific Research

جامعة عين تموشنت بلحاج بوشعيب

University of Ain Témouchent Belhadj Bouchaib

حاضنة الأعمال عين تموشنت

Business Incubator Ain Témouchent

BMC Appendix

ملحق نموذج العمل التجاري

Fiche technique du projet ■ البطاقة التقنية للمشروع

BOUZID DAHO Rania Hadjar MILOUD ABID Ahlem Sabrine LOURMIL Soumia	الاسم و اللقب **Votre prénom et nom** **Your first and last Name**
BeeGuard	الاسم التجاري للمشروع **Intitulé de votre projet** **Title of your Project**
0558446116	رقم الهاتف **Votre numéro de téléphone** **Your phone number**
beeguard2025@gmail.com	البريد الالكتروني **Votre adresse e-mail** **Your email address**
Ain Témouchent	مقر مزاولة النشاط (الولاية- البلدية) **Votre ville ou commune d'activité** **Your city or municipality of activity**

Nature de projet طبيعة المشروع ■

المنتج ذو طابع إنتاجي خدماتي

Sale of goods

1- Value proposition:

-1 القيمة المقترحة:

1.1 The value we offer to the customer:

- Improve bee health and increase the quantity and quality of bess.
- Smart monitoring of beehive condition (Temperature & Humidity).
- Reducing stress and losses to bees.
- System that can be adapted to multiple types of beehives.
- Saves beekeepers time and costs.
- Optimizations of Beekeeping interventions.
-

1.2 What other projects have been targeted for the same problem and implemente:

1.2.1At national Level:

The market is completely untapped, presenting a great opportunity for innovation and growth.

1.2.2At international Level:

1.2.2.1Pollentity (Beebot)

Pollenity, a Bulgaria-based technology company formerly known as Bee Smart Technologies, has developed an advanced hive monitoring device called the Beebot. This compact, solar-powered IoT device is installed inside traditional beehives and equipped with sensors that measure temperature humidity, hive weight and acoustic activity.

1.2.2.2BEEP

BEEP, an open-source initiative from the Netherlands, provides a comprehensive digital platform for remote hive monitoring and management. Its core solution includes a mobile and web application combined with a hardware device called the BEEP base, which is equipped with sensors to measure key environmental indicators within the hive, such as temperature, humidity, sound (vibration), and hive weight.

1.2.2.3Bee2Beep

This startup develops a remote hive monitoring system based environmental and behavioral sensors, accompanied by an intuitive web and mobile platform for visualizing the data.

2- Customer segments:

2-شرائح العملاء

- Professional and amateur beekeepers.
- Agricultural cooperatives.
- Environmental research and studies centers.
- Civilized beekeeping projects.
- Organic honey production companies.
- Honey producers and Agri-Businesses
- Veterinary and apicultural technicians

Who do we create value for?

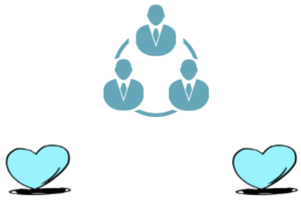
Beekeepers: by enabling real-time monitoring of hive conditions to ensure colony health and respond promptly to anomalies.

Beekeeping cooperatives: by providing accurate data to enhance honey yield and streamline production planning.

Veterinary and research professionals: by offering reliable environmental and behavioral indicators to support early disease detection and informed decision-making.

Smart agricultural systems: by integrating connected hives to improve operational efficiency, reduce losses, and support sustainable beekeeping practices.

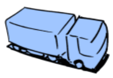
3- Customer Relationship:



3-العلاقات مع العملاء

- Technical support and guidance for installation and usage.
- Tutorial video on how to use the product
- Warranty and maintenance for a specific period
- Software updates

4- Channels:



4-القنوات:

- Beekeeper’s associations and agriculture fairs
- E-commerce platforms
- Social media platforms
- Awareness and educational days
- Exhibitions
- Advertisements

Preferred Distribution Channels by the Customer:

- Direct sales
- Online sales
- Mobile/web applications
- Distribution through specialized agricultural equipment stores

5- Key partners: 5-الشركات الرئيسية:

- National electronic component :
  - Arduino 1001 ,Oran
  - Dz Automation ,Oran
  - Tikno Dz , Béjaia
  - Power Tech , Blida
- Local carpenters or woodworking workshops(for beehive boxes)
- Agricultural cooperatives and beekeepers (for field tasting of the project)
- Business incubator, universities, and research centers
- Mobile app development
- IoT Services
- Agricultural tool suppliers

6- Key activities: 6-الأنشطة الرئيسية:

- System design and component integration
- Application development
- Creating a prototype ready for field testing
- Hive adaptation and structural modification
- IOT firmware programming
- User feedback and iteration
- Quality control and safety testing

6-1-Secondary activities

- Marketing and communication
- Training and user support
- Customer service and maintenance
- Business development

7- Key Resources:

7- الموارد الرئيسية:

7.1-Material Resources :

Suppliers المورد	**Local or Foreign Source** مصدر محلي أو أجنبي	**Resources** الموارد
Electronic Components Suppliers	Foreign	ESP32 Microcontroller DHT11 Sensor Power Bank(Battery) Relay 5V Fan Jumper Wires
Carpenter	Local	Beehive Box
Mercerize	Local	Insecto net Drill Glue
3D Printing Workshops	Local	Protective enclosures

7.2-Humain Resources:

Number	Humain Resources Categorize
1	Application Developer
1	Beekeeper

8- Cost Structure : 8-هيكل التكاليف:

8.1-Structure Costs:

/	تكاليف التعريف بالمنتج أو المؤسسة Frais d'établissement
50.000	تكاليف الحصول على العدادات (الماء- الكهرباء.......) Frais d'ouverture de compteurs (eaux-gaz-….)
300.000	تكاليف (التكوين- برامج الاعلام الالي المختصة) Logiciels, formations
/	Dépôt marque, brevet, modèle تكاليف براءة الاختراع و الحماية الصناعية و التجارية
/	Droits d'entrée تكاليف الحصول على تكنولوجيا أو ترخيص استعمالها
/	Achat fonds de commerce ou parts شراء الأصول التجارية أو الأسهم
/	Droit au bail الحق في الإيجار
/	Caution ou dépôt de garantie وديعة أو وديعة تأمين
/	Frais de dossier رسوم إيداع الملفات
30.000	Frais de notaire ou d'avocat تكاليف الموثق-المحامي-.........
300.000	Enseigne et éléments de communication تكاليف التعريف بالعلامة و تكاليف قنوات الاتصال
/	Achat immobilier شراء العقارات
/	Travaux et aménagements الأعمال والتحسينات الاماكن
500.000	Matériel الآلات- المركبات- الاجهزة
150.000	Matériel de bureau تجهيزات المكتب

100.000	Stock de matières et produits تكاليف التخزين
10.000	trésorerie de départ التدفق النقدي(الصندوق) الذي تحتاجه في بداية المشروع.
/	Composants électroniques المكونات الالكترونية

The Total = 1 431 000DA

8-2 Our project expenses or fixed costs:

72.000	Assurances التأمينات
37.200	Téléphone, internet الهاتف و الانترنت
30.000	Autres abonnements اشتراكات أخرى
60.000	Carburant, transports الوقود و تكاليف النقل
100.000	Frais de déplacement et hébergement تكاليف التنقل و المبيت
50.000	Eau, électricité, gaz فواتير الماء – الكهرباء- الغاز
/	Mutuelle التعاضدية الاجتماعية
20.000	Fournitures diverses لوازم متنوعة
30.000	Entretien matériel et vêtements صيانة المعدات والملابس
/	Nettoyage des locaux تنظيف المباني
300.000	Budget publicité et communication ميزانية الإعلان والاتصالات

The Total = 672 200DA

8-3 Salaries of employees and civil servants:

From 100.000 / Month	رواتب الموظفين Salaires employés
From 50.000 / Month	صافي أجور المسؤولين Rémunération nette dirigeant

9- Revenue Streams :



10-مصادر الإيرادات:

9.1-Total Revenue:

القيمة	البيان
2 * 30 * 12 = 720	عدد الوحدات المنتجة
1.5000 / unite * 720	سعر البيع
10800 000	سعر البيع × عدد الوحدات المنتجة = الايرادات الاجمالية

- ✓ As part of our smart beehive project, we plan to sell 720 connected hives per year, each priced at 15,000 DZD, generating annual revenue of 10,800,000 DZD (720 × 15,000 DZD).
- ✓ In addition, each hive requires a monthly subscription to the mobile application, charged at 1,000 DZD per hive.
- ✓ For all 720 hives, this results in an additional annual income of 720,000 DZD (1,000 DZD × 720 hives × 12 months)
- ✓ Therefore, by combining hive sales and app subscriptions, the total estimated annual revenue amounts to (720,000+10,800,000)

Total =11,520,000 DZD

9.2- Revenue Sources:

- ➢ System sale
- ➢ Monthly or yearly subscription to the application
- ➢ Collaborations with Beekeepers
- ➢ Additional Services (Installation, maintenance, consultation
- ➢ Partnerships with agricultural equipment store
- ➢ Wholesale for distributors

THANK YOU