FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 19, Nº 1, 2022, pp. 49 - 61
https://doi.org/10.22190/FUWLEP2201049P

Original Scientific Paper

IMPACT OF THE PRECISION BEEKEEPING ON THE LIVING ENVIRONMENT

UDC 638.1:502/504

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Abstract. *Bees are insects of great importance to humanity and the living environment. Bees are the main pollinators and plants are dependent on them. Consequently, global food production is dependent on bees and their work. In order to have a healthy living environment, it is of great importance for humans to help bees to be as healthy and productive as possible. The relationship between humans and bees is more than 9000 years old, but beekeeping principles and tools invented more than 200 years ago are still in use. The new principle that taking momentum in the beekeeping industry is Precision Beekeeping (PB). This is an apiary management strategy based on the monitoring of individual honeybee colonies to minimize resource consumption, maximize the productivity of bees and improve the quality of the living environment. In this research, we analyze the state-of-the-art systems for Precision Beekeeping. We make a comparative analysis of commercial solutions for precision beekeeping, with the goal to understand and determine the impact of device features on honeybees and the living environment.*

Key words: *Precision Beekeeping, Living Environment, Bees, Sensors*

1. INTRODUCTION

Bees represent insects that have great importance to humanity and the living environment [1]. Honey bees are one of the main vectors of pollination, they transfer pollen between flowers to fertilize them. This type of pollination applies to both spontaneous and cultivated species [2]. Agricultural production that depends on animal pollination quadrupled in the past 50 years [3].

Received February 11, 2022 / Accepted April 29, 2022
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More than 9000 years ago the relationship between humans and bees is established. Daring individuals would climb steep rock faces to steal honey from the nests of cliff-dwelling bees like *Apis dorsata* [4]. Since then, countless cultures have developed more mutualistic relationships with honey bees, offering shelter in constructed hives in exchange for a share of the sweet honey. However, the bee has been domesticated since 2400 BC [5]. Since then, humans have taken advantage of them, so their importance goes beyond ecology, being also economic.

The principles of contemporary beekeeping were set 200 years ago and are still applied. They require a physical presence in the apiary and manual inspection of each bee colony. The inspection process requires the beehive opening and visual inspection of the honeycombs for each of the frames. The hive can be inspected only during the day when there is no rain and the temperature is between 15°C and 38°C. On average, one beekeeper can inspect 10 hives a day, and inspection of a professional apiary with 150+ hives is time-consuming. Each hive is inspected on average 15 times a year, and in the meantime, the beekeeper does not have any insight into the condition of the bee colony, making it impossible to take timely actions. Based on his observations during inspection, the beekeeper has to make decisions on the spot and take further actions. This requires a lot of knowledge and experience for proper work and optimal actions. Colony inspection and timely taken actions are crucial for the proper development of a bee colony.

The principle that taking momentum in the beekeeping industry is Precision Beekeeping (PB), a sub-branch of Precision Agriculture. It is an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees [4].

In this research, we analyze state-of-the-art systems for Precision Beekeeping. We make a comparative analysis of commercial solutions for precision beekeeping about the sensors type they use. With the goal to understand and determine the impact of device features on bees and the living environment.

2. Bees Living Environment

Researchers believe that the original habitats of the honeybee are tropical climates and heavily forested areas. Honey bees can thrive in natural or domesticated environments, though they prefer to live in gardens, woodlands, orchards, meadows, and other areas where flowering plants are abundant. Within their natural habitat, honey bees build nests inside tree cavities and under the edges of objects to hide from predators [7].

Depictions of humans collecting honey from wild bees date to 10,000 years ago [8], and proof can be found on a cave painting near Valencia, Spain (Figure 1-a). The first documented record of the domestication of bees is shown in Egyptian art from around 4,500 years ago (Figure 1-b) [5].

Traces of beeswax are found in potsherds throughout the Middle East beginning about 7000 BCE [9]. Honey bees were kept in Egypt from antiquity. On the walls of the sun temple of Nyuserre Ini from the Fifth Dynasty (2422 BCE), workers are depicted blowing smoke into hives as they are removing honeycombs. Inscriptions detailing the production of honey are found on the tomb of Pabasa from the Twenty-sixth Dynasty (650 BCE), depicting pouring honey in jars and cylindrical hives. Sealed pots of honey were found in the grave goods of pharaohs such as Tutankhamun [10]. The first mobile beekeeping started in 3000 BCE in ancient Egypt. Beekeepers increased their honey production by carrying their bees on the Nile River between the upper and lower corn [11].

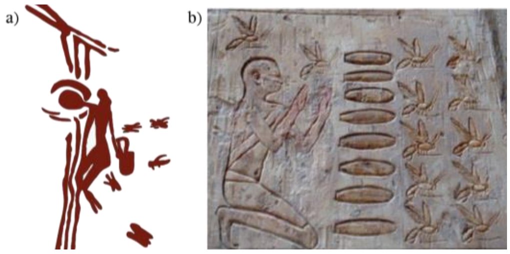

Fig. 1 The first mentions of bees [8]: a) Cave painting, Valencia, Spain and b) Egyptian art

The real beekeeping activity started when people took a part of the honey and left the honey they needed without destroying the bee colonies in the tree holes. In time, when the amount of honey produced by bees in natural tree hollows started to be insufficient, artificial bee nests were created. Humans began to maintain colonies of wild bees in artificial hives made from hollow logs, wooden boxes, pottery vessels, and woven straw baskets or "skeps".

Beekeeping has been primitive for a very long time. Until the 16th century, there was no major development in beekeeping knowledge, and beekeeping continued as a traditional pursuit passed down from generation to generation. Along with the developments in science and technology in the 16th century, important developments started to occur in beekeeping knowledge [11]. Despite all these observations and developments, there has been no development in beekeeping technology until the 16th century. All the beekeeping work done up to that time is to catch the colony in early spring and place it in a hive (Figure 2), to kill honey bees in some hives towards summer, to harvest honey and beeswax, to protect the remaining colonies, to feed them in the autumn and to spend the winter [12].

Fig. 2 Beekeeping before the invention of movable hives [12]

It was not until the 18th century that European understanding of the colonies and biology of bees allowed the construction of the movable comb hive so that honey could be harvested without destroying the entire colony. The 19th century saw this revolution in beekeeping practice completed through the perfection of the movable comb hive by

Lorenzo Lorraine Langstroth. He was the first person to make practical use of Huber's earlier discovery that there was a specific spatial measurement between the wax combs, later called the bee space, which bees do not block with wax, but keep as a free passage. Langstroth designed a series of wooden frames within a rectangular hive box, carefully maintaining the correct space between successive frames, and found that the bees would build parallel honeycombs in the box without bonding them to each other or to the hive walls. This enables the beekeeper to slide any frame out of the hive for inspection, without harming the bees or the comb, protecting the eggs, larvae and pupae contained within the cells. It also meant that combs containing honey could be gently removed and the honey extracted without destroying the comb. The emptied honey combs could then be returned to the bees intact for refilling [13]. With small modifications beehives and beekeeping principles invented more than 200 years ago are still in use (Figure 3).

Fig. 3 Contemporary apiary [patch.com]

3. Precision Beekeeping

Precision Beekeeping is a branch of precision agriculture, first mentioned in 2012 by Zacepins et al. [14] and described as “an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees”. PB tries to tackle challenges using bee data gathered over time and throughout two main biological levels: apiary-level and colony-level [15]:

- The apiary level consists of several beehives consisting of one colony, each. The colonies share the same perimeter within a geographical location.
- The colony level focuses on a single beehive. More precisely, on the colony’s organization, bees’ life, and behaviors.

One of the main objectives of PB is to implement real-time and online tools for continuous monitoring of bee colonies during their life and production stage using automatic, and information technology-based solutions, without exposing the bees to avoidable stress and waste of resources [16].

Implementation of precision beekeeping also can be split into three phases: data collection, data analysis, and application. During the data collection phase, measurements from bee colonies and the environment are collected. The data analysis phase draws conclusions regarding bee colony behavior and activity based on measurement data, predefined models, and expert knowledge. In the application phase, decisions are made and actions are undertaken based on data analysis for improving apiary performance.

Based on the sensors used for data collection PB has been grouped into five main types: weight; temperature and humidity; sound and vibration; bees' traffic counting and frame content awareness.

3.1. Weight

Placing a honeybee hive on a scale to weigh it disturbs the hive very little—and if the hive is kept on the scale, then weighing it does not disturb the bees at all. Occasional weighing (weekly or even daily) is usually done to determine when to harvest honey or to estimate hive food reserves [17], [18]. Continuous weighing with a sufficiently precise scale can provide that information as well as data on shorter-term changes in the hive. Weight data is easy to define and analyze: a colony has a single weight value at a given point in time, and scales are widely available and easily installed. Most load cells control for temperature variability, at least over a given range of values, but some weather factors, such as precipitation and wind can affect the data [19].

Most commercially available solutions measure the weight of the hive. One such device is the "SMS Scale" (Figure 4) produced by the company Optical from Krusevac, Serbia.

Fig. 4 Hive scale [smsvaga.com]

Another approach uses weight measurement of each frame individually providing a more detailed insight than measurement of the hive. An example of such a device is the "Smart BEE Frame" (Figure 5) produced by Habeetat, a company from Sarajevo, Bosnia and Herzegovina.

Fig. 5 Frames scale [habeetat.io]

3.2. Temperature and humidity

Like weight data, temperature and humidity measurements provide single values per sensor at a given point in time, but unlike weight data, there is a range of values within a beehive, depending on the number and placement of the sensors. The position within the hive of a given temperature or gas sensor will determine to what extent it is affected by exterior ambient conditions, and differences among various points within a hive can be large [19].

Temperature sensors, for example, within the brood cluster, usually the warmest part of the hive [20], will be affected less by exterior conditions while those nearer the exterior of the hive can be expected to be affected more. Sensors at fixed points may change over time with respect to their distance to the brood cluster as bees move and change the size of the cluster during the year and reduce or eliminate them in the winter [21] when gradients in temperature, for example, between exterior and interior, and top and bottom, are extreme. Arrays of sensors embedded on the surface of hive frames would solve this problem but may be expensive to implement [19].

Most of the commercially available solutions that measure temperature and humidity are small in size (Figure 6). Two examples are presented: “BuzzBox” produced by company osBeehives from the United States of America (Figure 6-a) and “ApisProtect” from Ireland (Figure 6-b).

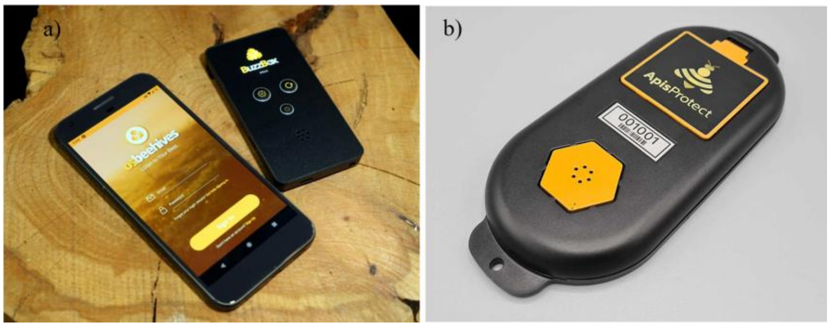

Fig. 6 Temperature and humidity sensors: a) BuzzBox [osbeehives.com] and b) ApisProtect [apisprotect.com]

3.3. Sound and vibration

Vibration and sound are physically linked phenomena measured at a point in space over time, either on the surface of the hive or within the hive volume. Vibration and sound data contain rich spectra of overlapping waveforms and require processing to distill biologically meaningful information. The vibration of the hive substrate is an important form of communication among bees [22].

Sound data is as rich as vibration data, but bee-produced sounds are somewhat better understood. Most beekeepers listen to their hives, and the meaning of some sounds is well known [23]. Rangel and Seeley [24] took advantage of this by embedding a microphone in each of five small (three-frame) observation hives and, over the course of about a month, used the microphones to detect a particular kind of sound, “piping”. When piping was detected at a certain threshold rate, in this case at least three signals in 30 s, they switched on video equipment to capture images that were later analyzed for bee movement. Long-term sound monitoring of entire hives has seldom been reported, probably because the resulting amount of data tends to be very large and unwieldy. Ferrari et al. [25] monitored sound, temperature, and relative humidity for 270 hours using within-hive sensors and observed 9 swarming events among three colonies; they observed increases in sound intensity and drops in temperature and humidity during the swarming.

Commercially available solutions that use sound for the detection of problems inside beehives are small in size and commonly placed on one of the frames. An example of such a device is “Beebot”, produced by the company Pollenity from Bulgaria (Figure 7).

Fig. 7 Beebot – sound monitoring [pollenity.com]

3.4. Bees traffic counting

Bees' traffic is described in terms of the number of bees entering and/or exiting the hive over a given time period, and so data can be collected, if need be, without the use of equipment more sophisticated than an observer and a stopwatch [19]. Traffic will thus be affected by food availability, food demand, and colony age structure [17], and sudden changes in that traffic may indicate acute changes on the colony level. Bees’ traffic can be an important variable to monitor when evaluating the impact of pesticides on honeybee colony health [26].

Commercially available solutions that count bees’ traffic are mounted outside of the hive, at the entrance. They usually use IR light to detect bees that leaving or entering the hive. An example of such a device is jointly developed by BeeHero from Israel and The World Bee Project from the United Kingdom (Figure 8).

Fig. 8 Bee counting device [beehero.io]

3.5 .Frame content awareness.

Traditional (manual) bee colonies inspection assumes visual inspection of each frame. Based on frame content that beekeepers see during inspection decision is made. Frame content awareness precision beekeeping systems provide the same visual information to the beekeeper, but in digital format, removing the need for a manual hive inspection.

Israeli company Beewise is creating container-type beehives (Figure 9) with 24 colonies inside. Their container is equipped with a mechanized system that can take each frame out of an individual colony and take a photo of it.

Fig. 9 Beewise system [beewise.ag]

Another approach for frame content awareness precision beekeeping is Beehold system, developed by a company from Nis, Serbia. Their system (Figure 10) is created for the individual colony and can be integrated into the standard Dadant Blatt or Langstroth beehives. They use sensors placed inside each frame that is able to determine the content of each honeycomb on the frames. Knowing the content, they can create a digital image of each frame and present it to the beekeeper using a mobile application.

Fig. 10 Beehold system [beehold.rs]

4. COMPARATIVE ANALYSIS OF AVAILABLE SOLUTIONS

To compare available commercial solutions for precision beekeeping we have performed an internet search using the following key words: precision beekeeping device; precision beekeeping system; precision apiculture device; precision apiculture system; smart hive, smart beehive, and digital hive. A comparison of commercial precision beekeeping devices (Table 1) is based on the sensors used for data collection: weight; temperature and humidity; sound and vibration; bees' traffic counting and frame content awareness.

Table 1 Available solutions for precision apiculture

No	Name	Country	Type				
			Weight	Temp. & humidity	Sound & vibration	Traffic counting	Content awaren.
1	Beehold	Serbia	+	+	+		+
2	Beewise	Israel		+	+		+
3	SMS Scale	Serbia	+	+			
4	Habeetat	B&H	+	+			
5	BuzzBox	USA		+	+		
6	ApisProtect	Ireland		+	+		
7	Beebot	Bulgaria		+	+		
8	uHive	Bulgaria	+	+	+		
9	hiveBase	Bulgaria	+				
10	Beep	Nederland	+	+	+		
11	SmartBee	UAE	+	+	+		
12	BeeAndMe	Austria	+	+	+		
13	Solutionbee	USA	+	+	+		
14	BeeHero	Israel		+	+		
15	Bee hive monitoring	Slovakia	+	+	+	+	
16	IoBee	France	+	+			
17	Arnia	UK	+	+			
18	gobuzzr	India	+	+			
19	BeeMate	Australia	+	+		+	
20	i-bee system	Ukraine	+	+	+		
21	libelium	Spain		+			
22	Intelligent Hives	Poland	+	+			
23	Beesage	Latvia	+	+	+		
24	Hive mind	Australia	+	+			
25	Hyper Hyve	USA		+	+		
26	Aranet	Latvia		+			
27	miBeez	Grece	+	+			
28	ToBe	Israel				+	
Total			19	26	15	3	2

5. Results and Discussion

Comparative analysis shows 28 commercial solutions (Table 1) for precision beekeeping from 18 countries (Figure 11).

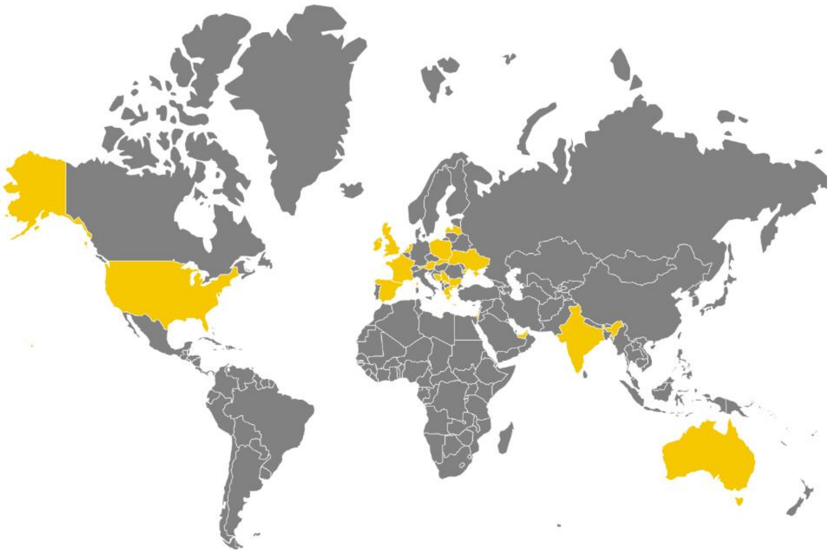

Fig. 11 Precision beekeeping solutions by country of origin

Research of available devices for precision beekeeping shows that 64.3% of them are developed in Europe, 10.7% in North America, 7.1% in Australia, and 17.9% in Asia (Figure 12).

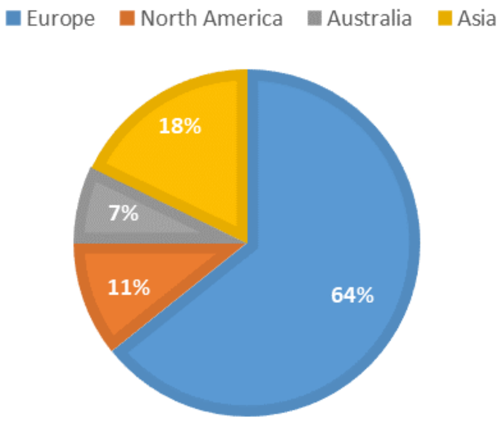

Fig. 11 Precision beekeeping solutions per continent

The majority of available commercial devices for precision beekeeping have a mixture of sensor groups used for data collection with an additional system for data analytics. Comparative analyses show that the dominant sensors used for data collection (Figure 12) are temperature and humidity (92.86%), followed by weight (67.86%), sound and vibration (53.57), bees' traffic counting (10.71%), and frame content awareness (7.14%).

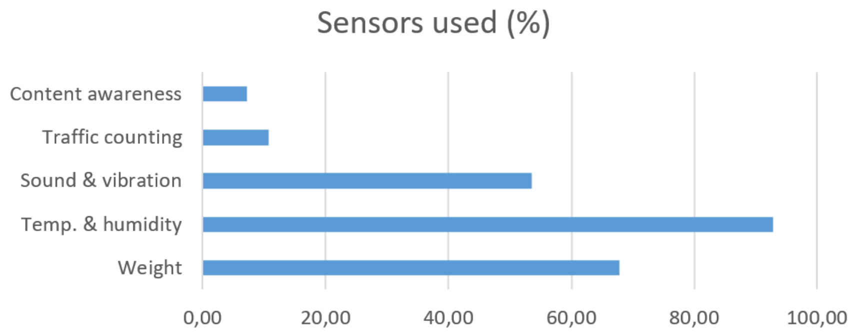

Fig. 12 Sensors used in devices

The reason for this distribution is the availability of sensors and the complexity of their assembly in a functional device. Temperature and humidity sensors are the easiest to find and assemble. Weight sensors are equally available, but harder to assemble inside the final device. Sound and vibration sensors are also available, but data collected that way require a lot of post-processing, mostly using Artificial Intelligence. Bees' traffic counting devices are created using special sensors or cameras with the support of Artificial Intelligence, making them more complex to create the first three sensors group. The last group of sensors for frame content awareness has only two representatives. One is Beewise which uses cameras and very complex robotized mechanisms making the process very expensive. Another is Beehold which uses small specialized sensors inside each frame that detect the content of each honeycomb.

6. Conclusions

Honey bees are insects of great importance to humanity and the living environment. Bees are the main pollinators and plant fertilization is dependent on them. Consequently, global food production is dependent on bees and their work. In order to have a healthy living environment, it is of great importance for humans to help bees to be as healthy and productive as possible. The relationship between humans and bees is very old and the principles of contemporary beekeeping set 200 years ago are still applied. Following technology development, humans started applying IT devices in beekeeping, which resulted in new precision beekeeping principles. Presented working principles and devices for precision beekeeping help maintain bees and allow early warnings for potential problems. At the same time, they allow non-invasive insight into the colony status without disturbing bees and their work. Comparative analyses show that the complexity of used sensors directly correlates to commercial device availability. Most available devices use sensors for indirect measurements like temperature and humidity, weight and sound. A small number of devices use a more complex and advanced system for direct information collecting such as bees' traffic counting and frame content awareness. All analyzed commercial devices for precision beekeeping improve beekeeping compared to traditional, and they also make bees healthier and more productive, and ultimately improve plants in the surrounding environment. The most promising approach is frame content awareness that allows distance visual monitoring as in the case of manual colony inspection supports an easy transition for beekeepers and use of their experience and knowledge.

In the future, it will be beneficiary to conduct a field study using some of the commercially available devices for precision beekeeping in order to measure the impact on bees and, consequentially, the living environment.

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UTICAJ PRECIZNOG PČELARSTVA NA ŽIVOTNU SREDINU

Pčele su insekti od velikog značaja za čovečanstvo i životnu sredinu. Pčele su glavni oprašivači zbog čega su biljke zavisne od njih. Shodno tome, globalna proizvodnja hrane zavisi od pčela i njihovog rada. Da bismo imali zdravu životnu sredinu, od velike je važnosti da čovek pomogne pčelama da budu što zdravije i produktivnije. Odnos između ljudi i pčela je star više od 9000 godina, ali su principi pčelarstva i alati izmišljeni pre više od 200 godina i dalje u upotrebi. Novi princip koji uzima zamah u pčelarskoj industriji je precizno pčelarstvo (PB). Ovo je strategija upravljanja pčelinjakom zasnovana na praćenju pojedinačnih pčelinjih društava kako bi se smanjila potrošnja resursa, maksimizirala produktivnost pčela i poboljšao kvalitet životne sredine. U ovom istraživanju analizirano je stanje savremenih sistema za precizno pčelarstvo. Izvršena je uporedna analiza komercijalnih rešenja za precizno pčelarstvo, sa ciljem da se razume i utvrdi uticaj karakteristika uređaja na pčele i životnu sredinu.

Ključne reči: *Precizno pčelarstvo, životna sredina, pčele, senzori*