

Improving Bee Living Conditions through Ecological Thermal Insulation and Remote Early Anomaly Detection-Vital Step Towards Preserving Bees Population

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Abstract

This publication underscores the vital role of bees, particularly their contribution to products like honey, pollen, and propolis, which offer significant health benefits. Notably, 79% of the world's food supply relies on bees; thus, their declining numbers pose a threat to pollination and food security. The study explores an ecological thermal insulation for hives using animal biomass and a monitoring system to detect anomalies in bee habitats early. This approach aims to protect bee populations and enhance global food security through improved data-driven practices.

Keywords

chicken feather, nonwovens, IoT, condition of bees.

1. Introduction

Bees are considered by society as unique insects. Thanks to their work, we obtain natural products such as honey, pollen, and propolis, which have been used in human diets for their high nutritional value and health benefits.

Moreover, the EU Parliament in its resolution T6-0579/2008 stated that 79% of the world's food supply depends on honeybees, and beekeepers in Brittany claim that this number exceeds 80% [1]. Over the past 20 years the population of honeybees has declined dramatically in most countries in the world [2]. The sudden decline in bee population - both breeding and wild - has far-reaching consequences. Pollination by bees ensures the reproduction of many plant species, especially crops, which are food for the world's population, hence it was decided to focus on reducing the risk of extinction of the bee population, which is increasing all the time. Certain of the main factors causing the decline in the bee population are late-detected diseases, theft, time-consuming maintenance or lack of technology development [3].

The aim of the research presented in the article was to improve the living

conditions of bees by introducing into the hive an ecological thermal insulation composite based on animal biomass and creating a research system for monitoring the living conditions of bees, which allows to detect anomalies at an early stage of their appearance (such as swarming conditions, bee diseases or the lack of a queen) in the hive, and to prevent them in the future. Solving this problem will play an important part in the environment and increase people's awareness of data collection and analysis [3,4].

2. Survey conducted among beekeepers

A survey conducted among beekeepers has provided valuable insights into their practices, concerns, and the challenges they face in beekeeping. Beekeepers, with their centuries of accumulated knowledge and experience, play a crucial role in the protection and breeding of bees. This wealth of knowledge makes them an indispensable source for understanding the multifaceted aspects of bee protection. Consequently, an author's survey was initiated to gauge beekeepers' awareness of the threats to bees and their knowledge of protecting

these vital pollinators, and to identify key parameters for hive monitoring.

The survey, carried out on June 10, 2023, saw participation from 40 beekeepers. The results revealed a significant awareness among beekeepers regarding Colony Collapse Disorder, with over 85% of respondents acknowledging familiarity with the phenomenon. The demographic of respondents varied, including those new to beekeeping as well as veterans with over a decade of experience. A notable 72.5% of beekeepers reported having lost bee colonies, underscoring the prevalent challenge of colony loss, which is not only costly but also time-consuming to recover from, taking anywhere from 3 to 12 months to rebuild a colony.

In light of the feedback received, it is pertinent to mention that the survey also explored innovative practices in beekeeping, albeit indirectly. One common practice among beekeepers is the warming of hives, especially during colder months, to ensure the survival and health of the bee colonies. While the survey did not directly query beekeepers about hive warming, the high interest in adopting new technologies (with 91% of

beekeepers showing interest) suggests an openness to integrating practices and solutions that enhance bee health and hive productivity. The need for comprehensive solutions in the market was highlighted, indicating a gap that technology and innovative practices like hive warming could fill.

Furthermore, beekeepers identified several key issues impacting bee breeding, such as the threat of colony collapse disorder, theft, the time-intensive nature of beekeeping, late detection of diseases, and the disturbance of bees' natural behaviors. These concerns underline the complex challenges beekeepers face and the critical need for supportive technologies and practices that can mitigate these issues, including the warming of hives.

In summary, the survey underscores the rich knowledge base and the readiness among beekeepers to embrace new technologies and practices for the betterment of beekeeping. The feedback on hive warming presents an opportunity to delve deeper into traditional and innovative beekeeping practices, further enhancing the understanding and support of bee health and protection. Future research and surveys could directly address such practices, providing clearer insights into their prevalence, effectiveness, and the potential for broader adoption within the beekeeping community.

3. “Internet of Bees” thanks to intelligent hives

Bees are key pollinators of European agricultural crops, not only from an economic point of view. It is estimated, that more than 35% of the food consumed by humans depends directly or indirectly on insects. The value of pollination worldwide amounted to 153 billion Euros in 2005, which accounted for 9.5% of the value of the world's agricultural crops used for human food production [4]. In a situation where bees become extinct, food will become a very scarce resource [5]. In the case of such an important social insect, it is necessary to take actions that will effectively support the

survival of bees. The project presented in this article introduces the names “Internet of Bees” and “Smart Apiary” to the electrical engineering field. The Internet of Bees is a computer system in which a mechanism is controlled or monitored by algorithms based on information and communication technology (ICT) [6]. In the Internet of Bees, the physical and software components are deeply interconnected, can operate on different spatial and temporal scales, exhibit many different modes of behavior, and interact with each other in ways that change depending on the context. Process control is often referred to as embedded systems. In embedded systems, there is more emphasis on the computational elements and less on the relationships between the computational and physical elements.

The Internet of Bees is similar to the Cyber Physical System (CPS) as well as the Internet of Things (IoT) in that it has the same basic architecture [7]. Nevertheless, the Internet of Bees is a system that detects and prevents anomalies in hives. The system not only monitors and detects anomalies or evaluates the productivity of bees, but also allows you to control environmental factors through automation - intelligent autonomous control. The Internet of Bees is a solution dedicated to beekeepers. Currently, beekeepers are supporting their work with manual measurements, which is a disturbing process for bee life. There are several commercial solutions on the market that offer single sensors that can be installed in hives, but there is no comprehensive solution yet, such as the Internet of Bees. Current solutions offer location tracking and temperature monitoring for bee hives, but they lack autonomous control mechanisms that directly influence bee life and health. Consequently, these tools fall short of preventing bee losses effectively.

4. Proposal for Internet of Bees (IoB) system architecture

Many analysts believe that the world is on the brink of a new innovation era based on ICT technology. One element

of this innovation is the development of Communications Technology (CT) that enables and creates communication networks between machines and the wider Internet, which is referred to as the “Internet of Things” (IoT) [8]. The Internet of Things is a set of technological solutions that are supposed to automate the home, office or the entire city. These are solutions that primarily translate into effective management of time, space and security. The idea of the Internet of Bees is a perfect example of a system that uses the features of the Internet of Things to control a bee colony. An intelligent hive is created by implementing a low-power device in an ordinary hive to monitor the life of bees. The user can place the device in the hive, deploy sensors in it, and turn it on, which will cause the data collected by these sensors to be sent to the cloud, where they are processed [9]. Advanced solutions of data analysis with a built-in artificial intelligence mechanism, combined with machine learning, are used for this. Analysis of various data and control of environmental factors (temperature and humidity) are carried out to prevent anomalies in the hive. To create an Internet of Bees system, major components need to be developed, selected, or created based on the concept of the IoB system structure, which is presented on Figure 1.

- Hardware - electronic components that are the source of telemetry data and control.
- Middleware - responsible for data storage and analysis.
- Presentation module - presentation and visualization of data

5. Prepared research environment based on the system architecture proposed

The Intelligent hive system consists of three main layers: the hardware layer, middleware layer, and presentation layer.

The hardware layer is responsible for collecting measurement data from the hives. It includes integrated circuits and various environmental sensors, such as temperature, humidity, frequency and weight sensors. The network of sensors

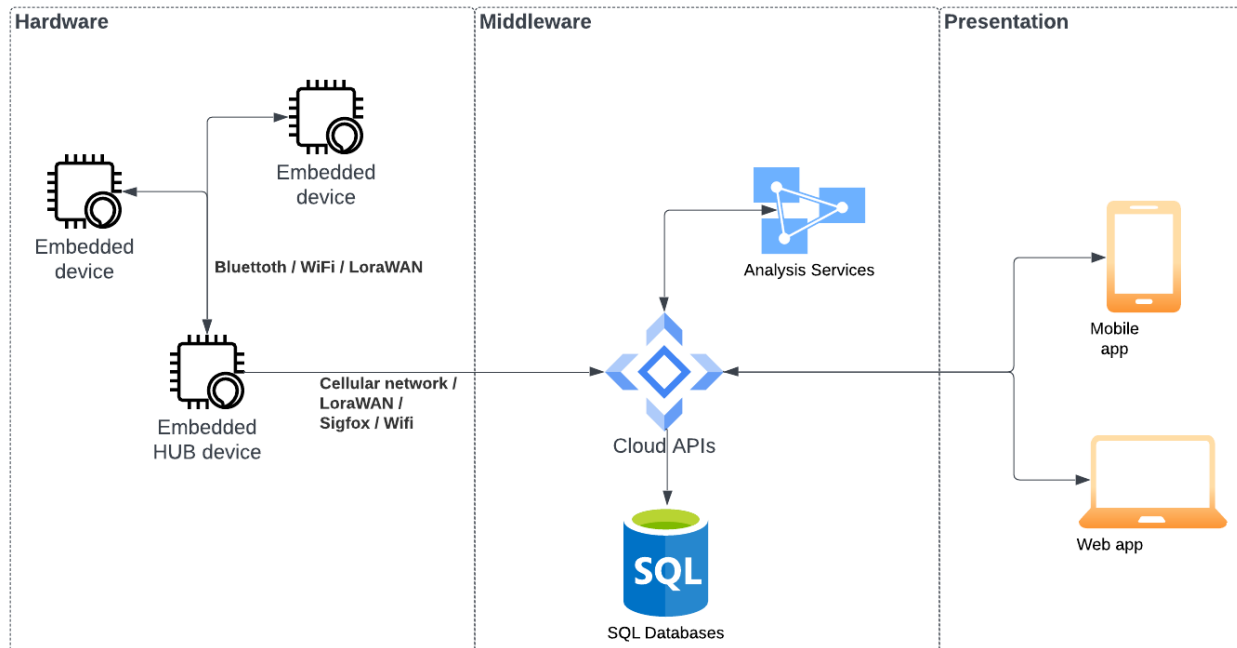


Fig. 1. Concept of IoB system structure

in the hives is connected to a central device, which then sends the collected measurement data to the middleware layer using technologies such as WiFi/Sigfox/LoraWAN.

The middleware layer serves as an intermediary between the hardware layer and the presentation layer. It includes a data broker, which receives the measurement data from the central device and stores it in a database. This layer also includes API management services, which manage the data stored in the database. There is also an option to store the measurement data directly in the cloud through the API.

The presentation layer is responsible for presenting the measurement data from the hives to the user. The API of the whole system communicates with the presentation layer using HTTPS, and the measurement data are displayed in a clear and organized manner, allowing the user to understand and analyze them easily.

6. Intelligent hive possibilities

The structure of the system proposed allows to monitor various parameters inside the hive (humidity temperature,

sound and weight), but in our experiment we focused on monitoring one of the key parameters to be tracked in the bee breeding process, i.e. the temperature in the hive. The Intelligent hive system has the following possibilities, among others:

- **Monitoring the temperature inside the hive - maintaining the optimum temperature for a particular stage of development** (34-35°C) [10] inside the hive is very important. Temperature monitoring gives the opportunity of registration of irregularities related to temperature changes and gives the opportunity to immediately intervene in the protection of bees living in the hive.
- **Identification of periods of thermal stress - prolonged or rapid changes in external temperature** (approx. 20°C) [11] can affect bee health and their development.
- **Detection of bee diseases – the temperature in the hive can be an indicator of bee health.** Even a slight temperature increase of 1°C can indicate the presence of diseases such as bee nosemosis [12]. The Intelligent hive system automatically alerts beekeepers when an abnormal temperature is detected inside the hive, enabling quick intervention and minimizing the risk of spreading diseases in the bee population.

- **Optimizing breeding conditions:** Monitoring hive temperature can help beekeepers optimize breeding conditions. The Intelligent hive system provides data that support decisions regarding hive placement, thermal insulation and other factors affecting the temperature inside the hive.
- **Automating the monitoring process:** Beekeepers spend a lot of time on the maintenance process of bee care. Based on the IoB system, several maintenance processes of beekeepers' work can be eliminated due to remote monitoring of bees.

With smart hives, beekeepers can monitor temperature fluctuations and identify periods of thermal stress. This information allows them to take appropriate action, such as providing extra ventilation or insulation to the hive in case of extreme weather conditions.

Direct actions have also been taken to protect the life of bees and provide them with optimal living conditions in the autumn and winter seasons. For this purpose, a prototype of a cover for the intelligent hive was elaborated.

7. Manufacturing of thermal insulation for a smart hive

7.1. Raw materials and methodology

The following raw materials were used to produce the hood insulation:

- wool (producer: Poltops, Żagań) 45%
- chicken feathers (producer: CEDROB S.A. Z.D. Niepołomice) 55%



Fig. 2. Chicken feathers (a) and wool (b)

7.2. Production of external thermal insulation

The cover was manufactured in the form of nonwoven which consisted of a mixture of sheep's wool (Fig. 2b) and chicken feather (Fig. 2a) wastes from a poultry slaughterhouse. It is also important from an ecological point of view, as such underutilized waste is exploited in utility items.

The composite non-woven fabric, with a grammage of 433 g/m², was thermally consolidated on both sides (700°C) and laminated, from one side with a spun-bond material which ensures good air permeability between the base nonwoven and the walls of the hive, and from the other side with a compost foil that provides protection against water and snow. The finished nonwoven was then manually formed on a model hive forming a cover (Fig. 3). Such a cover also provides protection against strong winds without cooling the hive too much.



Fig. 3. Thermal insulation cover

8. Testing of thermal insulation properties

8.1. Method and course of testing

The thermal insulation of composite nonwoven samples under conditions of exposure to thermal radiation was tested using a test stand that meets the requirements of the PN-EN ISO 6942:2005 standard. The source of thermal radiation is six ceramic rods

(silicon carbide, SiC), which heat up to a temperature of approximately 1370 K. Wien's displacement law shows that the power of electromagnetic radiation emitted by a source at this temperature has the highest value for the wavelength $\lambda_{\max} = 2.1 \mu\text{m}$.

The following designations were adopted for the composite nonwoven samples subject to testing: Sample 1 (covering hives in the summer season - with white foil) Sample 2 (covering hives in the winter season - with black foil).

The sample of composite nonwoven fabric for testing was placed in a thermal radiation field with a flux density of 3 kW/m². During the tests, when the outer surface of the sample was exposed to thermal radiation, the increase in the temperature of the inner side and surface of the sample was measured (Fig. 4).

The foil (designation "PES-Al foil") used to make the composite nonwoven fabrics was also tested (Fig. 5).

The results of temperature measurements of samples of composite nonwoven fabrics and foils obtained during their exposure to thermal radiation constituted the basis for determining the numerical values of indicators that measure the thermal insulation of the objects tested. The results presented in Table 1 are average values from the testing of two test samples.

The following were determined:

- **Heat transfer level, t_{12}** , defined in the PN-EN ISO 6942 standard as the time of the sample temperature increase by 12°C under conditions of its exposure to radiation with a specific heat flux density.
- **Heat transmission factor**, which is numerically equal to the ratio of the density of the heat flux penetrating through the sample to the density of the heat flux incident on the sample.

9. Results

Based on the results obtained, it was found that the thermal insulation properties of sample 1 and sample 2 differ slightly (about 4-5%), which should be considered an insignificant difference in the insulating properties of these samples when exposed to thermal radiation. It is worth emphasizing that with regard to the test result obtained for the sample marked “with PES-Al foil”, the temperature of this sample under the test conditions used increased by only 2.1°C in 120 s. The color of the foil surface on which the thermal radiation fell (“Black” and “White”) did not have a significant impact on the heating speed of these foils. Aluminized polyester foil turned out to be very effective protection against thermal radiation. Thanks to the ability of the metalized surface of this foil to reflect a significant part of the thermal radiation falling on it, heat transfer through this foil was effectively limited. As a result, the heating of the composite nonwoven fabric was slowed down.

This cover is characterized by good thermal and breathable properties while maintaining water resistance. The cover is manufactured in the form of nonwoven which consists of a mixture of sheep’s wool and chicken feather wastes from a poultry slaughterhouse. It is also important from an ecological point of view, as such underutilized waste is exploited in utility items. Such a cover also provides protection against strong winds without cooling the hive too much. The first tests from the winter season 2021-2022 gave a very good research result. Throughout the autumn and winter period, data was collected by a measuring device belonging to the Intelligent Hives company. It was observed that the bee colony that wintered in the covered hive survived that period very well. In evaluating the condition of the bee colony, we utilized established beekeeping protocols to assess their strength, which includes factors such as the population size of the colony, the presence and health of the brood (eggs, larvae, and pupae), the coverage of adult bees on the combs, and the observed rate of foraging activity. The colony in question was found to have a significantly higher population density

Samples	Heat transfer level, t_{12} , s	Heat transmission factor,
Nonwoven fabrics		
Sample 1	120	0.19
Sample 2	116	0.20
PES-Al foil	after 120 s of exposure to thermal radiation, the temperature of the sample increased by 2.1°C	0.05
Foils		
Black	43	0.98
White	45	0.95
PES-Al foil	after 45 s of exposure to thermal radiation, the sample temperature increased by 0.8°C	0.06

Table 1. Values of indicators characterizing the thermal insulation of the systems tested

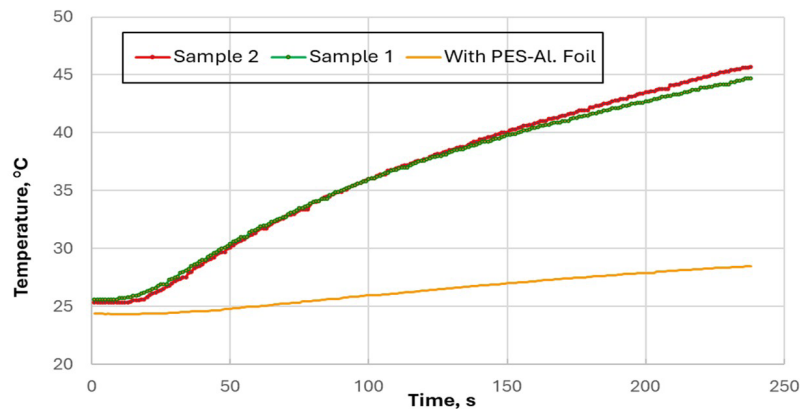


Fig. 4. Temperature of the internal surfaces of composite nonwoven samples versus exposure time of their external surfaces to thermal radiation with a flux density of 3 kW/m². Sample 1 – composite nonwoven sample; thermal radiation fell on the white foil. Sample 2 – composite nonwoven sample; thermal radiation fell on the black foil. With PES-Al. Foil – Sample 2 + aluminized PES foil; thermal radiation fell on the PES foil.

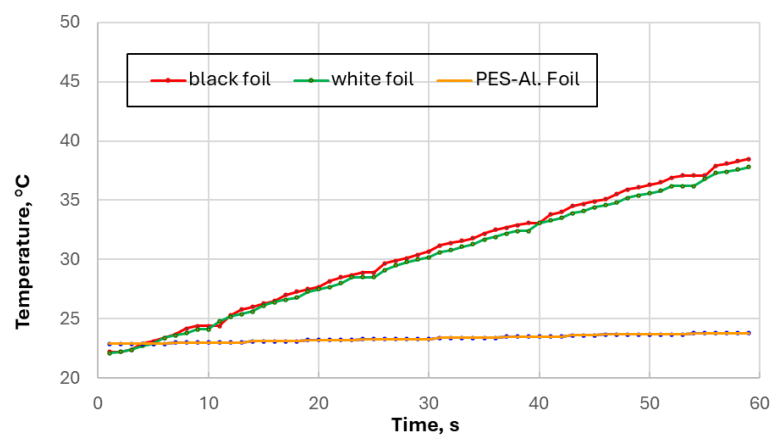
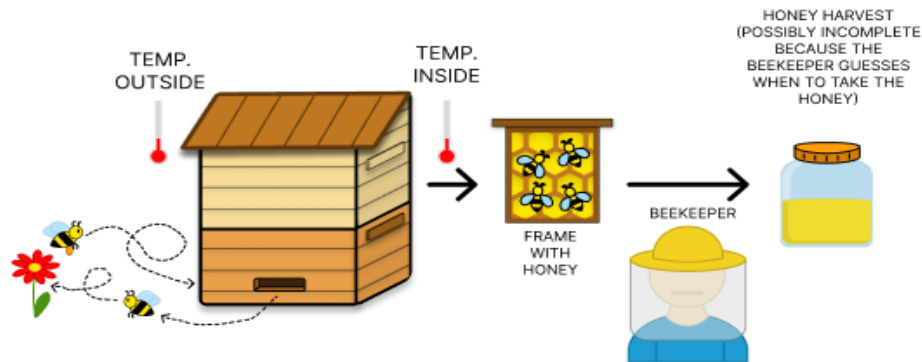


Fig. 5. Temperature of the internal surfaces of foils samples versus exposure time of their external surfaces to thermal radiation with a flux density of 3 kW/m².

and brood area compared to others in the same apiary. Additionally, there was a noticeable increase in the foraging rate, with bees returning heavily laden with

pollen and nectar. These observations led us to describe the colony’s condition as ‘very strong’. However, it is important to note that this assessment was based

Traditional hives



Intelligent Hives

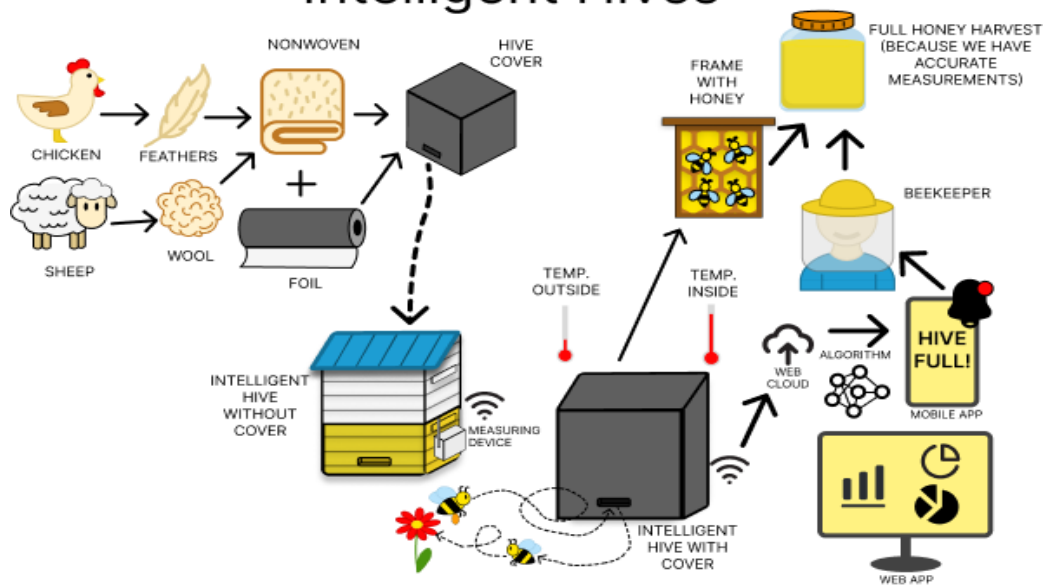


Fig. 6. Diagram comparing the principle of operation of a traditional hive and intelligent hive

on a comparison within the same apiary and acknowledges the variability that can exist among different colonies. Further studies involving a larger sample of colonies across various apiaries would be necessary to draw more generalized conclusions about the effectiveness of the interventions or practices being evaluated. No disturbing symptoms negatively affecting the life of bees were found. The cover also survived all weather conditions during that period. It did not undergo any deformation or distortion during the period of use. This is very important information because the solution proposed can be offered as a long-term and durable product.

In conclusion, the Intelligent hive system is designed to provide comprehensive

and accurate data on the condition of hives and their colonies, making it an indispensable tool for both beekeepers and scientists.

Below shows a flowchart of a traditional hive and that of the processes and operation of the intelligent hive (Fig. 6).

10. Results and analysis of measurement data from hives

In investigating the dynamics of honeybee family life and their impact on agricultural ecosystems and the natural environment, the role of environmental parameters and bee activity within the hive is critical. This is especially true in relation to the “innovative thermo-insulative cap.” The

statistical data analysis collected from an electronic hive throughout the entire year of 2023 enables a deeper understanding of the variability of living conditions for bees across different seasons.

The Figure 7. presents a comprehensive statistical analysis of environmental and activity parameters measured within an experimental beehive over the course of one year. The data include temperature, humidity, sound frequency (all inside hive) and hive weight, with an evident increase in data points during the summer months due to heightened bee activity. The parameters show significant variability during the warmer months, correlating with the bees’ active period of nectar and pollen collection and honey production, while winter months display a reduction

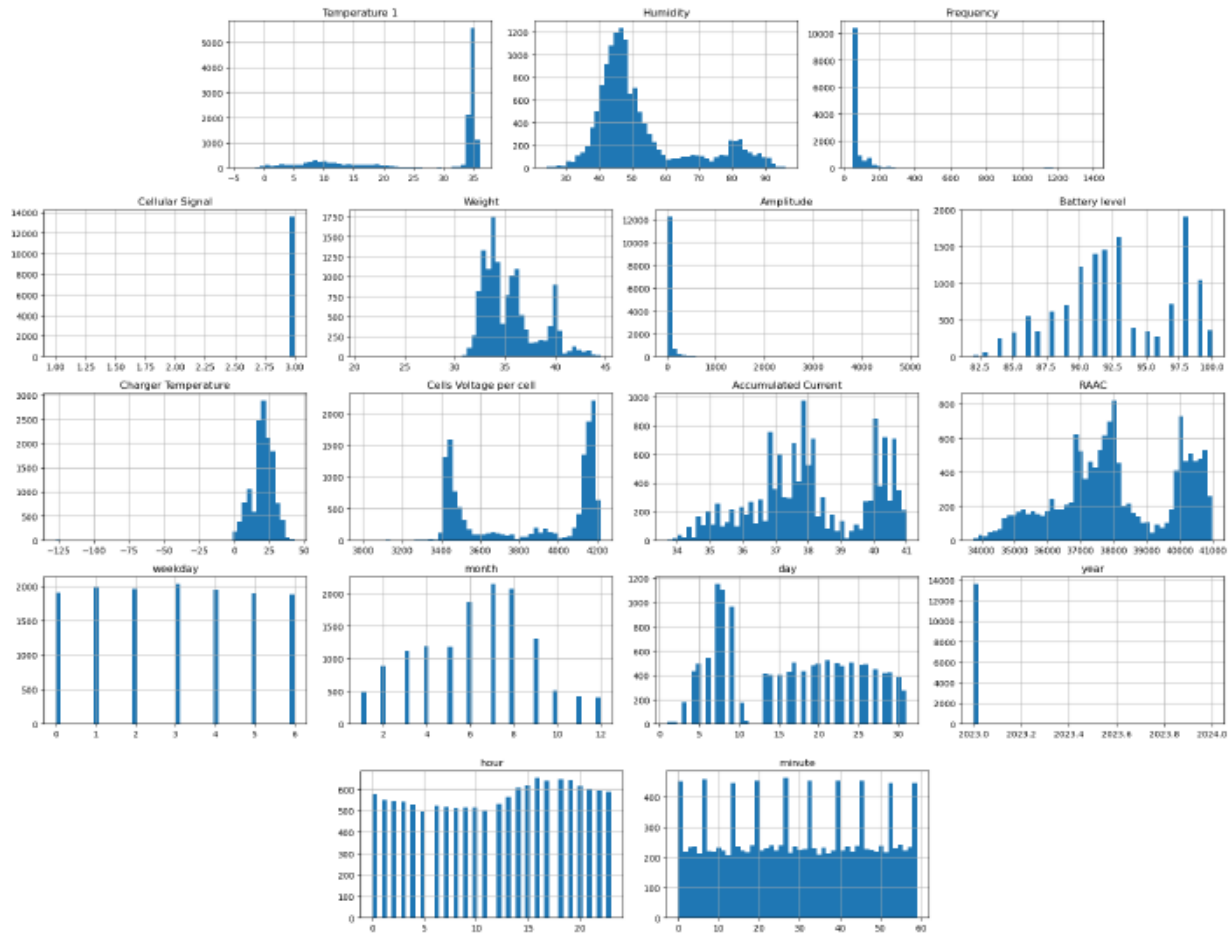


Fig. 7. Seasonal analysis of hive parameters from an experimental beehive

in variability, indicative of the bees' dormant state as they conserve energy and prepare for spring. The granularity of data collection ranges from minutes to years, offering detailed insights into the daily and seasonal rhythms of the bee colony. Based on the statistical data obtained from the electronic hive, we can draw significant conclusions about the life of honeybee families and their adaptation to seasonal environmental changes. An examination of parameters such as temperature, humidity, sound level, and hive weight throughout the year reveals a marked increase in activity and dynamics during the summer period. The data indicate an intensification of bee labor, which correlates with greater fluctuations in the values measured—reflecting both the collection of nectar and pollen as well as the honey production process. In contrast, the more tranquil winter season is characterized by fewer data fluctuations, indicating a state of rest for the bee family as they prepare

to survive low temperatures and await the arrival of spring. This analysis provides valuable insights that may contribute to the optimization of beekeeping practices and enhance awareness of the significance of bees for ecosystems.

Figure 8 illustrates the variability of the internal hive temperature as influenced by seasonal changes and the condition of the bee colony. The bee colony withers in winter quite a bit, thus the sensor may be at some point, within the course of a few days, at different distances from the bee colony withers. The density plot indicates that the temperatures inside the bee cluster during winter (inside the thermoregulated cluster) typically range between 20–30°C. The temperature of the outer layers of the cluster keeps at approximately 10–12°C. Intriguingly, bees heat primarily the cluster itself—temperatures within the center of the hive can drop below freezing. During summer, the temperature within the bee pathways

and brood combs from February to September remains almost constant at around 35°C. After disturbances, such as beekeeper interventions, bees rapidly reestablish this temperature. On the periphery of the winter cluster, temperatures are at 7–11°C, increasing to 25°C towards the center, and can rise to even higher temperatures post-disturbance, ensuring the survival and functionality of the nest. The histogram shows a notable peak around these optimal temperature ranges, affirming the bees' ability to maintain these critical temperatures regardless of external conditions.

Figure 9 depicts the distribution of humidity levels within a bee hive, which fluctuate according to the season and the health status of the bee colony. During winter, the humidity levels rise, typically ranging between 60–80%. Excess humidity can lead to mold growth on honey and frames, and it can make

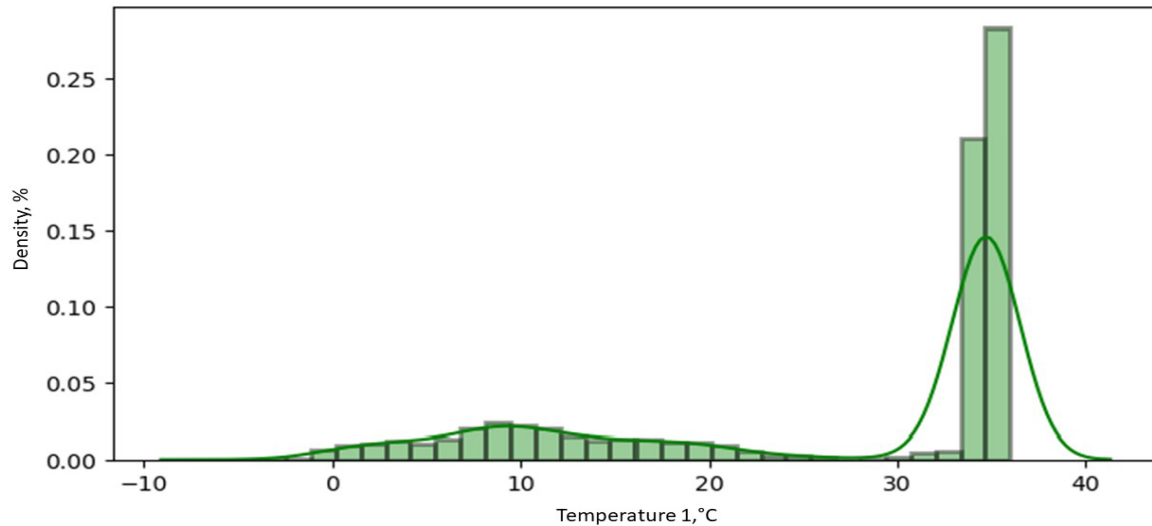


Fig. 8. Density distribution of hive temperature measurements in experimental hive

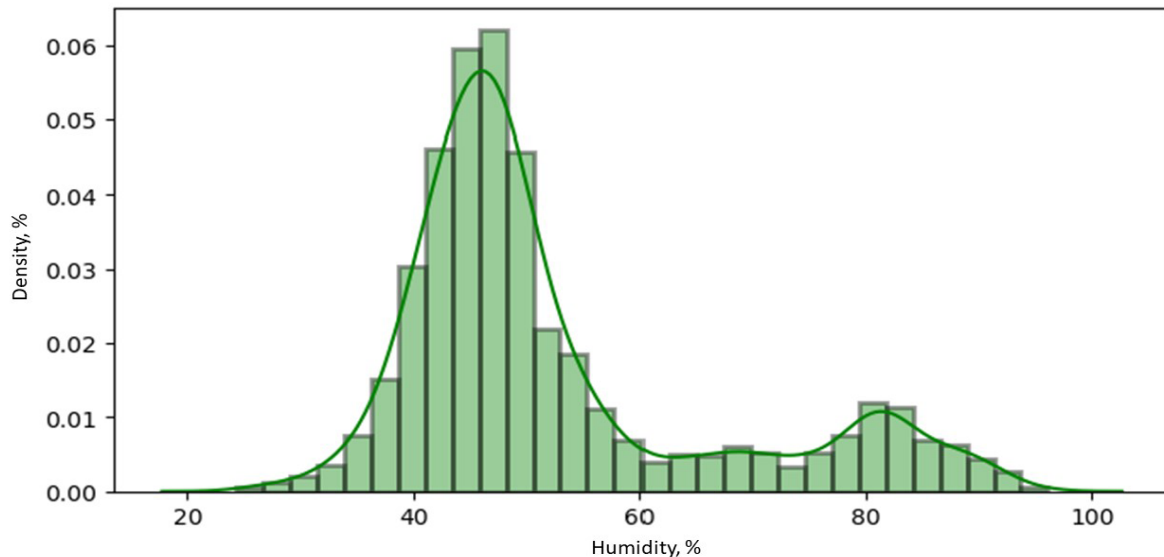


Fig. 9 Density distribution of hive humidity measurements in experimental hive

it difficult for bees to work efficiently. Conversely, in the summer, the humidity level between the brood combs is approximately 40-60%. The bee colony is able to self-regulate to maintain these levels effectively. The density plot shows a pronounced peak within this optimal range, illustrating the bees' capacity to control humidity within the hive, a crucial aspect of their survival and productivity.

Figure 10 depicts the variations in beehive weight, correlating with seasonal changes and the bee colony's lifecycle. In winter, the hive's weight decreases as bees consume their stored honey reserves to survive the colder months. With the

arrival of spring, the hive weight begins to increase as bees start to collect nectar and pollen from blooming plants. The weight of the hive peaks during summer due to the intensive nectar collection from flowering plants; it is during this season that monitoring the hive weight daily becomes critical. As autumn approaches, the hive weight gradually decreases as the bees begin to use their stored honey to prepare for winter. The density distribution showcases multiple peaks, reflecting the cyclical nature of hive productivity and the bees' ability to sustain themselves through the changing seasons.

Figure 11 illustrates the distribution of sound frequencies recorded within a beehive, demonstrating variations that correspond to the seasonal activities and health status of the bee colony. In winter, bees exhibit lower activity levels, resulting in quieter and less frequent sounds. As spring emerges and bees begin to forage for nectar and pollen, the sounds within the hive typically become louder and more frequent. The summer months, characterized by intense nectar collection, correspond to the loudest and most frequent sounds within the hive, which is evident in the peak frequency density shown. In autumn, as bees start their preparations for the winter, the

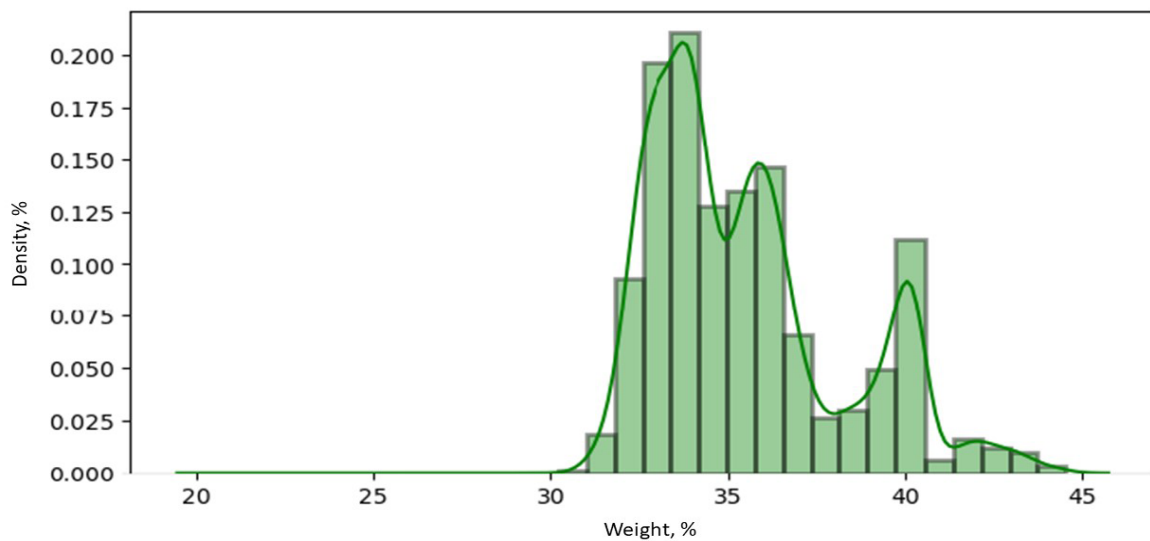


Fig. 10. Density plot of beehive weight of experimental hive

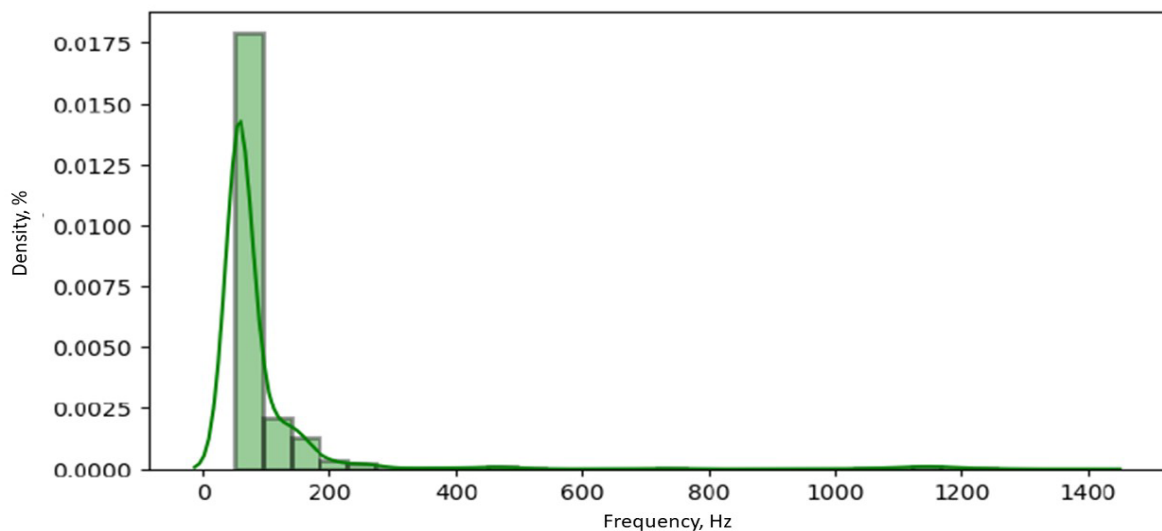


Fig. 11. Density distribution of sound frequency in a beehive

sound frequency within the hive tends to decrease again, becoming quieter and less frequent. The density curve peaks sharply at lower frequencies, indicating that the most common sounds in the hive are at these frequencies, with less frequent occurrences of higher frequencies.

The charts presented above show the analysis of the measurement values obtained from the hive monitoring device - BeeHub Queen. Any hive equipped with a monitoring device is able to obtain similar graphs for a given hive. For the purpose of this article, and to confirm the hypothesis of providing bees with better wintering conditions through

the use of a cover using waste chicken feathers from a poultry slaughterhouse, the results of temperatures inside the hive from the exposed hive were compared with the hive covered with a cover, and were plotted on the graph, labelled Figure 12. The period from February 1 to February 28, 2023 was used as the model period. Both hives were located in the same research apiary, about 50 cm apart. For a clear comparison, the average temperature inside the hive was measured on each day of February 2023.

According to Figure 12, the data obtained from the research equipment confirmed the assumptions of the experiment. Each

bee colony creates its own environment in the hive. During the swarming period, it exposes a specific temperature in the hive. Despite the changing external conditions, bees can maintain the optimal temperature in the nest, the best for brooding, in the range of 33-36°C [13]. During the winter, the bees maintain a temperature of about 25°C at the centre of the withers. By observing the temperature using measuring electronics in the hive, it is possible to determine at what stage of development the bee colony is. For example, during low outside temperatures, the temperature in the upper part of the hive rises, resulting in increased food intake. The amount of

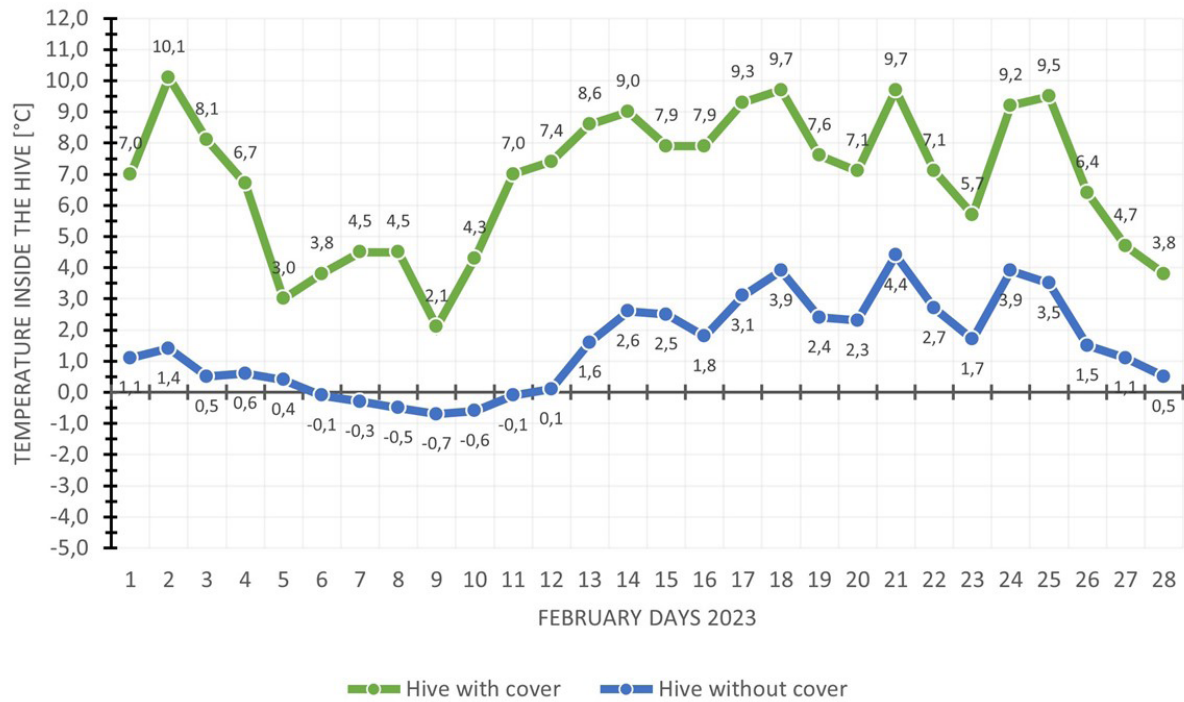


Fig. 12. Comparison of temperatures inside the hive with and without covers

food in the hive left for the survival of bee colonies is constant and must be sufficient for all the autumn-winter season. If not, the temperature inside the hive drops rapidly to the outside temperature due to malnutrition. Swarm extinctions are both the result of lack of food and disease [14]. A chilled hive should be immediately eliminated to prevent spreading the disease to other bees and in some cases to increase pollination efficiency [15,16]. For this reason, it is important to take special care of bees in the autumn and winter season. The experiment conducted not only confirmed the validity of the creation and development of the Internet of Bees, but also allowed to determine the basic algorithm to support a bee colony during overwintering.

A simple algorithm to identify anomalies was tested on historical colony temperature data collected from prototype devices, which successfully identified many cases of hive anomalies such as colony cooling and swarming preparation. During the bees' preparation period before final swarming, the temperature in the upper part of the hive increases by 1.3-3.5°C from the normal brood-rearing temperature of 34-36°C to 37°C.

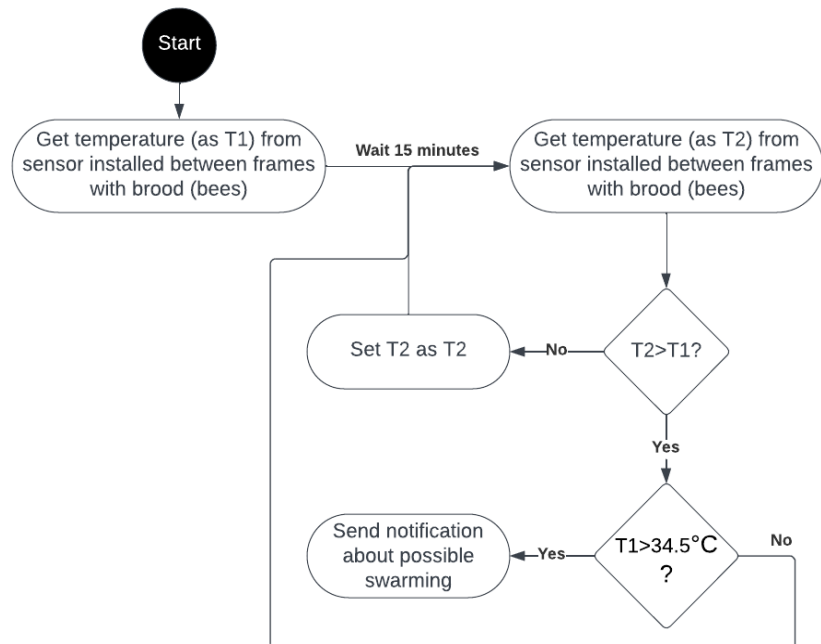


Fig. 13. Diagram of how the algorithm for detecting diseases in bees works

In the cases of swarming observed, it was found that the colony needs about 14 minutes to warm up before the final take-off [17]. Thus, by developing the algorithm (Fig. 13), one can not only detect anomalies but also classify them. The experiment also confirmed the integrity of the wireless sensor

system with the cloud, where data is archived and displayed in a beekeeper (user of the system) friendly manner. Research is also being conducted to determine how much the bees' existence is improved by applying a cover during the winter period. Preliminary studies have shown that the condition of bees



Fig. 14. Experimental intelligent apiary

after overwintering is significantly better than that of bee families in hives without covers. The month of February 2023 was assumed as the research period to discuss the data. Both hives were placed in the same location (Fig. 14). The average temperature for all day recorded by the device in the period from February 1, 2023 to February 28, 2023 was also assumed.

The difference between the temperature measured inside the hive with the cover and that without the cover can be easily seen in the graph (Fig. 12). The average difference between these hives in the research period measured was 5.4°C. It happened that this difference reached almost 9°C. This is due to the fact that the cover is protected from the outside with a black foil; thus, when the sun is shining on the hive, it significantly affects the temperature inside the hive.

11. Conclusions

Agriculture in the 21st century is very different from that last century. Although agriculture is the main industry sector that is currently least intensively used by IT, the potential for IoB implementation in this sector is significant. Installed IoB devices can provide farmers with valuable information, such as what crops to plant and where, when to plough, what the best plowing route is, when to sow seeds, and how to reduce production losses. Having reliable and diverse field data can help farmers make key decisions, such as how to manage irrigation during critical periods to increase yields and improve honey production or crop quality. Beekeepers also receive technology that will allow them to significantly optimize honey harvests. Thanks to special algorithms and the use of covers based on waste feathers for hives, the survival

rate of colonies in apiaries will be much higher than before, because it will be possible to react in time to any disturbing signals. The use of beehive covers made of waste poultry feathers also has positive economic effects on apiaries and the environment. A stronger and warmer bee colony can start collecting food earlier, which means you can expect larger harvests and burdensome waste will become a valuable raw material due to its properties. The second economic aspect results from the fact that despite unfavorable weather conditions in autumn and winter, it is warmer in a covered hive, which means that the bees will consume less food. However, there are significant cultural and skill barriers to using this technology. Therefore, it is important that the solution proposed is easy to install and use, the data is legible and transparent for every user, and the information received allows for proper interpretation and reaction to it.

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