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# Monitoring Acoustic Changes of Honey Bees (*Apis mellifera* L.) and their Effect on the Hive Environment during Venom Collection using IoT Technology

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## ABSTRACT
The operation of a bee venom collector device (BVCD) introduces significant behavioral and environmental disturbances to a honey bee (*Apis mellifera*) colony. By keeping an eye on things and gathering data, beekeepers can make well-informed decisions to safeguard bee colonies. This study investigated the relationship between sound levels on (SOD) and under (SUD) the BVCD and environmental factors within a beehive, focusing on internal temperature (InT), internal relative humidity (InRH), and internal atmospheric pressure (InAP). A multi-sensor platform combined with an IoT unit was employed for real-time monitoring, enabling the collection of comprehensive data. The analysis revealed a strong positive correlation between sound levels and InT, means a higher InT was associated with increased sound levels. Conversely, a weak correlation was found between sound levels and InRH, indicating that changes of acoustic patterns do not significantly change the humidity. Similarly, the InAP relationship changed between positive to negative depending on the operation states, suggesting that other factors influence it. The study identified three distinct phases of beehive activity towards BVCD: pre-operation, operation and post-operation. Each phase exhibited unique sound patterns and environmental conditions. During pre-operation, sound levels increased as bees began to interact with the device. In the operation, sound levels peaked due to intense bee activity and aggression towards the device. Finally, during post-operation, sound levels decreased as bees returned to normal behavior. By understanding the intricate relationship between sound levels and environmental factors, it can gain valuable insights into beehive health, behavior, and potential threats. This knowledge can inform strategies for bee conservation and sustainable smart beekeeping practices.

***Keywords:*** *Apis mellifera,* bee venom collector device, sound level, temperature, relative humidity, atmospheric pressure, IoT

## 1. Introduction

Honeybees are fascinating creatures that play a vital role in pollination and ecosystem health (UNEP, 2019; Edwards Murph, 2017). However, beekeepers around the world are reporting record-breaking colony losses, which has made condition monitoring necessary to keep them healthy (Li *et al*., 2022; Senger *et al*., 2024). Therefore, this has triggered an increasing interest in bee colony safeguarding.

There is no doubt that preserving the global honey bee population and allowing them to reach their full potential are critical issues. Therefore, Edwards Murphy *et al*. (2016) utilized heterogeneous wireless sensor network (WSN) technologies to gather data unobtrusively from a beehive, describing the conditions and activity of the honey bee colony. Sensors were used to monitor living beehives, like humidity and temperature. This data provided insights into honey bee behavior and health, leading to useful agricultural and environmental monitoring for accurate short-term forecasts. As well, Walendziuk

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& Sawicki (2014) used the WSN system to perform measurements of parameters such as ambient temperature, atmospheric pressure, internal temperature, humidity, and sound level. The measured values were transferred to the website. As well as Anwar *et al*. (2022); Senger *et al*. (2024) and Cecchi et al. (2019) used a multi-sensor platform to monitor beehive conditions in real-time. Therefore, advancements in sensing and information technology allow for the simultaneous collection of diverse data from multiple sensors, enabling the monitoring of bee colony status in real-time (Meikle & Holst, 2015).

Effective monitoring indicators need to be selected first to identify the health status of bee colonies. A number of bee colony attributes have previously been adopted, such as humidity (Catania & Vallone, 2020; Cecchi *et al*., 2020; Oskin & Ovsyannikov, 2019), temperature (Ali *et al*., 2023; Kridi *et al*., 2016; Kviesis *et al*., 2020; Zacepins *et al*., 2016), and sound (Ramsey *et al*., 2020; Zgank, 2020). Among these characteristics, temperature is used most frequently. Given that temperature is the most effective indicator of bee colony health (Li *et al*., 2022).

Bees depend heavily on sound in their lives, and conservation of these insects depends on our ability to comprehend the effects of sound. By studying the acoustic signals emitted by bees and the effects of external sounds. By analyzing the sounds emitted by beehives, researchers can monitor the health and behavior of bee colonies (*Terenzi et al*., 2020). Wing buzzing, alarm pheromones and related noises, and piping sounds—high-pitched noises frequently linked to swarming behavior and queen replacement—are just a few of the sounds that bees use to communicate with one another (Seeley & Tautz, 2001). Ferrari *et al*. (2008) conducted research that used temperature, humidity, and sound analysis in the beehive to identify swarming periods. It was concluded that there are some frequency shifts and temperature changes during the swarming period. However, perhaps because of the intricate measurements, the aforementioned methods are not commonly used in actual beekeeping. Edwards Murphy (2017) focused on the use of sound, weight, and visual inspection to identify the health and condition of the colony. Maybe by integrating sound monitoring alongside temperature data collection, beekeepers can gain a more comprehensive understanding of their colonies and make informed management decisions for their conservation. Additionally, potential problems such as disease, pest infestation, or queen loss (Pérez *et al*., 2016). As well as optimizing beekeeping practices. using the system based on IoT-based or WSN to classify sound for honeybee colony activity. In addition to primary factors, weather conditions and spatiotemporal patterns are also deemed crucial (Sharif *et al*., 2023). According to Michelsen's 1986 study, all information is transmitted through airborne sounds and no vibration is created during the dance. The waggle sound has a sound pressure level (SPL) of 73 dB and is pulsed for 20 ms.

Ali *et al*. (2023) found that the hive temperature while collecting venom reveals the differences among bee hives in different conditions of collecting. As an efficient response variable for determining the productivity of venom, they suggested the maximum internal temperature of the hive. Zacepins *et al*. (2016) determined that a single temperature sensor provides adequate information for detecting swarming behavior. For future research, the temperature can be used as the main analysis tool while the multi-sensor parameters are used as supplementary means to enhance the diagnostic accuracy (Li *et al*., 2022). A temperature has a typical range of 34–35 °C, which was registered by a temperature sensor placed (Zacepins *et al*., 2015). Humidity and temperature show no significant correlation within a daily time scale, highlighting the complexity of humidity changes. The sound increases with the rise of temperature between 10°C and 30°C (Li *et al*., 2022).

No specific peer-reviewed studies investigating the impact of BVCD on hive sound and temperature were identified. A number of variables, including temperature, relative humidity, sound level, and internal atmospheric pressure, can affect how BVCD affects hive conditions. The BVCDs offer a sustainable method for harvesting venom; it's essential to consider their potential impact on the beehive's internal environment, particularly sound and temperature. The electrical stimulation used in BVCDs can produce noise that may disrupt the bees' natural behavior and communication patterns (Ali *et al*., 2023). Despite their value in harvesting a useful product, bee colonies depend on the responsible use of BVCD to remain healthy and productive. Beekeepers can reduce adverse effects and guarantee the long-term well-being and productivity of their colonies by being aware of and actively addressing the possible effects on the hive environment. The study aims to analyze the relationships between bee sounds, temperature, humidity, and atmospheric pressure inside beehives using a multi-sensor platform for real-time monitoring in conjunction with operating a BVCD. Advanced in-hive monitoring systems use embedded systems and include IoT technology.

## 2. Materials and Methods

In September 2024, the study was conducted at the Bee Research Department of the Agricultural Research Centre (ARC), Plant Protection Research Institute (PPRI), Giza (latitude 30.046356° N, longitude 31.207320° E, and elevation 18 m above sea level).

### Honeybee colonies

Three Craniolian hybrid honeybee colonies (*Apis mellifera* L.) were used during the spring season of 2024; every one of them contained eight frames covered with bees. The colonies were housed in wood hives of the Langstroth type, which had walls that were 25 mm thick and outer dimensions of 510, 410, and 270 mm as well as interior dimensions of 485, 385, and 250 mm.

### Bees Monitoring System (BMS) Design and Implementation

This section has a detailed look into the materials and processes involved in the specification and hardware implementation techniques to sense and display different changes inside the beehive during the operating conditions of the device of the bee venom collecting (BVCD). The HTML platforms for IoT applications were used as the development platform. This prototype is an actual scale model. Fig. 1 shows an illustration of the block diagram of the system.

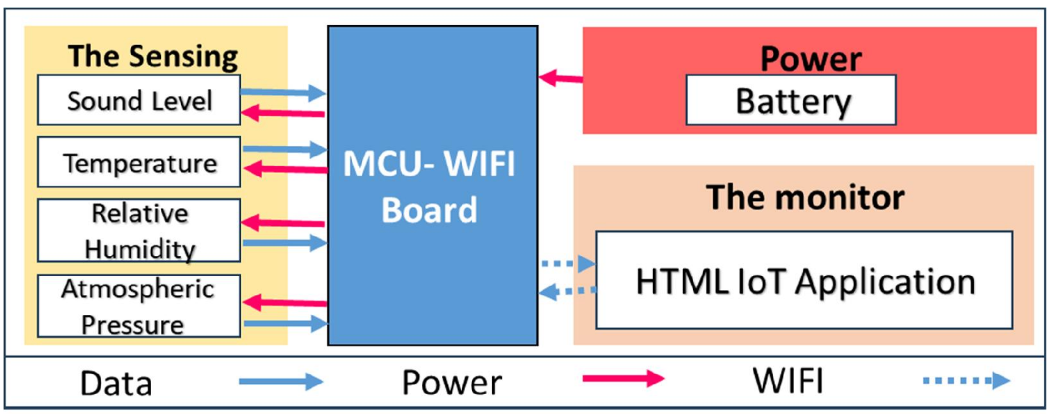


**Fig. 1:** Block Diagram of the MBS

There are two main modules in this system: the monitor and sensing modules, plus the MCU unit and power unit, as in Fig. 1. And three paths: the first of Data, the second of Power, and the third of WIFI

### Base of BMS

The base of the BMS was made from wood, which contains two frames, according to Ali *et al*. (2023). The two frames are assembled as shown in Fig 2. To protect them from the sun and other outside factors, they were positioned beneath the beehive's cover.

The electronic monitoring system was based on the approach proposed by Ali *et al*. (2023). The BMS consists of an MCU-ESP32s (WIFI) and sensor network that is divided into two groups. Each group is put on a separate frame, as shown in Fig 2. In this system, the sensors collect data once every 3000 milliseconds.

### MCU- WIFI - board

The ESP-WROOM-32s module is an affordable microcontroller with integrated 2.4 GHz, WIFI, and dual-mode Bluetooth. Firmware based on the widely used ESP32-12E module that allows it to link to the internet. RAM and 4MB SPI Flash internal memory. The module can communicate wirelessly via WIFI, 2.4GHz, and Bluetooth 4.0 thanks to the integrated antenna.

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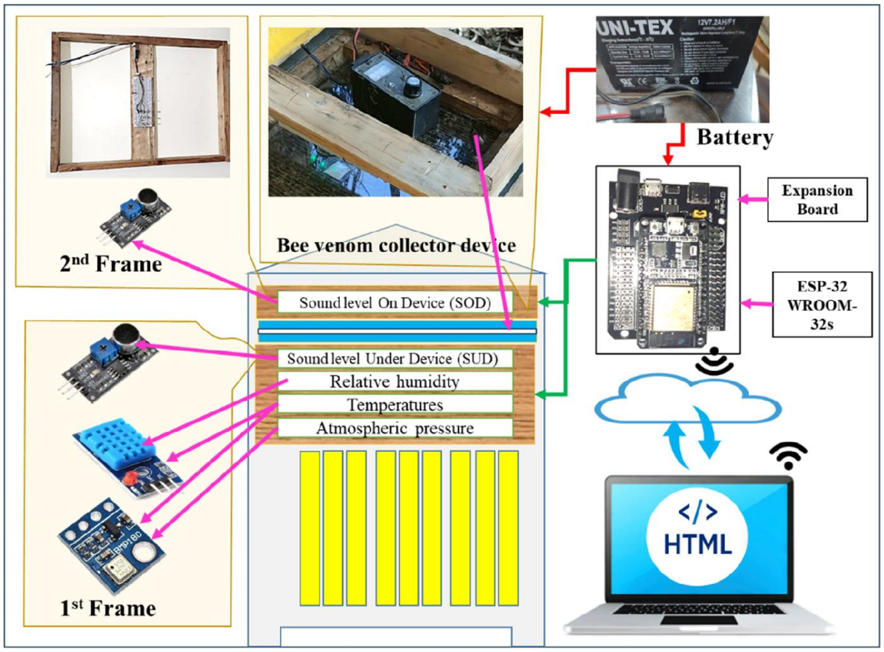


**Fig. 2:** The BMS consists of hardware design-based

**Sensing Modules**

Four sensors were used as in Fig. 2; two of them were installed on the edges of the bottom frame from the inside in opposite positions, so that the data gathered was accurate to the conditions surrounding the bees. Internal temperature (InT) and relative humidity (InRH) were measured by the DHT11 sensor, and InT and internal atmospheric pressure (InAP) were measured by the BMP180 sensor. The other two sensors were used to detect the sound levels, which have a potentiometer knob that can be adjusted to change the sensitivity of the sound level sensor to sound; the first one was put on the glass plate of the device (SOD) to represent the intensity of the sound level measured at the device top, and the other was put on the bee frames and under the glass plate of the device (SUD) to present the intensity of the sound level measured at the under of the device. A sound sensor measures the bee's noise and is then connected to the microcontroller. Any sound differences in the beehive cause the sensor to produce an electrical pulse that varies depending on the sound falling on it. The module will output the value of sound by dB after calibration with a high-accuracy measurement device.

**Monitor module**

This module enhances the IoT capabilities of the BMS by utilizing the Wi-Fi module of a NodeMCU ESP32 development board. It transmits the status of the beehive structure to the HTMI-IoT web application. The IoT communication protocol is preferred over other options as it can effectively handle large amounts of data transmitted over the Internet. To support this IoT infrastructure, we designed an HTML-based web page for monitoring the system on a PC screen.

The NodeMCU ESP32 was programmed using the Arduino IDE, implementing the necessary code to establish a connection between the NodeMCU and the HTML interface. This connection allows for system monitoring, and the NodeMCU connects to the Wi-Fi network, enabling communication with the HTML web page via the IoT credentials provided by the user. Figure 3 illustrates the user interface of the website, which was built with HTML for monitoring purposes and cloud database integration. To continually monitor the values from the sensors, a PC screen was connected to the MCU-WIFI using a USB-WIFI module. This setup allows the user to observe and record data such as sound, temperature, humidity, and atmospheric pressure. Moreover, the system was integrated with a Google Sheets file for cloud storage, which simplifies data retrieval in terms of numbers and text, ensuring cost efficiency.

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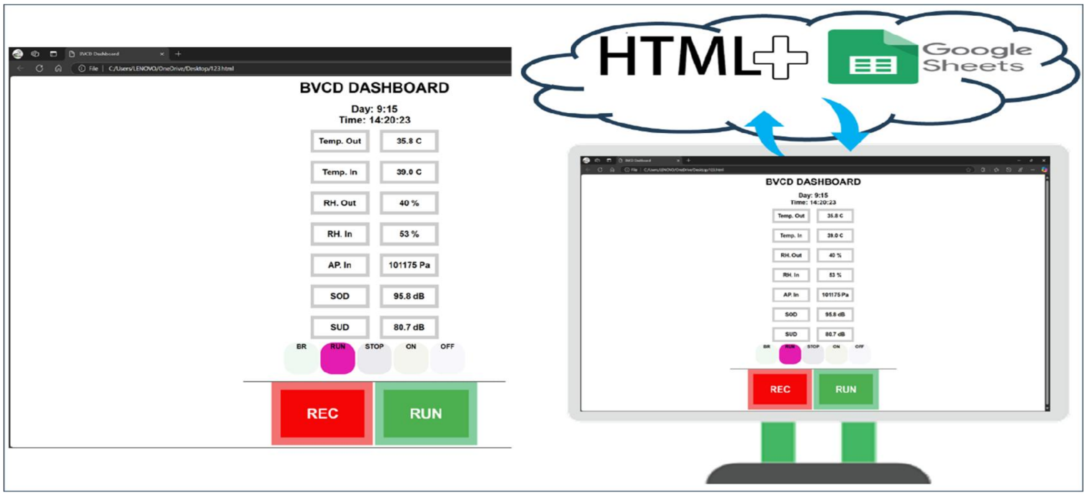


**Fig. 3:** Cloud software design based on HTML and interface website.

**The specifications of BVCD**

Table 1 displays the BVCD component details (Electric shock device / VC-6F/ Apitronic, Canada).

**Table 1:** The specifications of BVCD.

| Input DC Voltage & Currant, V & A | Timer, s | | Collector Frames, m | Operation Mode | Temp., ˚C | Humidity (max). % (at 40 ˚C) | Max operating time, h |
|---|---|---|---|---|---|---|---|
| | ON | OFF | | | | | |
| 11.5-12.75 & 0.15 | 0.5 - 2 | 3 -5 | 0.5 ×0.4 | Semi-automatic | -5: 40 | 95 | 8 |

The collector frame was connected with wires to the collector device. During the operation, the device works automatically and supplies preset impulses to the wire grids.

**Methodology**

The sensors DHT11, BMP180 sensor, and sound level sensors are fixed in the BMS and connected to the WIFI board Node-MCU. Next, a software program was developed to collect sensor data for the beehive environment accordingly.

The diagram of this system is shown in Fig. 1, which shows all the processes in sequence. It helps in better understanding how this system works. This flowchart describes the project flow, from Node-MCU configuration to sensors (DHT11 sensor, BMP180, sound level sensor). The reading value is then sent to the website through the HTML.

The BMS unit equipped with sensors, which was attached to the BVCD, was placed at the beehive top, and then the hive cover was tightly closed to avoid the effect of lighting and other factors on the colony.

The BVCD was operated for 20 minutes, while the BMS unit was running for 30 minutes (five minutes before, 20 minutes during, and five minutes after operating the BVCD) to assess the beehive conditions and determine the relations between SOD, SUD, InT, InRH, and InAP.

**Data Analysis**

Data collected from the three beehives after finishing the all-experimental and using Pearson's correlation matrix displays correlation coefficients between all variables, indicating the strength and direction of the relationship. The values in the matrix range from 1.00 for perfect positive correlation, indicating the same direction of variables as one increase, to -1.00 for perfect negative correlation, indicating opposite directions. A visual depiction of the relationship between variables can be obtained by visualizing the correlation matrix using a heatmap.

Data analyses were divided firstly depending on the variations in state of device (pre-operation, operation, and stop-work) and the time series patterns to identify trends to gain deeper insights (the data was collected over time). Using scatter plots to find the relationship between two or three variables to determine the strength of the relationship and using standard deviation (SD) and average (Ave.) to determine values of all-time series patterns.

## 3. Results

Heatmap of Pearson's correlation matrix in Fig. 4 shows the relationship between SOD, SUD, InT, InRH, and InAP throughout the period of taking readings. From the given matrix, we may derive the following insights:

There is a substantial positive link between SUD and InT, as evidenced by the maximum correlation coefficient value of 0.87 (P<0.001). The correlation coefficients between SOD and SUD are 0.68 (P<0.001), and between InT and SOD, they are 0.61 (P<0.001). The correlation coefficient values for InRH-InAP and InRH-InT were 0.48 (P<0.001) and -0.48 (P<0.001), respectively. Furthermore, all of the other correlation coefficients are between +0.43 and -0.43 (P<0.05), indicating that there are no significant relationships between the SUD and the other factors.

There were positive correlations found between SOD, SUD, and InT, indicating that they frequently fluctuate together. This indicates a positive correlation between the readings obtained on and under the device. Additionally, a strong positive correlation has been found between SUD and InT. Although SOD and InT have a positive correlation, it is not as strong as the correlations that came before it.

| | *SOD* | *SUD* | *InT* | *InRh* | *InAP* |
|---|---|---|---|---|---|
| **SOD** | **1.00** | | | | |
| **SUD** | **0.68** | **1.00** | | | |
| **InT** | **0.61** | **0.87** | **1.00** | | |
| **InRH** | **-0.09** | **-0.18** | **-0.48** | **1.00** | |
| **InAP** | **0.08** | **0.06** | **-0.26** | **0.48** | **1.00** |

**Fig. 4:** Heatmap of Pearson's correlation matrix at ( P<0.05)

**All these relationships can be analyzed separately through the following approach:**

**The relationship between the SOD and SUD:**

The four scatter plots showed the relationship between two variables, SOD and SUD, as shown in Fig. (5-A, B, C, and D). In Fig. (5-A), the different colored dots in the plots refer to the sound levels pre-operating, operation (run), and post-operation of the BVCD. There seems to be a positive correlation between SUD and SOD. Although there is not much of a correlation, the sound level tends to rise at the SUD position as it does at the SOD position. The data points are clustered in different regions, suggesting potential variations in the impact of operating conditions. The change in the distribution of data points between the "pre-operating" and "run" states suggests that the device operating had a significant impact on the sound levels.

To gain deeper insights (the data is collected over time), the data analyses the time series patterns to identify trends and time variations, as shown in Figs. 5(B, C, and D). Which can be reviewed in three cases as follows:

### Pre-operation

This is illustrated by fig. (5-B), which shows the existence of a direct relationship for each of SOD and SUD. The results showed that the sound level values rose after installing the device on the cell and even before turning it on for both the SOD and SUD, where the readings began with Ave. 59.9 and 73.7 dB at first min, respectively. While, one minute before running BVCD, the Ave. was 65.9 dB and 77.07 dB, respectively. And general average values of the readings before running the device were 65.49 and 71.41 dB, respectively. The presence of a large dispersion in the SOD output values, SD (10.54).

However, the SD value for SUD was 1.54, which indicates the escalation of SOD values compared to SUD values. This coincides with the beginnings of a slight attack individually for bees on the device before running it, noting the sound height from the internal of SUD slightly and individually.

It will observe the effect of isolating the glass plate from sound by lowering the average SOD, which is above the glass plate compared to the average of SUD from the beginning.

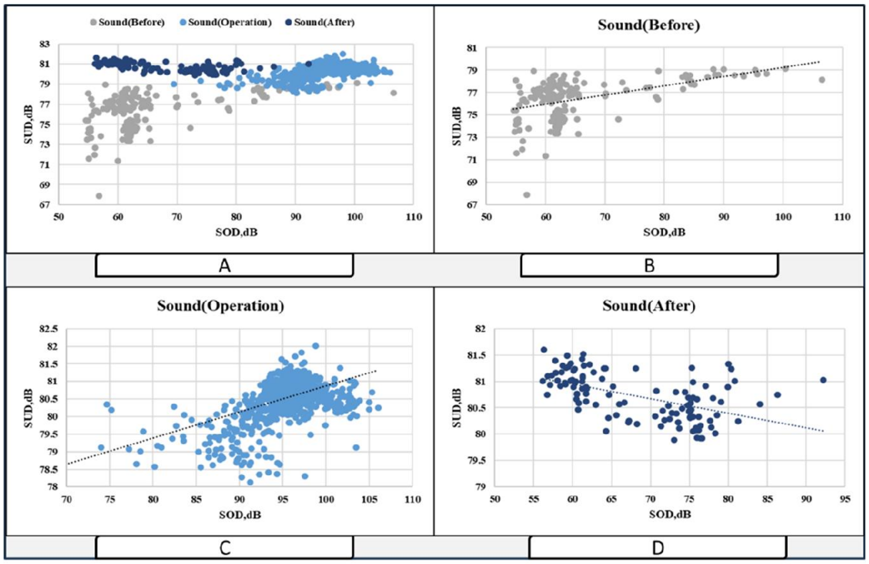


**Fig. 5:** The scatter plots of the relationship between two sensors of sound intensity level.

**Operation (run)**

The fig. (5-C) shows the existence of a direct relationship for each SOD and SUD and can be observed that a low level of dispersion in SOD has SD (3.44) and Ave. (95.53 dB), while in SUD has SD (0.51) and Ave. (80.54 dB). It is clear from the data that the cloud of values turned from scattered in the far left to concentrated far right to be higher than the sound level inside the beehive. This may be explained as a result due to the severe attack of bees on the glass plate of the BVCD and the high sound of bees colliding with the device, which can appear in the upper sensor.

**Post-operation**

As shown in fig. (5-D), an inverse relationship was observed between sound levels of SOD and SUD. It has been observed that low sound level values of SOD very significantly in exchange for the SUD inside the beehive continued to rise, and those were the SD (10.50, 0.44) and Ave. (68.33, 80.72 dB) for both the SOD and the SUD, respectively. Which is explained by the departure of bees from the device immediately after the device stops and crowding above the frames, which caused the high level of SUD.

**Relationship with internal temperature (InT)**

The scatter plot provided visualizes the relationship between InT (°C) and sound level (dB), as shown in Fig. (6-A). The different colored dots represent different states or conditions of the system at various times. The InT seems to be a general trend to increase above the normal InT; the sound levels are increasing also. This implies that the two variables have a positive correlation. The fact that the relationship is not exactly linear suggests that there may be additional factors influencing the InT. There are a few data points that deviate significantly from the general trend. These outliers could represent anomalies or special conditions. It is generally noted that the operating states of the device are naturally divided at a vertical level during temperature levels, and this can be seen in Fig. 6-A.

To gain deeper insights, time series analysis was used, where the data was collected over time; analyzing the time series patterns can reveal trends and variations. The data points were clustered into distinct groups, each represented by a different color. These clusters correspond to different operating conditions of the system.

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Therefore, we will classify it into three stages: the figs. (6-B, C, and D) show the relationship in each of the cases of the device work before operation and during and after the separation of the BVCD respectively and each group of them can be addressed separately to understand the form of the relationship and change Which can be reviewed in three cases as follows:

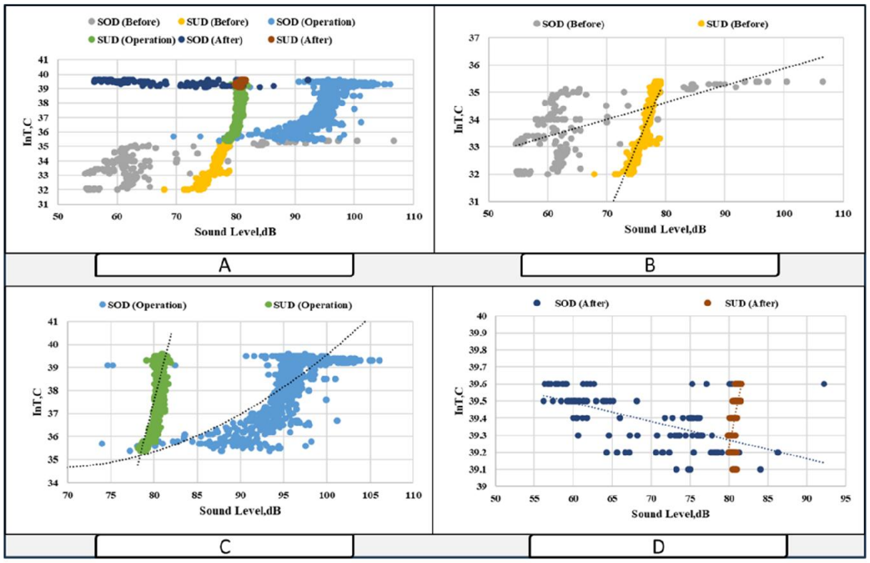


**Fig. 6:** The scatter plots of the relationship between InT and sound levels.

**Pre-Operation**

Fig. (6-B) shows the existence of a direct relationship for InT, SOD, and SUD and the values in InT between 32.00:35.40 °C and Ave. of 33.74 °C, which indicates the escalation of sound level values with high InT, which indicates crowding bees around the device from into the beehive and the beginnings of a slight attack individually by bees on the device before its operation.

**Operation (run)**

Fig. (6-C) illustrated the existence of a direct relationship for InT, SOD, and SUD, and the InT was between 35.40:39.60 °C and Ave. of 38.35 °C. It is clear from the data that the cloud shifts values to the far right to be higher than the SUD. This can be explained by the high InT as a result of the bees' collision with the device and its exposure to electrocution, which means there is a match between the increase in the upper sensor and the increase in the InT, which can be important in determining the start of the attack and continuation of the bees on the device.

But it is noted that at high InT, the values appear similar to the shape of the "Umbrella," which shows the high sound levels with the stability of InT, which shows the effect of bees and their direction to maintain the InT of the beehive while reducing it with the continuation of its attempts to attack the BVCD, and it is also noted that the sound level rises to the maximum extent possible at this stage. May be the bees possible reason is that bee colonies have actively controlled the beehive InT in this temperature range.

**Post-Operation**

Fig. (6-D) shows the existence of an inverse relationship to InT and SOD and is semi-stable with the SUD and the decline in InT between 39.10 and 39.60 °C, which explains the departure of bees from the device immediately after the device stops. The continuation with high InT is explained by the crowding of bees at the frame top and is confirmed by the high level of the internal sound of the hive.

**Relationship with internal relative humidity (InRH)**

The scatter plot (Fig. 7-A) was provided to visualize the relationship between InRH and sound level (dB). It was observed that there doesn't seem to be a strong correlation between sound level and InRH. The data points are scattered across a wide range of values, indicating that changes in sound level don't significantly affect the InRH. Which further indicates the complexity of InRH changes, this large dispersion in general in the InRH of SD (12.52) and Ave. (53.67%), which can be reviewed in three cases as follows:

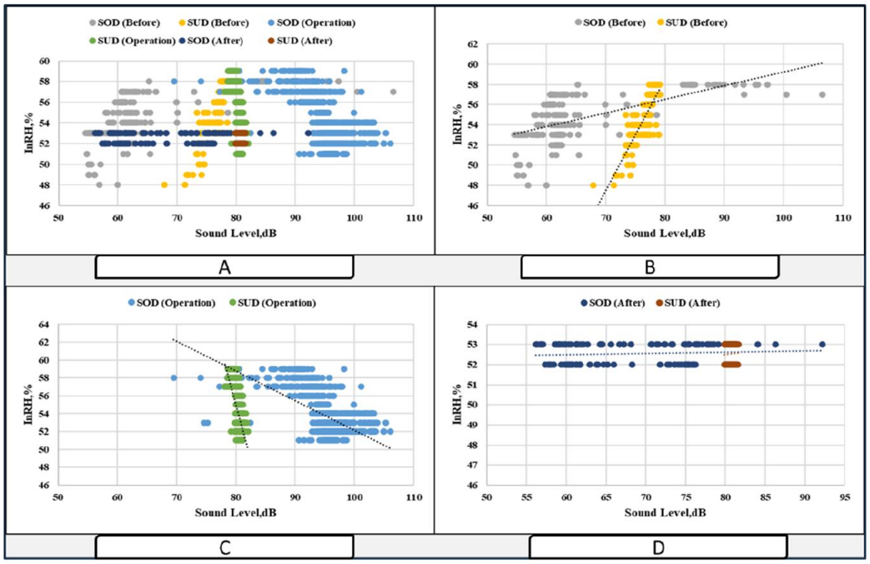


**Fig. 7:** The scatter plots of the relationship between InRH and sound levels.

**Pre-Operation**

Fig. 7-B showed the existence of a direct relationship for the InRH, SOD, and SUD, and the values of the InRH ranged between 48 and 58%. This indicates the escalation of sound values with high InRH, which indicates the beginnings of a slight vital activity individually for bees on the frames before its operation.

**Operation (run)**

Fig. 7-C showed the existence of an inverse relationship for all the InRH and SOD and SUD in both ways and the decline of the InRH between 51:59% and Ave (53.65%), and it is clear from the data that the low level of InRH inside the hive may be attributed to the high InT of high rates and the existence of a reverse relationship between InT and InRH level.

**Post-Operation**

Fig. (7-D) showed the presence of a decrease in the sound, whether SUD or SOD, in a way that is both with stability in InRH between 52 and 53%, and the low stability of the level of InRH may be attributed to the stability of the InT to high rates and the existence of a relationship between the InT and the InRH, which is explained by the constant crowding of bees on top of the frames.

**Relationship with internal atmospheric pressure (InAP)**

The four scatter plots (Fig. 8-A, B, C, and D) were provided to visualize the relationship between InAP, SOD, and SUD. The different colored dots represent different states or conditions of the system at various times. In Fig. (8-A), there seems to be a weak positive correlation between sound levels and InAP. As the sound level increases, the InAP also tends to increase slightly. The data points were clustered in different time ranges, suggesting potential variations in operating conditions, which can be reviewed in three cases as follows:

**Pre-Operation**

Fig. (8-B) showed the existence of a direct relationship between InAP and sound level. The values of InAP were ranged between 101163 and 101185 Pa, which refers to the escalation of SUD with high InAP, which refers to the rise in sound level SUD is associated with the rise in InAP, which is logical with the link between sound level and InAP.

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**Operation (run)**

Fig. 8-C showed the existence of an inverse relationship for all InAP, SOD, and SUD. The values of InAP were between 101158 :101194 Pa and Ave. of 101174 Pa, and it is clear from the data that the effect of InRH on InAP is higher than the effect of high sound level on InAP, which leads to a decrease in InAP with a rise in sound level inside the beehive.

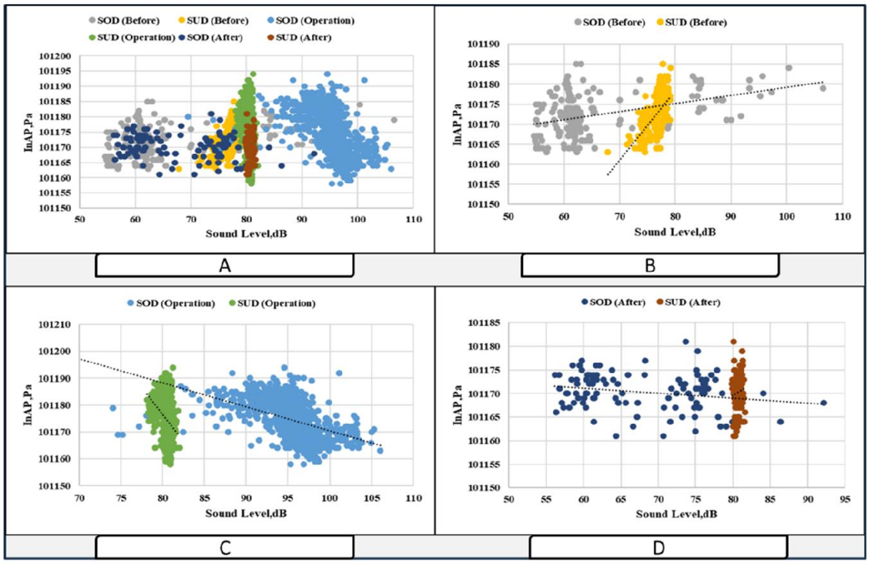


**Fig. 8:** The scatter plots of the relationship between InAP and sound levels.

**Post-Operation**

Fig. 8-D showed the existence of a direct relationship between InAP and SUD and was semi-stable with the SOD and the decline of InAP between 101161 and 101181 Pa, which explains the decrease in the effect of heat above the InAP and the increase in the effect of sound, resulting in the direct relationship of InAP with the internal sound level.

## 4. Discussion

From the above-mentioned data, the study demonstrates a positive association between sound levels inside beehives and working conditions of the BVCD. The data points are clustered in distinct regions, suggesting probable variances in the impact of operating conditions. The data analysis showed that the gadget functioning greatly altered sound levels. The InT and sound levels in a beehive are often growing above normal, demonstrating a favorable association between the two variables. However, the connection is not flawless linear, implying that other factors might possibly influence the InT. Some data points diverge greatly from the general trend. The working modes of the device are naturally divided at a vertical level during InT levels, which can effectively reflect the activity of the bee colony. According to Li *et al*. (2022), there is no strong link between sound levels and InRH, showing that changes in sound level do not significantly impact relative humidity. The high dispersion in RH levels can be studied in many circumstances. A small positive association was established between sound levels and InAP, with a slight increase in InAP as sound levels increased. The data points were clustered in different time spans, suggesting changes in operation conditions. Time series analysis was utilized to show trends and variances in data throughout time, according to Smerkol *et al*. (2024). These clusters indicate system operating situations. Thus, we shall break it into three stages, each of which may be investigated separately to understand the link and evolution. Three cases are mentioned below:

In the first case, observed during the pre-operation phase, sound levels increased after the device was installed on the cell, even before it was turned on, for both the SOD and SUD. The data revealed a significant dispersion in the SOD output values, indicating a notable increase in SOD values compared to those of the SUD. This was accompanied by an initial slight attack by bees on the device before its operation. The InT values ranged from 32.00 to 35.40 °C, with an Ave. of 33.74 °C, suggesting that the rise in sound levels coincided with high InT. This increase indicates that the bees were crowded around the device and were starting to become aggressive. The presence of venom residue on the glass plate of the BVCD likely added to the bees' stress. Additionally, the InRH values varied from 48% to 58%, reflecting a moderate level of activity among the bees on the frames. A direct relationship was observed between the InAP and sound levels, with values ranging between 101163 and 101185 Pa. This suggests that an increase in sound (SUD) associated with higher InAP.

In the second case of operation position, low levels of dispersion in SOD and SUD were observed, with values shifting from scattered on the left to concentrated on the right, surpassing the sound level inside the beehive. This is attributed to bees attacking the glass plate of the BVCD and the loud sounds from their collisions. In the run position, InT values ranged from 35.40 to 39.60 °C, averaging 38.35 °C, indicating a link between upper sensor increases and InT rises, marking the start of bee attacks. The "Umbrella" shape in high InT reflects increased sound levels and stable InT, suggesting bees maintain hive InT during these attacks. Sound levels peaked, likely due to the colony's active InT regulation, as noted by Li *et al*. (2022). InRH values fell between 51 and 59%, averaging 53.65%, indicating low InRH due to high InT alongside an inverse relationship between InT and InRH. Additionally, a rise in sound levels correlated with a decrease in InAP, with Pearson's correlation showing a positive link between InRH and InAP.

In the post-operation phase, low sound levels of SOD were noted, while SUD increased significantly within the beehive. InT values inversely correlated with SOD and were related to SUD, suggesting bees left the device once it stopped. Sound levels dropped with stable InRH at 52-53%. The fluctuation in InRH is linked to high-InT stability and the bee crowding on frames. There was a direct relationship between InAP and SUD, with a semi-stable connection to SOD and a decline in InAP between 101161 and 101181 Pa, indicating bees were attempting to restore normal hive conditions despite ongoing stress.

To clarify what happens inside the beehive more fully, we will review some of the opinions of prior studies. According to Ferrari *et al*. (2008), noise levels within the hive climb dramatically compared to the 30–50 dB reported under normal, undisturbed settings. This increase is driven by the enhanced wing vibrations and alarm responses of worker bees responding to the electrical stimuli. The elevated noise levels are not only suggestive of stress but also impede regular colony operations such as communication and brood care. Also, Ferrari *et al*. (2008) found that heightened acoustic levels are associated with agitation and may significantly affect colony efficiency and cohesion. Additionally, Kirchner (1993) underlined that audio communication is crucial for waggle dances, which could be hampered by the noise. Regarding the InT, the temperature of the brood nest is normally maintained at 34–36°C, as Kronenberg & Heller (1982) and Jarimi *et al*. (2020) noted which rises during venom collecting due to the increased metabolic activity of bees striving to respond to the stimuli. This temperature difference may disrupt brood development if sustained over long periods, particularly in eggs and young larvae. Clarke & Robert, (2018) noted that the InT differential can effectively indicate the activity of the bee colony. Stabentheiner *et al*. (2010) underlined that even modest deviation from the ideal InT range can diminish larvae survival rates and affect development. The InT rise is accompanied by a fall in InRH, which is generally maintained between 50 and 70%; this is owing to the fanning behavior of bees seeking to regulate InT and distribute alarm pheromones emitted throughout the process. The reduced InRH may impact the dehydration of nectar into honey and could also affect brood growth, as brood chambers require a restricted range of InRH for optimal conditions. Human *et al.* (2006) revealed that changes in hive InRH, especially protracted declines can alter brood mortality and honey production efficiency. Although there are no direct studies that have quantified changes of InAP during venom collection, the heightened activity of the bees during venom collection can lead to localized airflow changes altering the air pressure, which explains the increase in InAP. Tautz & Sandeman (2003) proved that InAP matches exterior circumstances since beehives are not hermetically sealed. However, bees respond to variations in InAP, often suspending flight activity during severe decreases, as these often precede adverse weather conditions.

The disturbances caused by BVCDs highlight the need for caution in their use. It is necessary to prohibit their use for the long term so as not to affect the strength of the colonies. Given the difficulty of dealing with honey bee colonies, which are very aggressive during and after operating the BVCD, which reduces the tendency of beekeepers to produce poison, so Internet of Things (IoT) technology was used to collect data and monitor the colonies. For example, Zacepins et al. (2015) reported that IoT systems effectively track hive microclimate, enabling early detection of stressors such as overheating or excessive InRh, which can otherwise lead to reduced productivity or colony collapse.

## 5. Conclusion

This study examined the relationship between sound levels and environmental variables like temperature, humidity, and atmospheric pressure inside beehive. The research utilized a multi-sensor array for real-time monitoring, uncovering substantial insights about beehive behavior and the effects of BVCD. The investigation found a considerable positive link was observed between sound levels and the working state of the bee venom gathering equipment. This shows that the device's action directly changes the auditory environment within the hive. The study also identified a positive association between interior temperature and sound levels, showing that higher sound levels can lead to greater temperature, presumably due to increased bee stress. A minor negative association was established between relative humidity and sound levels, showing that acoustic patterns do not appreciably alter humidity variations. And a very modest positive association was detected between air pressure and sound levels, indicating additional elements affecting it.

Bees demonstrated limited increased activity near the device before it was activated, resulting in higher sound levels, a little rise in temperature and atmospheric pressure, and a minor drop in relative humidity. During the device's operation, bees interacted more actively with it, resulting in heightened sound and temperature levels, along with a modest drop in both relative humidity and air pressure. After the gadget was turned off, sound levels reduced as the bees gradually reverted to their normal activity patterns.

### Future Directions

Further research should explore sound-based interventions to improve bee health and productivity while implementing conservation strategies to support bee populations. Long-term studies are necessary to assess the impact of bee venom collection on hive health, including controlled experiments on collection devices and frequencies. Observing bee behavior, such as foraging, brood rearing, and aggression, will aid in evaluating the effects of venom collection. The ultimate goal is to reduce the negative impacts of venom collection and promote sustainable beekeeping practices.

### References

Ali, E.A.E., A. Saad, M. S. Younis and A. A. A. Metwally, 2023. Using Sensing Technology Inside Beehive to Determine the Optimal Conditions Affecting the Demand for Bee (*Apis mellifera* L.) Venom Collector Device. International Journal of Engineering Inventions, 12(7), 76–85. https://www.ijeijournal.com/papers/Vol12-Issue7/12077685.pdf

Anwar, O., A. Keating, R. Cardell-Oliver, A. Datta and G. Putrino, 2022. Design and development of low-power, long-range data acquisition system for beehives- BeeDAS. Computers and Electronics in Agriculture, 201. https://doi.org/10.1016/j.compag.2022.107281

Catania, P., and M. Vallone, 2020. Application of a precision apiculture system to monitor honey daily production. Sensors (Switzerland), 20(7). https://doi.org/10.3390/s20072012

Cecchi, S., S. Spinsante, A. Terenzi and S. Orcioni, 2020. A smart sensor-based measurement system for advanced bee hive monitoring. Sensors (Switzerland), 20(9). https://doi.org/10.3390/s20092726

Cecchi, S., A. Terenzi, S. Orcioni, S. Spinsante, V. Mariani Primiani, F. Moglie, S. Ruschioni, C. Mattei, P. Riolo and N. Isidoro, 2019. Multi-sensor platform for real time measurements of honey bee hive parameters. *IOP Conference Series:* Earth and Environmental Science, 275(1). https://doi.org/10.1088/1755-1315/275/1/012016

Clarke, D., and D. Robert, 2018. Predictive modelling of honey bee foraging activity using local weather conditions. Apidologie, 49(3). https://doi.org/10.1007/s13592-018-0565-3

Edwards Murphy, F., 2017. *Wireless sensor networks, actuation, and signal processing for apiculture*. University College Cork. https://hdl.handle.net/10468/6379

Edwards Murphy, F., M. Magno, P. M. Whelan, J. O'Halloran and E. M. Popovici, 2016. B+WSN: Smart beehive with preliminary decision tree analysis for agriculture and honey bee health monitoring. Computers and Electronics in Agriculture, 124. https://doi.org/10.1016/j.compag.2016.04.008

Ferrari, S., M. Silva, M.Guarino and D. Berckmans, 2008. Monitoring of swarming sounds in bee hives for early detection of the swarming period. Computers and Electronics in Agriculture, 64(1). https://doi.org/10.1016/j.compag.2008.05.010

Human, H., S.W. Nicolson and V. Dietemann, 2006. Do honeybees, *Apis mellifera* scutellata, regulate humidity in their nest? Naturwissenschaften, 93(8). https://doi.org/10.1007/s00114-006-0117-y

Jarimi, H., E. Tapia-Brito and S. Riff, 2020. A review on thermoregulation techniques in honey bees' (*Apis mellifera*) beehive microclimate and its similarities to the heating and cooling management in buildings. Future Cities and Environment, 6(1). https://doi.org/10.5334/fce.81

Kirchner, W. H., 1993. Vibrational signals in the tremble dance of the honeybee, *Apis mellifera.* Behavioral Ecology and Sociobiology, 33(3). https://doi.org/10.1007/BF00216597

Kridi, D.S., C.G.N. de Carvalho and D.G. Gomes, 2016. Application of wireless sensor networks for beehive monitoring and in-hive thermal patterns detection. Computers and Electronics in Agriculture, *127*. https://doi.org/10.1016/j.compag.2016.05.013

Kronenberg, F., and H.C. Heller, 1982. Colonial thermoregulation in honey bees (*Apis mellifera*). Journal of Comparative Physiology, 148, 65-76. https://doi.org/10.1007/BF00688889

Kviesis, A., V. Komasilovs, O. Komasilova and A. Zacepins, 2020. Application of fuzzy logic for honey bee colony state detection based on temperature data. Biosystems Engineering, 193, 90–100. https://doi.org/10.1016/j.biosystemseng.2020.02.010

Li, L., C. Lu, W. Hong, Y. Zhu, Y. Lu, Y. Wang, B. Xu and S. Liu, 2022. Analysis of temperature characteristics for overwintering bee colonies based on long-term monitoring data. Computers and Electronics in Agriculture, 198. https://doi.org/10.1016/j.compag.2022.107104

Meikle, W. G., and N. Holst, 2015. Application of continuous monitoring of honeybee colonies. In Apidologi*e* (Vol. 46, Issue 1). https://doi.org/10.1007/s13592-014-0298-x

Oskin, S.V., and D.A. Ovsyannikov, 2019. Modeling the Main Physical Processes in Beehives. Biophysics (Russian Federation), 64(1). https://doi.org/10.1134/S0006350919010159

Pérez, N., F. Jesús, C. Pérez, S. Niell, A. Draper, N. Obrusnik, P. Zinemanas, Y. M. Spina, Letelier, L.C. and P. Monzón, 2016. Continuous monitoring of beehives' sound for environmental pollution control. Ecological Engineering, 90, 326–330. https://doi.org/10.1016/J.ECOLENG.2016.01.082

Ramsey, M.T., M. Bencsik, M. I. ewton, M. Reyes, M. Pioz, D. Crauser, N. S. Delso and Y. Le Conte, 2020. The prediction of swarming in honeybee colonies using vibrational spectra. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-66115-5

Seeley, T. D., and J. Tautz, (2001). Worker piping in honey bee swarms and its role in preparing for liftoff. Journal of Comparative Physiology - A Sensory, Neural, and Behavioral Physiology, 187(8), 667–676. https://doi.org/10.1007/S00359-001-0243-0

Senger, D., C. Gruber, T. Kluss and C. Johannsen, 2024. Weight, temperature and humidity sensor data of honey bee colonies in Germany, 2019–2022. Data in Brief, 52. https://doi.org/10.1016/j.dib.2023.110015

Sharif, M.Z., N. Di and B. Yu, 2023. Honeybee (Apis spp.) (Hymenoptera: Apidae) Colony Monitoring Using Acoustic Signals from the Beehive: An Assessment by Global Experts and Our Feedback. Agriculture (Switzerland), 13(4). https://doi.org/10.3390/agriculture13040769

Smerkol, M., Ž. Šešet, B. Bregant, S. Simončič, M. Finžgar and A. Gradišek, 2024. Smart beehive monitoring system for identification of relevant beehive events. *Proceedings - 2024 International Conference on Intelligent Environments, IE 2024*, 97–100. https://doi.org/10.1109/IE61493.2024.10599912

Stabentheiner, A., H. Kovac and R. Brodschneider, 2010. Honeybee colony thermoregulation - Regulatory mechanisms and contribution of individuals in dependence on age, location and thermal stress. PLoS ONE, *5*(1). https://doi.org/10.1371/journal.pone.0008967

Tautz, J., and D. C. Sandeman, 2003. Recruitment of honeybees to non-scented food sources. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, 189(4). https://doi.org/10.1007/s00359-003-0402-6

Terenzi, A., S. Cecchi and S. Spinsante, 2020. On the Importance of the Sound Emitted by Honey Bee Hives. Veterinary Sciences, 7(4), 168. https://doi.org/10.3390/VETSCI7040168

UNEP., 2019. *Why bees are essential to people and planet?* https://www.unep.org/news-and-stories/story/why-bees-are-essential-people-and-planet

Walendziuk, W., and A. Sawicki, 2014. Telemetric measurement system of beehive environment conditions. Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2014, 9290. https://doi.org/10.1117/12.2073050

Zacepins, A., V. Brusbardis, J. Meitalovs and E. Stalidzans, 2015. Challenges in the development of Precision Beekeeping. In Biosystems Engineering (Vol. 130, pp. 60–71). https://doi.org/10.1016/j.biosystemseng.2014.12.001

Zacepins, A., A. Kviesis, E. Stalidzans, M. Liepniece and J. Meitalovs, 2016. Remote detection of the swarming of honey bee colonies by single-point temperature monitoring. Biosystems Engineering, 148. https://doi.org/10.1016/j.biosystemseng.2016.05.012

Zgank, A., 2020. Bee swarm activity acoustic classification for an iot-based farm service. Sensors (Switzerland), 20(1). https://doi.org/10.3390/s20010021