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Application of Wireless Sensor Network for advancements in non intrusive Precision beekeeping

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***Abstract*—Honey bees play a vital role in many ecological and environmental processes which are of immense value to all life forms. In the last fifty years, their contribution to the pollination of dependent crops has increased three folds, playing a key role in ecological systems, industrial crop production, production of commercial products with medicinal properties. The conventional method involves manual inspection, which requires the bee keeper to visually inspect the activities by opening the hive. This causes agitation among the bees. In addition, this method is purely based on experience of the bee keeper and is prone to human error. These factors have led to the need for advancement in apicultural techniques bringing under its umbrella numerous researchers working on various specializations. This work presents a brief discussion on some of the systems developed based on the concepts of Wireless Sensor Networks which have been deployed to monitor bee health and honey production, detect abnormal activities like swarming, absconding of bees, bee hive robbery and identification of queen-less states.**

Keywords—apis mellifera, internet of things, precision api-culture system, precision beekeeping, wireless sensor networks.

I. INTRODUCTION

About 9.5% of the world's agricultural produce of human consumable foods, which accounts for €153 billion is pollinated through honey bees. As high as 75% of the global fruits, seed crops, and vegetable produce depend on animal pollination, representing 35% of the global food production, with *Apis mellifera* being the most common species for this purpose. Despite their economic and ecological importance, honey bees have been suffering existential crisis due to various contributing factors which include the drastic modification of their life cycles as well as their environment by human beings. The evolution of plants and flowers, which for a long time has been dictated by resistance and adaptation, has also caused immense stress on bee life. The situation has reached such an alarming stage that they have difficulty in finding flowers to feed on. In addition to these, factors like weak worker bees, disease-causing parasites, overwintering, worker bees with low body fat reserves, and low honey stores also contribute to the loss in the bee population [1]. Fluctuations in external environmental factors like temperature and humidity affect the immune system negatively, making them more susceptible to various diseases. A major breakthrough occurred in 2006, when multiple well-known factors, like increased use of pesticides, mite infections caused by the *Varroa destructor* (*V. destructor*), fungal and viral diseases, climate change, starvation, and increased presence of pollutants collectively contributed to the large-scale decline and extinction of honey bees on a global scale and was termed the Colony Collapse Disorder (CCD). In addition to the above-mentioned factors, attacks by Asian giant hornets (with the capability to kill 40 other kinds of bees), hive robberies owing to resource scarcities, accidental death of the queen and attack by predators can result in destruction of the colony [2]. Beekeepers have adopted various methods to keep track of hive health and conditions to prevent the loss of colonies. The traditional methods involving manual inspection have helped prevent the loss of colonies. Yet these methods are stressful to the bees, as it weakens the colony and attracts pests, with a possibility of 1% bee loss on weekly inspections. This method limits the scope of observations as it disrupts the bee behavior and aggravates the colonies. The beekeepers are severely limited by the quality and quantity of data. Their methods rely on experience and visual observations over reliable and numerical data. The inability to predict bee behaviors like swarming and absconding causes tremendous losses to the beekeepers which stresses the need for better monitoring methods. The lack of standardized methods and documented records demand for an advanced and scientific approach in the field of apiculture. This has led to the dawn of application of concepts of Internet of Things (IoT) and wireless sensor networks leading to precision beekeeping. This technique involves monitoring colonies to maximize productivity while also reducing labor requirement and financial resource consumption. Generation of in-hive colony data on a seasonal basis through continuous sensor- based monitoring is of benefit to researchers and apiary managers as it helps predict annual brooding phases, time of extraction of honey, loss in bee population and health of queen bee. This strategy involves data-driven steps to collect, process and analyze to make informed decisions. This paper discusses the various methodologies adopted by researchers for improved colony surveillance, monitoring honey production, prediction of colony damage and bee hive management.

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II. Relevant Theories

Various sensors are used to collect timely and reliable data about important parameters to provide useful insights for sustainable and profitable beekeeping. The observed ideal in-hive temperature ranges between 32°C and 35°C. At extreme temperatures, there is also an increase in metabolism rates demanding higher sugar consumption. The presence of low temperatures in the operculated breeding phase increases the mortality rate while also shortening the longevity of the workers. Low temperatures combined with high-speed winds (9-14 kmph) affect the mating behavior of the queen as well as prevents bees from foraging. The optimum relative in-hive humidity is observed to be 70%. Increased humidity poses threats of fungal growth, bacterial infection, parasitic attack, and even virus outbreaks [3]. The viscosity of honey is also affected by hive humidity. Acoustic data can be analyzed as amplitude spectrum and frequency spectrum. Close analysis of the variations in frequencies can help predict the possibility of swarming. Higher noise levels indicate a higher probability of hive robbery, predator attack, increased levels of organic insecticides and *Varroa* infestation. Another factor is the weight of the hive, which helps keep track of the quantity of honey produced and also the brood production. Weight data can also illustrate the rate of growth and food consumption in the colony, presence of nutritional stress, quantity of nectar collection during nectar flow season, beginning of overwintering season to name a few. Video monitoring is one of the methods that can be applied to keep continuous track of hive activities. Monitoring these activities gives us information about hive health. Alternatively, Radio Frequency Identification (RFID) tags can be installed on individual bees to recognize their movements and front of the hive activities. RFID in combination with motion detection cameras has been used [4] to identify the food type collected by the foragers and the variation of the same with time.

III. Methodology

The bee activities can be broadly classified as "front of the hive activities" and "in hive activities". "Front of the hive" activity can be further categorized as "General activity"- involving orientation of worker bees with the environment, fanning to regulate temperature and hive protection; "Foraging activities"- includes collection of pollen and nectar. "In hive" activities include honey production, laying of eggs, feeding, incubation along with others. The most influential among all parameters for monitoring the hive conditions are temperature, humidity, hive weight, acoustics, concentration of gases, percentage of bee pheromones, in-hive frequencies and bee count. The purpose of study of the above mentioned parameters can be broadly classified into the following category:

A. Colony surveillance

B. Monitoring honey production

C. Prediction of colony damages

D. Bee hive management

A. Colony Surveillance

Colony surveillance refers to the process of monitoring the overall colony health and performance. The system architecture proposed [5] deployed sensors for measurement of data which was used to help increase productivity and accurate bee keeping. The DS18B20 sensor provided the temperature data, humidity values were obtained from DHT11 and an arrangement of four 50 kg Load cells used along with Load Cell Transmitter Hx711 produced the weight data. The obtained data was sent to Ubidots platform services (a third-party cloud service). The ESP8266 Wi-Fi module connected to internet services made the data accessible at all times. JSON communication standards (developed keeping in mind the sensor networks) were used to communicate between the gateway and Ubidots. A numeric representation widget presented the weight readings while a visualization of the same eased the work of the beekeeper. A mechanism to alert the beekeeper upon variation in temperature in the operculated breeding states was developed. The research [6] is an example of application of concepts of IoT in beekeeping sector. The aim is to perform apiary controls both at individual colony and apex level without interfering with the natural processes. It also aims at optimizing inspection frequencies. For achieving the same, two cameras were installed for real-time video monitoring of all the hives (whole view) and activities of individual hives (close view). LTE router with I/O, GNSS and RS232/RS485 was used for gateway-concentrator-MQTTbroker communication. From this setup, the absolute mean temperature was observed to be 34.8°C, which differs greatly from the classical assumption. This system assists in analyzing data correlation with use of video, meteo data, mass changes with time and also interprets nest temperatures, humidity and links to local conditions (geographical and biological). The significant difference in the responses of gas sensors placed among various hives was studied [7]. The study involved continuous monitoring of six honey bee colonies over a period of twelve hours. Placement of the sensors were in the flow-through type chambers, this aimed at minimizingcross-interferences among the sensors. Each chamber had gas inlets and outlets and was fitted with necessary electrical components. Every sensor is connected to a measuring unit and voltage supply. The monitoring of internal hive atmosphere was a single measurement consisting of two stages -exposure to air drawn from the hive followed by exposure to ambient air. Statistical Analysis of Variance (ANOVA) was performedon the gas sensor response at a single time point of individual measurement. A comparison between the gas sensor response as a non-random factor and caused variance as a random factorwas studied using the ANOVA model. The difference in gas sensor response is seen to be associated with the rate of *V. destructor* infestation, the same was proven in the statistical analysis where the covariance was observed to be logical and consistent. Greater response implied higher infestation rates. A significant difference in gas sensor response was seen with infestation rates greater than 9.1%. With rates lesser than 4.2% the difference was negligible. The results indicate that gas sensor responses can be potential feature in the detection of *Varroa* infestation. Doppler radar principle is yet another approach to assess bee colony health. This principle has been evaluated by [8]. The method uses overall return signal strength rather than "identify and track individual" method to monitor bee colony activity. The approach is preferred becausethe energy in return signal and the in and out movement of bees are proportional which simplifies data sampling and processing. The produced signal value can be used to evaluatethe colony health. Flight activity levels measured in terms of total energy output of Doppler radar at low frequencies formed the basis for colony activity monitoring. The Doppler sensor was initiated for 30 seconds every 5 minutes to measure the bee colony activity. Sum of incoming and outgoing bees constitutes the total bee activity. A novel approach to assessing honey bee colony was investigated which assessed three phases of study involving determination of relationship between colony health and forager activity, determining correlation of the Doppler unit Root Mean Square (RMS) and forager activity and finally check if the Doppler unit RMS predicted the colony health as the total count of worker and brood population. The results revealed that a portable Doppler unit was a potential candidate in measuring bee colony health. Migratory beekeeping is a practice to increase honey yield. This technique involves three major stages as follows:(i)Relocation of colonies to regions with increased pollen content where the colony completes development and prepares for the honey season.(ii)The colonies are moved to regions with dense nectar flow to achieve highest honey yield per hive and the annual honey production is realized during this stage.(iii)The last stage involves relocation to regions with optimal climatic conditions to winter the colonies and meet their nutritional specifications. The process is decision intensive and hence the development of a web-based information system was undertaken [9]. The system provides reliable information to migrant beekeepers about the regions to be visited taking into consideration nectar flow and conditions of the climate in the regions. Evaluation of the factors was made through Fuzzy Cognitive Maps (FCM) and an Intelligent Decision Support System (IDSS) was developed. A total of 117 questions, prepared in accordance to 7-point Likert scale was answered by 175 people and the responses were later reduced to a single value by defuzzification method. The weight matrix includes the relationship between concepts in their reduced terms. Sigmoid threshold function was preferredowing to absolute values in the state vector. The weight matrix in the FCM needed training and the categorical data was digitized. The dependent and independent variables were prepared and a multiple linear regression model was developed. The IDSS developed provides user with information on amount of honey production with the current colonies in the region of choice, honey type, potential of honey yield at a region and other relevant features to be considered. The statistical analysis of cognitive map in the conceptual modelling stage of FCM showed 82.3% of beekeeping potential in accordance with multiple linear regression. A data storage architecture which isuseful to understand and measure the factors that cause mass destruction of colonies was introduced [10]. The model is a digital tool to help the beekeepers regularly check their colony health. The lambda architecture developed can absorb large amount of data at high rates such as videos, images, punctual data and time series data. The uniqueness of this architecture lies in its ability to normalize, share and trade data among many researchers. Weight measurements of the colony provideinsights on honey production and can be analyzed to determine suitable period for their collection. The study [11] proposes a business model using two instruments i.e., a fixed IoT scale which records rich continuous measurements (to be used as reference) and another nomad scale installed on other hives(used for communication with the smartphone). Monthly analysis results showed that negative slope was associated withthe extraction of honey or the decline in bee count during summer or spring whereas drop in bee count during winter or fall symbolized bee deaths. Positive slopes implied production of honey, formation of adult bees and occasional intervention by beekeeper. The system provides a comprehensive view of the farm and brief overview of each hive, saving time and assisting in decision-making. Beekeeper can fine tune the adaptation level of health treatments to strengthen colony constitution. A precise adjustment is required to avoid colony loss, minimize amount of artificial feeding and favor treatments acceptable under organic labels.

B. Monitoring Honey Production

Precision Apiculture System (PAS) is a platform to monitor and control various environmental parameters to assist in beekeeping. A PAS system has been designed considering wind, temperature and relative humidity inside and outside the hive to examine their influence on honey production [12]. The system consists of an Arduino board embedded with Atmel microcontroller along with Load cells for weight measurement, sensors for humidity and temperature measurements, and anemometer to measure wind-speed. During the monitoring period, a slight decrease of about 200gm in the honey production was noticed at night time. This could be reasoned out as favoring water evaporation from the nectar and pollen collected during the day time. The temperature also remained constant indicating absence of criticalities like swarming and absconding. The PAS was also successful in identifying the effect of reduction in honey production due to strong winds (exceeding 5mps) and lowering of external temperature. Hence the data recorded was concluded to be valid and the results were confirmed to be accurate, providing a rational decision support system to the operators. This makes it possible to predict certain processes like date of start of production, daily production based on climate, date of end of production, warning of swarming and other related factors. The effect of extended periods of drought and high temperature on honey production was monitored taking into account the weight of the hive [13]. The study was conducted during the flowering period of the year 2016 and 2017.The bee colonies were checked at beginning, middle and end of the flowering period while also considering factors like adult bee population, bee brood and pollen and honey reserves. This was implemented using a wireless communication system with a three-tier hierarchical model. The lowest level comprises of wireless nodes which monitor the bee hives and sends the data through IEEE protocol 802.15.4, industrial computer is placed at the intermediate level and internet data server at the upper level. The system includes a Waspmote module along with Atmega1281 microcontroller. In 2017, flowering was reduced in a span of three weeks as compared to 2016. At the same time weight gain was observed to be 7.67kg and 18.92kg respectively. The evolution of bee population and honey, pollen reserves were significantly affected by the severe climatic conditions. Pollen spectrum and characteristics of honey were also affected. The results of this study provide objective data about the influence of climatic changes on bee activities.

C. Prediction of Colony Damages

Study of temperature dynamics to predict swarming possibilities were investigated [14]. Ten colonies were monitored for four months using digital DS18S20 thermometers. The data was processed in Raspberry Pi and was transferred to a remote MySQL database. The difference in temperature patterns of swarming and non-swarming colonies was examined to observe if there are any visible differences between this factor and other internal or external factors. Upon testing this algorithm on historical data, the success rate was found to be 100% i.e., there was no false positive or false negative detection in the monitoring of 10 colonies. Another important observation was that the bees take approximately 8 to 20 minutes to warm up before their final flight with a temperature rise by 1.5°C to 3.4°C. The temperature eventually falls back to normal. Other approaches to predict swarming through auditory analysis and monitoring micro climatic heaving and changes in weight were deployed [15]. The circuit utilized Arduino Uno with ATmega328P and NodeMCU with ESP8266 Wi-Fi module, BMP180 to measure temperature, DHT11 for humidity and Load cell for hive weight were employed. The detection of swarming through the acoustic analysis was accomplished using 256FHT algorithm (Fast Hartley Transform). The beekeeper can access information about brood temperature, humidity, ambient temperature and hive weight from the cloud, thus reducing the need for human intervention. Increase in hive temperature and humidity was also noticed during swarming. As soon as swarming is predicted, the beekeeper is alerted through cloud services. A phenomenon that causes tremendous damage to the bee swarm is hive robbery. This event can be forecasted from the analysis of audio and video recordings [16]. A Raspberry Pi based system called Beemon was designed and developed to monitor the beehive. The entering and leaving of bees were monitored by placing the system in front of the hive with a camera facing downward. A microphone, humidity and temperature sensors were placed within the hive. The in-hive traffic estimation was done using Beevee application which used object tracking, change detection along with implementation of simple neural network to keep track of the number of bees entering and leaving the hive. Two different applications were used for audio analysis. The performance of Beevee application was appreciable for low to medium traffic levels but failed at high levels. This application determines the direction of bee movement by tracking the bees in consecutive image frames of a video fragment. A sudden rise in the graph of bee count and audio data was observed on the day the hive was massively robbed. Analyzing audio and video data can provide early insights on possible hive robberies therefore providing sufficient time to strengthen the hive.

D. *Bee Hive Management*

The effect of Radio Frequency- Electromagnetic Radiation (RF-EMR) from the Wi-Fi modules was studied [17] with the objective to develop an online WSN to monitor in-hive parameters alongside a wired version of the same to test their aim. About 6 beehives divided into two groups of three each were monitored. First set of hives was exposed to 2.4GHz Wi-Fi signal while the second was placed outside the RF range. During the period of exposure, the internal temperature was found to rise by 0.09°C and the humidity increased by 1.53%, sound amplitude increased by 0.03dB however a reduction in frequency by 2.57Hz was observed. The control colonies were seen to experience sudden variations in both amplitude and frequencies during the night hours, this has been attributed to the possibility of predator attacks or any other animal that consumes honey. However, no surveillance was done to prove the previous point. This study indicated that higher levels of RF-EMR above 2.4GHz for about 72 hours did not cause much variation in the in-hive parameters compared to the second group that was exempted from RF exposure. However, they further added that it is not possible to conclude that longer period of exposures would also produce similar results at the physiological levels. The authors developed a fuzzy logic-based tool [18] that was devised to automatically control temperature within the hive and also monitor humidity and weight parameters as extremities in this would cause changes in the pattern and quantity of honey yield. The Arduino microcontroller read the sensor data, which was then displayed on the LCD screen and simultaneously sent to the database over internet. The thingSpeak application's main page presents a display of the sensor readings which are sent to the Android application over the internet. Two components were used in the temperature maintenance, that was a fan and a heating element. The need to control the two components arises from the fact that their overwork could damage the hive itself. The idea of fuzzy logic is used to map the vulnerable temperatures with the temperature of the released heat and fan speed. The optimal temperature is found to be 32°C to 33°C.Once the temperature exceeded 35°C, fans started off to cool down the hive and when the temperature was below 30°C, fans along with heater were switched on to make the hive warm. The test results showed that the system steered the temperature from 31°C to 32.1°C in about 1 minute and 15 seconds while the steer in temperature from 34.4°C to 32.9°C was successful in 1 minute and 5 seconds. The identification of queen-less states in a bee colony was undertaken [19]. Five colonies were examined using a system comprising of Raspberry Pi 2 and omnidirectional microphones. The sound patterns of queen-less and queen-right colonies were compared. Mel Frequency Cepstral Coefficients (MFCC), a widespread technique on feature extraction on speech recognition was utilized for bee sound characterization. A multiclass classification model with three possible outcome variables was developed. A Lasso logistic regression model coupled to one versus all strategy was used for feature selection and regularization. To obtain visual confirmation and inspection of results, the data was analyzed by scatter plots of Singular Value Decomposition (SVD). The model can achieve high classification rate, i.e., 95% of correct classification, when reduced set of features are considered.

TABLE I. COMPARISON OF COMPONENTS USED IN VARIUOS SYSTEMS

Sl. No	*Particulars*	*Components*
1.	A. Zacepins, A. Kviesis, E. Stalidzans, M. Liepniece and J. Meitalovs(2016)	Raspberry Pi, DS18S20 temperature sensor, MySQL database
2.	Flores, José & Gil-Lebrero, Sergio & Gamiz, Victoria & Rodriguez, M.Inma & Ortiz, Manuel & Quiles Latorre, Francisco (2018)	Atmega1281 microcontroller, Waspmote module,150kg Load cell, Wbee monitoring system
3.	N. Anand, V. B. Raj, M. S. Ullas and A. Srivastava (2018)	Arduino Uno with Atmega 328P, NodeMCU with ESP8266 Wi-fi module, BMP180 Temperature sensors, DHT11 humidity sensor
4.	I. Z. Ochoa, S. Gutierrez and F. Rodríguez (2019)	Ubidots platform, DS18B20 temperature sensor, DHT11 humidity sensor, HX711 Load Cell transmitter, ESP 8266 Wi-fi Module
5.	A. Zabasta, A. Zhiravetska, N. Kunicina and K. Kondratjevs (2019)	LTE router with I/O, GNSS, RS232/RS485, Cameras
6.	Andrzej Szczurek, Monika Maciejewska, Beata Bąk, Jerzy Wilde, Maciej Siuda (2019)	Gas sensors- TGS832, TGS2602, TGS823, TGS826, TGS2603, TGS2600
7.	Henry, Evan & Adamchuk, Viacheslav &	2.4GHz Wi-fi module, AM2303 temperature-cum-humidity sensor,

Sl. No	Particulars	Components
	Stanhope, Trevor & Buddle, Christopher & Rindlaub, Nathaniel (2019)	acoustic sensors, PLMC15 omnidirectional microphone, Raspberry Pi 2B microcomputer.
8.	N. H. Khairul Anuar, Mohd Amri Md Yunus, Muhammad Ariff Baharuddin, Shafishuhaza Sahlan, Azwad Abid, Muhammad Muhaimin Ramli, Muhammad Razzi Abu Amin, and Zul Fazzre Mohd Lotpi. (2019)	Raspberry Pi 2, omnidirectional microphone
9.	A.E. Souza Cunha, J. Rose, J. Prior, H.M. Aumann, N.W. Emanetoglu, F.A. Drummond (2020)	HB-100 Doppler Sensor,32-bit ATSAMD21G18®, a RFM69HCW® radio link, LUPO® 4 Digit Hand-Held Digital Tally Counter 9999,
10.	Catania, P.; Vallone, M (2020)	Arduino with Atmel microcontroller (Atmega2560), AM2302 temperature-cum-humidity sensor, PSD-S1 metal Load cell, HC05 Bluetooth module and anemometer
11.	R. Tashakkori, G. B. Buchanan and L. M. Craig (2020)	Raspberry pi-based system including temperature and humidity sensors, Beemon system, Beevee application
12.	V. A. Wardhany, A. Hidayat, Subono and M. Jhoswanda(2020)	Arduino UNO microcontroller, LCD display, DHT22 temperature and humidity sensor, HX711 Load cell, solar cell, DC fan and electrical heating element.
13.	A. Albayrak, F. Duran and R. Bayır(2021)	Fuzzy Cognitive mapping, Intelligent Decision Support System.

IV. Discusson

Continued research on the application of wireless sensor networks in the field of apiculture has led to the advancement of bee monitoring and development of PAS causing a shift from conventional methods to IoT based approach. The use of various sensor-based methodology with respect to the components used has been compared in Table1. This has provided key insights into the bee behavior and associated activities, assisting bee keepers in taking calculated decisions. Yet, there are many unexplored phenomena, which could potentially affect the apiculturists. The natural thermal regulation, to maintain an optimum in-hive temperature between 32°C and 35°C, depends largely on the presence of healthy bees in the colony. However, the existing thermal control systems tend to regulate the temperatures purely based on the sensed in-hive temperatures, leading to loss of information on the health status of the bees. Although a narrow temperature range of 34 ± 1.5°C is preferred in the operculated stage, studies have shown that learning capacities and short-term memory and their ability to perform the communication dance were boosted in the worker bees that were raised at 36°C. Systems to perform selective temperature regulation need to be developed to help take advantage of these phenomenon. Health status based on temperature and other measurable parameters can be said to be biased as it does not take into account other factors like stressors, queens' condition and brood state. Research conducted into the understanding of queen's body mass and other distinctive properties have often resulted in opposing conclusions. Absence of queen bee leads to a drastic increase in the drone bee population, causing depletion of food reserves. This demands the development of a system to detect the absence of queen. Communication among bees essentially comprises of low frequency signal transmissions. Analysis of sound patterns of bees has shown that colonies with similar patterns tend to group. Since, the vibrational patterns are complex and diffusive within the hive, information on acoustic communication in bees is limited. Attempts have been made to increase the productivity of bees by identifying and artificially isolating active forager bees which in turn resulted in in-hive workers to forage. The use of wireless sensor networks has a few drawbacks with respect to installation, maintenance and accuracy. The positioning of sensors in the hive is yet to be standardized. The maintenance of the invasive wiring is also impractical to the commercial beekeepers, and also high priced for the local beekeepers. The sensors' efficiency tends to reduce owing to the deposits of pollen and nectar. This requires the hive to be opened for cleaning at least once in every two weeks which can be dealt by making a separate compartment built into the hive with a small opening provided near the sensing region for the respective sensors. The usability of the various sensors has been actively implemented by a significant number of researchers; however, the technology has not reached the non- commercial bee keepers in a higher percentage. One's first inclination would be to argue that the reason could be the use of multiple sensors individually with elaborate wiring which makes the implementation cumbersome. A possible solution would be an integrated Printed Circuit Board (PCB) which implements all the necessary sensors onto one chip such that all the data are collected from a single point source. These problems further justify the need for efficient system with improved technologies and further research on the use of WSN in the field of apiculture.

V. Conclusion

The study of WSN for application in apiculture has led to improved surveillance and measurement of colony health, honey production, prediction of swarming and many other events. Thus, the need for an integrated system which collects all the necessary data is becoming increasingly significant. Implementation of these systems on a larger scale would provide researchers and apiculturists with huge amounts of accurate data varying across the different phenomenon which can possibly occur in a colony. This would help develop systems to produce early predictions of *V. destructor*, identification of queen-less states, night swarming and other occasional yet impactful phenomenon.

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