Beehive Monitoring Based on IoT Technologies and AI

Benahmed Khelifa[1], Merbouh Abdeldjalil[1], Tab Mohamed Abdeessamd[1], Lorena Parra[2, 3], Jaime Lloret[3*], Bourouis Amina[1]

[1] Department of Mathematics and Computer Science, Faculty of Exact Sciences, Tahri Mohamed University, Bechar, Algeria

[2] Departamento de Producción Agrícola, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, 28040, Madrid, Spain

[3] Instituto de Investigación para la Gestión Integrada de Zonas Costeras, Universitat Politècnica de València, 46730 Grau de Gandia, Spain

Emails: benahmed_khelifa@yahoo.fr, jalilbns08@gmail.com, tab.mr@yahoo.com, lorena.parra@upm.es, jlloret@dcom.upv.es, amina.bourouis@univ-bechar.dz

***Abstract*— The bee is the best pollinator of plants, essential to the balance of ecosystems and our food. Beekeeping and honey collection in their traditional forms have existed for decades in southern Algeria. Currently, beekeeping faces many problems: climate change, chemical pesticides, diseases, theft, predators, and pollutants. The aim of this work is to propose a system to monitor the state of a hive from inside and outside to remedy the problems raised. In this article, we propose an automated hive system based on the Internet of things (IoT) and Artificial Intelligence (AI). This system will collect the internal and external climatic parameters of the hive using different wireless sensors and transfer these values to the beekeeper's smartphone. Actuators placed in the hive will regulate the hive climate and perform other actions. The results of the experiment indicate that the proposed system is effective for monitoring and securing a beehive. An accuracy value of 0.9022 indicates that the decision tree model used for monitoring achieves a high level of accuracy.**

Keywords- Beehive; Smart beehive; IoT; sensor network; Artificial Intelligence; decision trees.

I. INTRODUCTION

Apiculture involves the keeping of honeybees for the purpose of collecting honey and its derivatives. It is an important practice that has many benefits: honey is an essential nutrient which is used in many industries, bees are natural pollinators that heavily influence the biodiversity of our planet and greatly enhance agricultural yield, and investing in this sector represents an opportunity to reduce poverty in rural areas [1][2]. Honey is commonly used as food and medicine, making its protection from contamination crucial to reducing health issues [3].

Bees and their keepers are facing great challenges due to climate change, the use of chemicals in agriculture, pollution, the urbanization of our planet, water scarcity, and overexploitation of plants. For these reasons, several scientists are concerned about the possibility of bee extinction and how it could affect human life in general. Among the issues of apiculture is the sudden hive collapse syndrome where a beehive dies unexpectedly. Another is overheating in the hive due to unprecedented planet-wide temperature increase leading the bees to less food collection and more focus on temperature regulation resulting in less honey production. In addition, sabotage and theft result in incredible loss for beekeepers. Furthermore, natural predators like certain types of birds and insects destroy entire colonies especially when beekeepers keep their hives in distant and rural areas where plant life is more abundant, and pollution is less apparent [4].

To face these problems, beekeepers need to keep constant watch on their hives making sure their temperature is stable, that they receive additional water and food during drought periods, and that they are active and safe from both human and animal enemies. As such, we can say that beekeeper challenges range from hive and bee health, climate, and status monitoring, to controlling their hives for optimal environmental metrics for bee survival and increased yield. Recently, smart IoT and AI technologies are used everywhere in precision agriculture management [5]-[7], including the monitoring and control of environmental metrics.

Considering the needs of beekeepers and the available IoT technologies, we aim in this work to propose a new beehive monitoring system based on both IoT and AI technologies. Our proposed system consists of two subsystems: the first one for monitoring the microclimate of the hive using sensors for temperature, humidity, carbon dioxide (CO2), and weight; the second subsystem is designed to secure the hive against predators, diseases, etc. This security system is based on smart cameras and speakers. Both subsystems use AI processing algorithms, Wifi communications and an Android application ensuring the communication of full system data access by the beekeeper.

The rest of this work is organized as follows. In Section 2, we present a literature review as well as the extraction of parameters/tools used in this research area. In Section 3, we describe the architecture and design of our proposed system. Section 4 presents the results of the work and their discussion. Finally, we conclude this work with a summary and some perspectives in Section 5.

II. RELATED WORK

Many approaches have been used throughout the years to leverage technology to assist in collecting data that can be used to study the health and behavior of individual honeybees and their hives.

In [8], the authors proposed an IoT-based beehive monitoring system. This system captures sensor data (temperature, humidity, weight, video and audio) recordings at the hives and sends them using the Message Queuing Telemetry Transport (MQTT) protocol to a ThingsBoard dashboard. In [9], the authors describe the recent advances in precision beekeeping as systems and as services. In [10], the article proposes a Self-Powered Smart Beehive Monitoring, Control System (SBMaCS) using IoT, and interconnecting various sensors of temperature, humidity, weight, motion s, and flame. In this article, the authors develop a mobile phone application that interacts with the SBMaCS hardware to monitor and control the various parameters related to the beehives. In [11], the authors proposed a smart beehive monitoring by microservices and a Web platform using the following hardware and software: Raspberry Pi, Android OS and Microsoft SQL Server. In [12], smart sensor systems were developed for real-time and long-term measurement of relevant parameters related to beehive conditions such as the hive weight, sounds emitted by the bees, temperature, humidity, and CO2 inside the beehive, as well as weather conditions outside. In [13], an innovative Edge-based IoT solution is presented for the detection of Varroa disease. The solution relies on Tensor Processing Unit (TPU) acceleration for machine learning-based models pre-trained in the hybrid cloud environment for bee identification and Varroa destructor infection detection. This proposed system can detect the presence of varroosis in beehives in real-time with the use of Edge Artificial Intelligence invoked for the analysis of video streams. In [14], the authors propose an IoT based smart beehive monitoring system integrated with advanced sensors, the system monitors temperature, humidity, hive weight, and diurnal cycle. The system provides real-time data, remote connectivity, and actionable insights for beekeepers. The system enables early disease detection, proactive interventions, and optimized hive management.

Based on this literature review, we conclude the following: Most of the research works in the field of smart hive monitoring have been based on various techniques, algorithms, Artificial Intelligence (AI) and IoT technologies. However, none of these works have addressed the issues of hive security or the challenges associated with the arid climate of a Saharan region. Our study aims to integrate these aspects by taking these specific constraints into account, while using Artificial Intelligence for data classification and decision making. This opens new perspectives for sustainable hive management in harsh environments.

III. Proposed System

A. System architecture

Figure 1 shows the architecture of our system. The first component is the beehive climate monitoring component. This part is equipped with sensors for temperature, humidity, CO2, pressure, weight and an internal camera. The security component of the beehive includes an external camera, a motion sensor, a proximity sensor, and a GPS. The actuator part contains a fan and a speaker. The software component includes the cloud, databases, and the Web application.

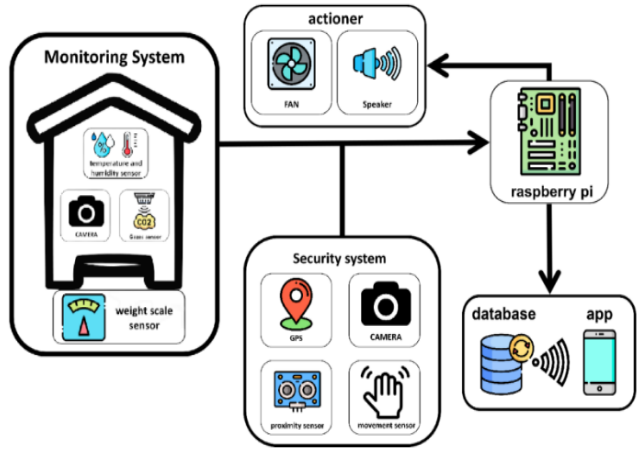


Figure 1. Architecture of the proposed system.

B. Description of the used components

In this section we describe the different components included in the proposed system.

- Raspberry Pi

Raspberry Pi is a Controller using the operating system Raspberry Pi OS (Raspbian). This installation necessitates an SD card. To install Raspberry Pi OS on SD card we used Raspberry Pi Imager.

- BME280

The BME280 sensor typically uses the I2C (Inter-Integrated Circuit) protocol for communication with the Raspberry Pi.

- DHT11

Installing the Adafruit_DHT library is a reliable means to acquire temperature and humidity data from DHT series sensors. Connecting the DHT11 sensor to the Raspberry Pi.

- MQ135

Since the Raspberry Pi 3 B+ lacks analog pins, we utilized an Arduino Uno to read the output of the MQ135 sensor. We established a serial communication between the

- HC-SR04

The RPi.GPIO libraries provide convenient functions to access the GPIO pins to interface with HC-SR04 sensor. Connect HC-SR04 to the Raspberry Pi.

- Raspberry Pi Camera V2

Installing the Pi camera library in Python allows access and control of the Raspberry Pi Camera Module. Connect Raspberry Pi Camera Module to the Raspberry Pi.

- SRD-05VDC-SL-C Relay

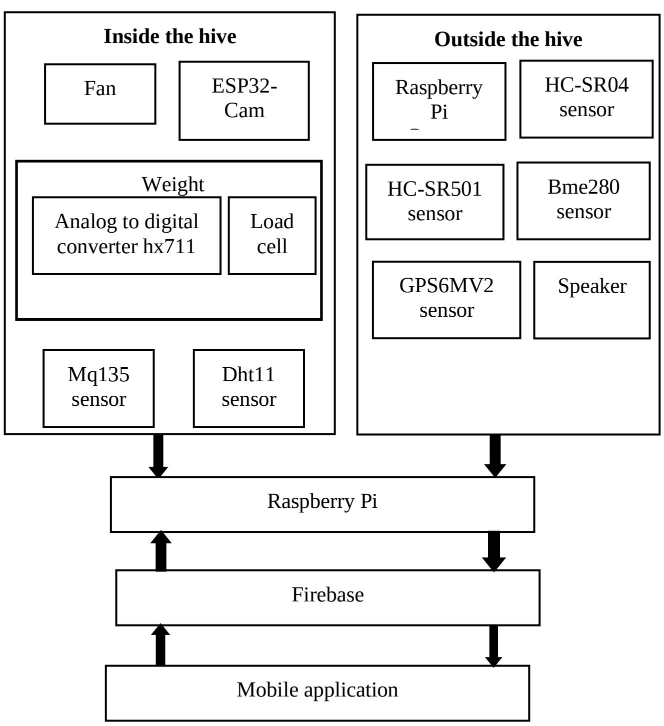
The RPi.GPIO libraries provide convenient functions to access the GPIO pins to interface with the SRD-05VDC-SL-C relay. Connect the relay to the Raspberry Pi.

In Figure 2, the experimental components of our monitoring system are identified. Both the pictures of the physical components, (Figure 2 a) to c)), and a scheme of their communication (Figure 2 d)) are displayed.

(a) Beehive External and Internal components.

(b) Weight sensor.

c) Security sensors.



(d) Components communication.

Figure 2. System description including physical components a) to c) and their communication d).

C. *System funcional modules*

Our proposed system performs two primary functions. Firstly, it monitors the beehive by collecting and analyzing data (temperature, humidity, weight, etc.) at regular intervals which is then sent to the cloud for storage and can be accessed through our mobile app. Secondly, it secures the beehive by conducting environmental scans to detect potential hazards (predators, thieves, etc.), with alerts sent to the mobile app. Below, Figure 3 shows the two monitoring modules of a beehive.

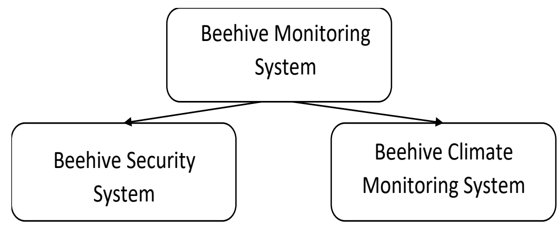


Figure 3. Beehive monitoring modules.

The module of beehive climate monitoring system is presented in Figure 4. This system collects temperature, pressure, humidity, CO2, weight, and photos from sensors and a camera at regular intervals.

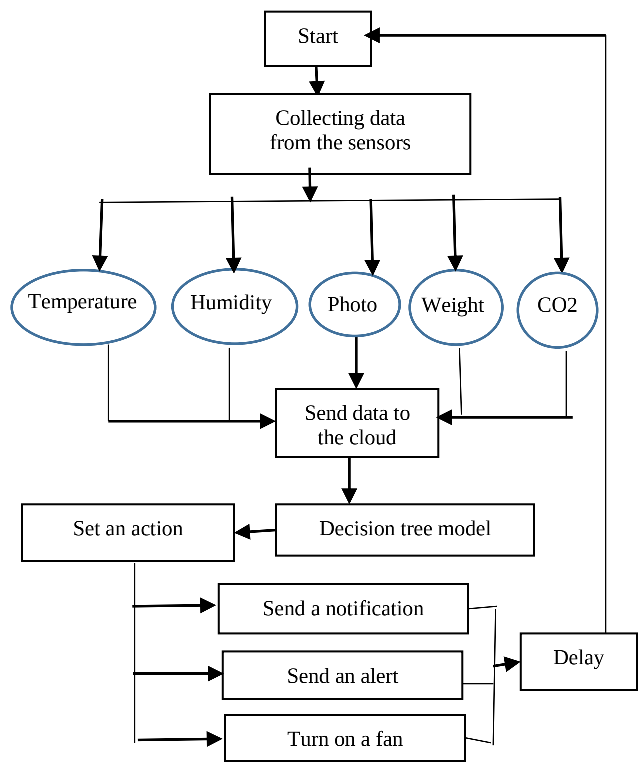


Figure 4. Climate monitoring diagram.

The collected data is then analyzed by the Decision tree (an AI Algorithm) to identify any necessary actions and send results to the cloud for storage. The data can be easily accessed through the mobile app.

To improve the productivity of the bees as well as their safety from the dangers of the surrounding area, the system in Figure 5 is designed to conduct environmental scans on a regular basis. This involves using a combination of proximity sensors, HC SR501 sensors, and a camera to detect potential hazards in the beehive's surroundings. The proximity sensors can detect any objects that are too close to the hive and may pose a threat to bees like predators or humans. The HC SR501 sensors can detect any movement such as intruders. The camera can capture images of the beehive's environment allowing beekeepers to visually inspect the area for any potential hazards.

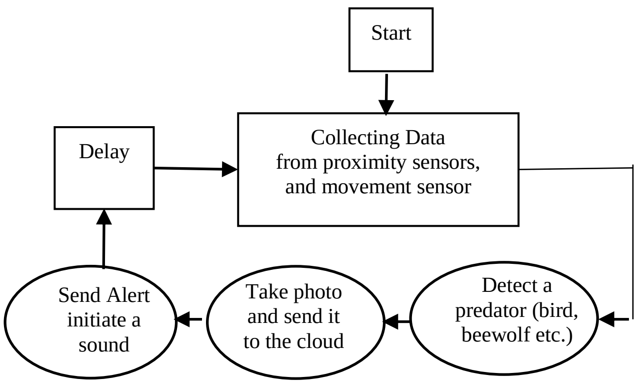


Figure 5. Beehive security system.

These used sensors and cameras can detect potential threats to ensure the security of the hive and take appropriate measures. For example, if the proximity sensors detect a predator (bird, beewolf, thief, etc.), the system can warn the beekeeper and send him a notification and a photo. The system through a speaker can trigger a hawk sound to deter nearby birds which effectively protect the hives. The camera can also be used to monitor activity around the hive as well as the detection of diseases such as varroa.

IV. Results and Discussions

In this section, we will present the implementation of our beehive monitoring system. The experiment took place in the south-west of Algeria, in Bechar city, which is an arid area with a dry Saharan climate. The data from this experiment are derived from the beehive shown in Figure 2 a).

A. *Collected data*

The data collected in Table 1 are a series of measurements taken at different dates and times, concerning various environmental factors of a beehive. Here is a general description of the data collected from IoT sensors of our proposed system:

1. Date: The dates range from March 8, 2023, to June 10, 2023, capturing a period of several months.
2. Interior Temperature: The temperature recorded inside the location varied between 24.5°C and 37.0°C, with the highest temperature observed on May 29, 2023.
3. Exterior Temperature: The recorded exterior temperature ranged from 27.2°C to 40.4°C, with the highest temperature observed on June 10, 2023.
4. Rainfalls: The data indicates whether rainfall occurred during the measurements.
5. CO2 Levels: The CO2 levels ranged from 465.62 to 538.94 parts per million (ppm), with the highest level observed on May 29, 2023.
6. Humidity: Humidity levels ranged from 32% to 80%, with the highest humidity recorded on April 26, 2023.
7. Weight: The weight measurements indicate a range from 11.38 to 18, representing units specific to the context of the data collection.
8. Pressure: The pressure values ranged from 925.6 Pa to 933.7 Pa.

TABLE I. Collected data form different sensors and at different dates.

Date/Time	Interior temp. (°C)	Exterior temp. (°C)	Rain falls	CO2 (ppm)	Humidity (%)	Wight (Kg)	Pressure (Pa)
08/03/2023 22:38	24.5	27.2	false	490.06	70	15	930.6
26/04/2023 16:53	25.0	28.0	false	498.21	80	18	925.6
27/04/2023 00:55	30.2	31.0	false	506.35	60	12	927.1
29/05/2023 17:07	37.0	38.1	true	538.94	34	11.5	930.1
10/06/2023 15:10	33.0	40.4	false	506.35	32	11.4	933.7

B. *Decision tree model*

In our monitoring system, hive management is done based on AI and Machine Learning (ML) models to improve the efficiency of beekeeping operations.

The decision tree is a model created and integrated into our monitoring system for decision making and beehive management. Table 2 illustrates the different classes of hive state generated by our decision tree model.

TABLE II. GENERATED CLASSES BY THE DECISION TREE MODEL

Example	Attributes						Result			
	Humidity %RH	Exterior Temp. Cº	Interior Temp. Cº	Weight Kg	Co2 ppm	Rainfall in last 24h	Send Notification	Send Alert	Requires hive visit	**Class**
1	70 -95	9- 47	10- 36	1- 35	440-500	N	N	N	N	Normal
2	70 -95	<8	10- 36	1- 35	440-500	N	Y	N	N	Hibemation
3	>96	9- 47	10- 36	1- 35	440-500	N	Y	N	N	Evaporating Nectar
4	0 -70	9- 35	10- 36	1- 35	440-500	N	Y	N	N	Low humidity hive
5	60-85	9- 35	10- 36	1- 35	440-500	N	N	Y	Y	Colony no longer in hive
6	70 -95	9- 35	10- 36	1-35	400-440	N	N	Y	Y	Diminished population - Reduced C02 production
7	70 -95	9- 47	>38	1-35	440-500	N	N	Y	Y	Hive is too hot
8	>96	2- 47	10- 36	1-35	440-500	Y	N	Y	Y	Hive is too damp
9	0- 100	9- 47	10- 36	>'5	440-500	N	Y	N	N	Hive is too heavy

Table 3 shows the evaluation of the performance of the proposed decision tree model system, including the following metrics: F1-Score, recall, and accuracy.

TABLE III. EVALUATION METRICS VALUES

Metrics	Metric value (%)
F1 Score	88.5
Recall	88.3
Accuracy	90.2

These results highlight its excellent performance in classification tasks.

C. Discussion and Graphs

Analysis of these graphs provides an insight into the environmental conditions surrounding the hive which can be valuable to beekeepers in managing and understanding hive health and productivity.

From the observations, it has been found that there is a close relationship between the different environmental parameters of the hive (temperature, humidity, CO2, weight, etc.). The ideal conditions for these parameters can be regulated by the bees themselves or with the help of the proposed intelligent system actuators. For example, fans can be used to improve air circulation if the temperature or CO2 becomes too high; a misting system can be used to control humidity if it is insufficient. Another is heating, which can increase the temperature when needed, mainly during cold seasons.

By combining natural bee regulation and advanced technologies, it is possible to create an optimal environment for colony development which can increase productivity and overall hive health. This represents an opportunity for modern beekeeping to evolve towards more sustainable and efficient practices.

The gathered data is presented in the next paragraphs. First, the results of temperature inside and outside the beehive on March 10, 2023, are presented in Figures 6 and 7.

It is possible to see that inside the hive the temperatures are lower than outside during the day. Regarding the rest of the monitored parameters inside the hive, we can identify in Figure 8 that the humidity is minimum at midday with maximum values during the night. Finally, the CO2 concentration is maximum in the late hours of the day, as shown in Figure 9, since this is the moment in which the bees are inside the hive.

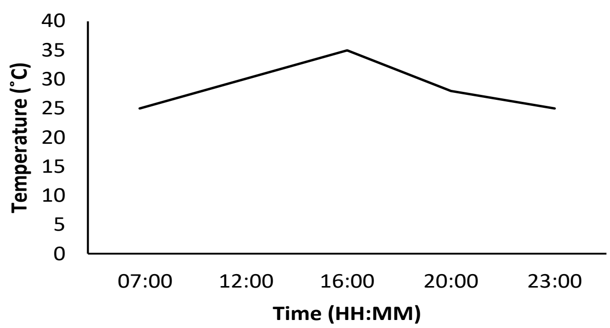


Figure 6. Variation of Temperature Outside the Hive on March 10, 2023.

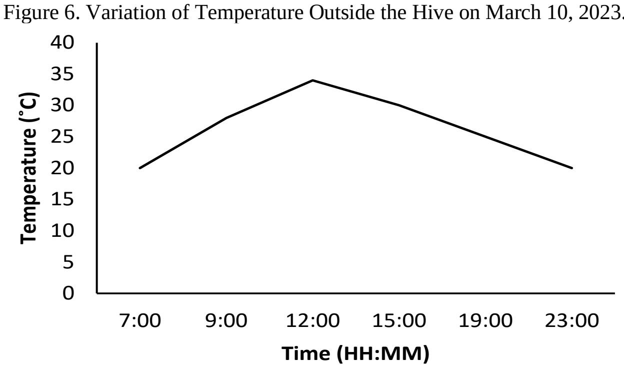


Figure 7. Variation of Temperature Inside the Hive on March 10, 2023.

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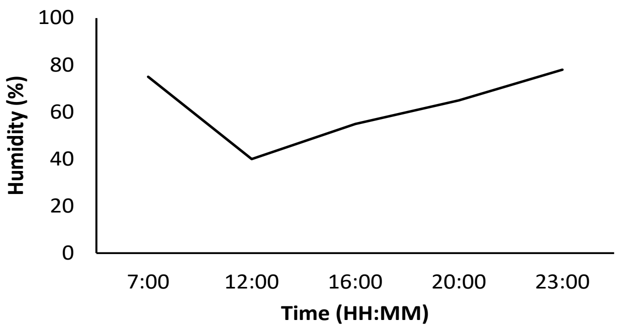

Figure 8. Variation of Relative Humidity Inside the Hive on March 26/27, 2023.

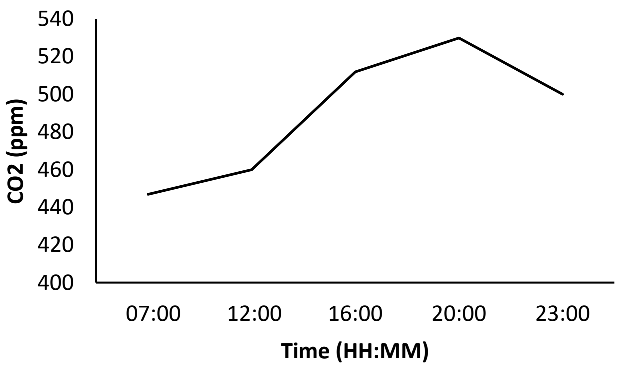

Figure 9. Variation of CO2 Inside the Hive on March 10, 2023.

Moreover, with this gathered data it has been possible to compare the parameters of a beehive on two different dates: March 9/10, 2023, and June 9/10, 2023. This information is presented in the following figures. In Figure 10, we compare the temperature inside the hive. It is possible to see that despite the high difference on date, the temperature inside the hive is very similar. Figure 11 represents the variation on the humidity inside the hive. In this case, there are differences among the dates with high humidity values in March.

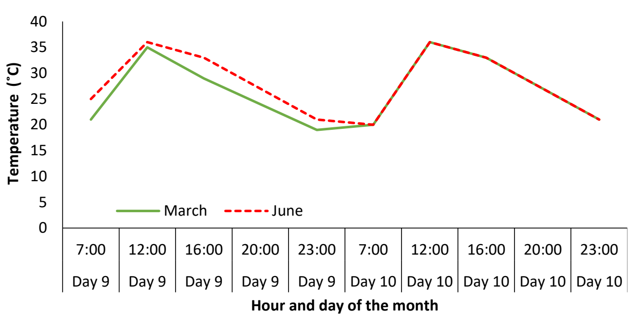

Figure 10. Variation of Temperature Inside the Hive in March and June.

In Figure 12, the variation in the beehive weight is depicted. The weight is slightly higher in June than in March.

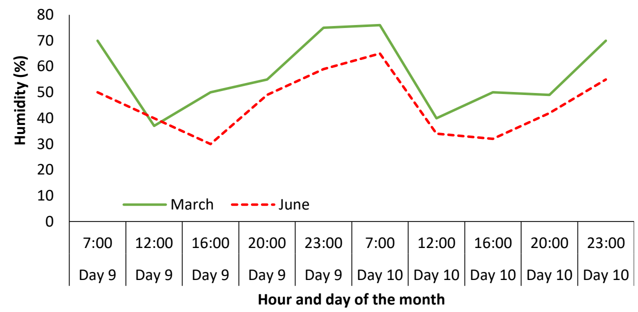

Figure 11. Variation of Relative Humidity Inside the Hive in March and June.

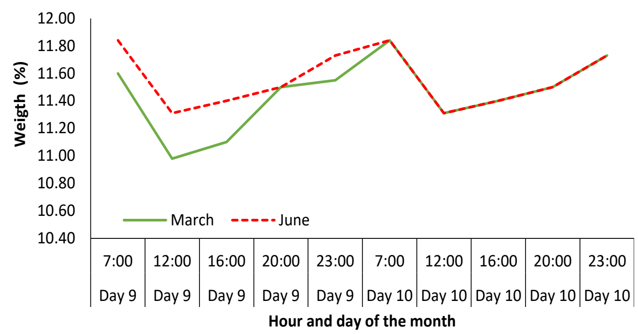

Figure 12. Variation of Weight Inside the Hive in March and June.

V. Conclusion and Perspectives

This work highlights the growing importance of IoT and AI technologies in monitoring beehives in the Sahara region in southwestern Algeria. These technological advances offer innovative solutions to monitor the health status of the hive and protect the bees from predators such as bee-eating birds, diseases like varroa, and theft, therefore, contributing to the preservation of the ecosystem and the sustainability of beekeeping. The experimental part of this work shows that AI algorithms can analyze data from IoT devices which ensures intelligent monitoring of the hive.

Our future work will provide more details on the results of experiments related to hive security, namely the detection of predators and diseases affecting bee colonies, besides the study of other parameters like bee sounds, and bee behavior based on Artificial Intelligence and Internet of Things technologies. We also plan to evaluate the system in varied environments and integrate more data analysis methods and AI models for better, deeper insights.

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