myBee: An Information System for Precision Beekeeping

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Abstract: Over the last few years, beekeepers have become aware of the necessity of integrating Information Technology into Apiculture. As a result, Precision Beekeeping emerged, which is an area that applies the said technology to monitor bees and, consequently, the state of the colony. However, the development of these platforms is complex due to the requirement of them adapting to various heterogeneous environments and constantly-updated technologies. Thus, the objective of this paper is to propose and develop a Precision Beekeeping Information System, called `myBee`, whose infrastructure is flexible, secure, fault tolerant, and efficient in decision-making. A real case study shows that `myBee` is an efficient information system that supports beekeepers in maintaining their apiaries.

1 INTRODUCTION

A healthy ecosystem is indispensable for human life, animals and natural resources. Honey Bees are natural sensors of ecosystems and one of the most important insects. They possess the ability to pollinate (Magno et al., 2015; Murphy et al., 2015), consequently providing nutrients for humans and animals, as well as aiding in ecosystem health. Thus, it is indispensable to preserve them, as they play a major contribution to ecosystems, as well as to the global economy (Zacepins et al., 2016).

Recently, beekeepers have perceived the necessity of adopting Information Technologies (`IT`) into the agricultural field (Kviesis and Zacepins, 2016). This occurs not only for the important role of honey bees in crop production, but also due to the fact that bee population has been decreasing over the last few years (Kviesis et al., 2015; Murphy et al., 2015; Zacepins et al., 2016). Therefore, monitoring these insects has become a crucial activity (Magno et al., 2015; Zacepins et al., 2016).

In this context, Precision Beekeeping (`PB`) emerged, which is a subdivision of Precision Agriculture that applies `IT` in order to determine the state of the bee colony and improve its preservation (Zacepins et al., 2015).

Since bees are important worldwide (Murphy et al., 2015), several Information Systems (`IS`) have been developed (Zacepins et al., 2015; Kviesis et al., 2015) and applied to `PB`. However, it is worth mentioning that although different platforms have been implemented, `PB` is still in development stages (Zacepins et al., 2015; Magno et al., 2015; Kviesis and Zacepins, 2016; Zacepins et al., 2016). In addition, the majority of Precision Beekeeping Information Systems (`PBIS`), proposed in the literature, do not include the distinguishing characteristics of a well-developed `IS`.

A well-developed `IS` has the following characteristics:

- simplifies the development and maintenance process;
- provides reusability of modules and subsystems;
- has modules and subsystems that are plug-and-play;
- provides compatibility for different devices;
- provides compatibility for stationary and mobile systems;

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- provides security; as well as,
- provides quality of service.

The objective of this paper is to describe the well-developed Precision Beekeeping Information System (PBIS), called myBee, whose objective is to support beekeepers in maintaining their apiaries. A real case study shows that myBee is an efficient PBIS.

The rest of the paper is organized as follows. Section 2 presents related works in regards to Precision Beekeeping and Information Systems. Section 3 describes the PBIS, myBee. Section 4 presents myBee in a real-world environment. Finally, Section 5 discusses the conclusions and future works.

2 RELATED WORKS

The following related works are divided into two categories: Precision Beekeeping Systems and Information Systems.

2.1 Precision Beekeeping Systems

Armands Kviesis *et al.* (2015) proposed a PB system platform that utilized a *SHT15* sensor to measure temperature and humidity. A total of eight beehives were placed outdoors, each with measurement nodes in closed boxes and protected with waterproof material. All temperature and humidity data were stored in a SQL database, which can be visualized in a web application.

Gatis Riders *et al.* (2015) proposed a decision-support module to better-comprehend the collected data and, consequently, execute reliable actions. The sensor utilized in the experiment was *DS18S20*, which measures temperature. The sensors were connected to a Raspberry Pi and data was sent to a server and stored in a MySQL database. Two systems were developed, the first monitored ten honey bee colonies inside a wintering building, while the second monitored ten honey bee colonies outside. The data can be visualized in either a web or desktop application, providing the option to view the maximum, minimum, median and average temperatures, by day, for all installed sensors. Both systems have a decision-support and analysis module.

Marco Giammarini *et al.* (2015) developed a monitoring system to collect temperature and humidity data of two beehives in the summer. One beehive was placed in a wooden box, while the other in a plastic box. A GSM modem was implemented for sharing and downloading data; remote monitoring; and software debugging.

Fiona Edwards Murphy *et al.* (2015) implemented a system, utilizing a Wireless Sensor Network (WSN), to monitor a bee colony. The platform collected data such as temperature, carbon and nitrogen dioxide, humidity, pollutants and battery percentage of the device being utilized. The researchers applied WSN due to being a non-intrusive technology, thus, allowing more accurate data collection. The information can be accessed through a web interface or mobile device.

Michele Magno *et al.* (2015) implemented a prototype to collect images and audio within a beehive. The platform utilizes a Libelium Waspmote and Raspberry Pi in order to process and store the data. Additionally, microphones, accelerometers, thermal and infrared cameras were used, along with emergency notifications to the user in case an undesirable event occurs to the beehive. The goal was to utilize the said equipments to collect data in a discreet manner.

2.2 Information Systems

Wilson Goudalo *et al.* (2016) mention how, currently, Information Systems play a significant role for Enterprises. Thus, they proposed various methods to provide simple user interfaces for managing security. The authors applied seven principles of the ISO 9241-11 (ISO, 1998), which are: *clarity*, *discriminability*, *brevity*, *consistency*, *detectability*, *readibility* and *comprehensiveness*. All these principles, including security concerns, were all taken into consideration when implementing myBee.

Delfina Soares *et al.* (2014) defined *interoperability* as a characteristic in which entities preserve autonomy and independence. Thus, myBee's architecture and protocol can be categorized as *interoperable* due to exchanging information while being independent from one another. The authors also recalled the importance of a social-technical perspective for information systems, which we believe applies to myBee as well, due to offering data reports that influence user-decisions and system operations.

Hadi Kandjani *et al.* (2013) proposed a framework to classify system-planning methodologies. The authors stated that selecting a proper methodology to develop an information system is a *key* factor for its success. We believe the methodology utilized to implement myBee was a success due to the obtained observations. In addition, the authors mentioned that several methodologies for implementing and planning information systems are available, thus, myBee's architecture is flexible to be utilized in various fields, which simplifies and streamlines the development process.

Ovidiu Noran (2013) proposed enhancements, based on interoperability, to Disaster Management Information Systems, using an enterprise architecture perspective and artifacts. The author claimed that these types of systems are important due to allowing a collaboration for environmental incidents. This statement can also be applied to `myBee`, which provides crucial data for beekeepers and, therefore, collaborates and supports the environment. In addition, `myBee`'s architecture is based on interoperability, allowing communication and easy access between each component.

Jorge Aguiar *et al.* (2013) proposed an improvement for Decision Support Systems corresponding to Intensive Care Units based on TAM (Technology Acceptance Model). The architecture for an ICU information system can be divided into two subsystems: one to collect the data and another to process and display data. This statement can also be applied to `myBee`, which is divided into two flexible and efficient subsystems (stationary and mobile). As in (Aguiar et al., 2013), we proposed improvements to an information system, which will contribute on improving and supporting a specific area (Precision Beekeeping).

3 myBee

This paper proposes a `PBIS` called `myBee`, which is based on two approaches described by Kviesis & Zacepins (2015):

1. using an interface device for each beehive; and
2. sending data to a remote computational center.

Therefore, this platform will offer a more detailed analysis of the bee colonies, resulting in a better maintenance and preservation of Honey Bees.

A well-developed `IS` requires a flexible (Rabaey et al., 2006), scalable and efficient architecture. In fact, Zacepins & Stalidzans (2012) claim that infrastructures with sub-elements are needed for `PB`. Thus, `myBee`'s architecture was developed pursuing the following characteristics:

1. **Flexibility:** the `PBIS` has to be based on simplicity. As a result, `myBee` can be easily maintained and modified to better suit the beekeeper's needs.
2. **Fault Tolerant:** the `PBIS` has to efficiently handle potential errors. Thus, `myBee` was implemented with several precautionary measures including data redundancy.
3. **Security:** the `PBIS` has to provide security mechanisms to ensure that the data is not violated. Thus, `myBee` uses a secure protocol.
4. **Efficiency in Decision-making:** the `PBIS` has to simplify the maintenance of bee colonies. As a result, `myBee` provides several reports, estimates future conditions and warns about undesirable behaviours.

Figure 1 outlines `myBee`.

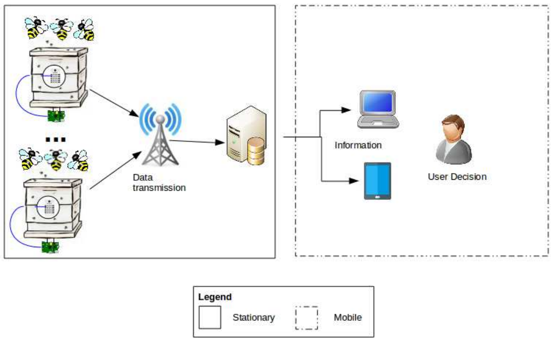


Figure 1: PB System Platform.

As indicated in Figure 1, `myBee` is divided into two subsystems:

1. the *Stationary System*; and
2. the *Mobile System*.

The *Stationary System* consists in collecting and storing the data. The *Mobile System* consists of the software to monitor the collected data. A brief description of `myBee` is as follows: *DHT22* sensors located at the center of the beehives monitor the conditions, collecting pieces of information, which are sent through a wireless network to a server. Therefore, using the *Mobile System* beekeepers can monitor, via a web interface on a computer or mobile device, the conditions of the bee colonies.

3.1 The Stationary System

The *Stationary System*, whose objective is to provide a well-defined and developed `IS`, is a three-layered architecture divided by a *middleware* component. The architecture was designed to provide flexibility and simplicity in accessing the layers. Thus, the *middleware* component is the most important and distinguishing characteristic of the proposed infrastructure. In addition, a *Management/MachineLearning* component permits the user to configure or modify the operations, protocols, storage and physical components. Furthermore, it estimates future conditions of the bee colony.

Figure 2 displays the layered-based infrastructure for the Stationary System platform.

It is worth mentioning that the Stationary System architecture can be utilized in a wide range of scenarios and is not limited to the `PB` branch. As stated

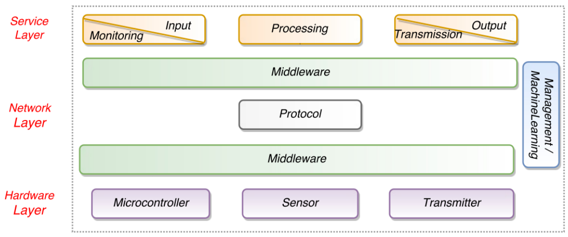


Figure 2: Stationary System Architecture.

before, this is due to the *middleware*, which provides scalability and flexibility.

3.1.1 The Layers

Service Layer. The Service Layer focuses on the three basic operations of an `IS`:

- **Monitoring/Input:** consists in *collecting* the data and then sending it to the *Processing* module.
- **Processing:** consists in manipulating the collected data. In addition, this module determines the type of output, whether it will be stored, sent to the base station/server, or both.
- **Transmission/Output:** consists in transmitting the information, using the protocol in the Network Layer, to the server.

Network Layer. The Network Layer offers functionalities such as protocol configuration, and enabling and disabling data transmission. `myBee` was designed to offer flexibility, scalability and compatibility. Thus, the user can add several protocols to the `PBIS`, which are handled by the *Management* module.

Hardware Layer. The Hardware Layer offers functionality to add, configure, enable and disable the physical components, which are also controlled by the *Management* module. The hardware devices consist of microcontrollers, sensors and transmitters.

3.1.2 The Implementation

In order to implement a software architecture that is flexible and simple to maintain, a class structure was designed and specialized to add specific functionalities (components). Thus, it is possible to modify the architecture to provide new functionality, such as using a different communication protocol, or even supporting a different device. Basically, the software architecture has the following classes:

- Monitor: provides the functionality to monitor a certain condition of the environment.
- Process: provides the functionality to process the monitored data.
- Transmit: provides the functionality to receive and transmit the data.
- Protocol: provides the functionality for communication between devices.
- Microcontroller: provides the functionality to manage a microcontroller.
- Sensor: provides the functionality to manage a sensor.
- Transmitter: provides the functionality to manage the transmitter/receiver.
- Middleware: provides the functionality for communication between the layers.
- Management: provides the necessary functionality to manage the entire architecture, as well as the computational intelligence.

In fact, the aforementioned classes are abstract, meaning they must be specialized to provide concrete functionality, with the exception of the Middleware and Management classes.

3.1.3 Some Details

`myBee` has a basic functionality with specialized abstract classes that compose the software architecture. This functionality allows `myBee` to: use low-cost devices and a database system manager; monitor the temperature and humidity of the beehives; organize monitoring-devices in a mesh network; provide reports and statistics; and anticipate future behaviour. Temperature and humidity sensors were chosen due to being the most appropriate way to monitor bee colonies (Zacepins and Meitalovs, 2014).

Hardware. Currently, the Stationary System supports a Raspberry Pi, *DHT22* sensor, and the microcontrollers *GPIO7* and *GPIO18*. This indicates that the said system uses low-cost hardware, which is able to: deactivate the sensor *DHT22* for a certain time; collect the temperature and humidity of the beehive; store data; and transmit/receive data.

Database. The Stationary System supports the database management system, `MySQL`. The data is stored on a database as shown in Figure 3.

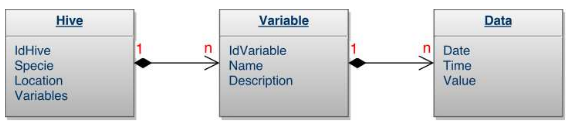


Figure 3: Database.

Protocol. The monitoring-devices that compose the Stationary System automatically organize themselves as a mesh network.

A mesh network differs from a traditional network because each node has the responsibility of serving as an access point. Thus, each node behaves as a router and, therefore, composes a single network which can be accessed from any point.

Since mesh networks have several access points, this allows for a simpler implementation and higher fault-tolerance. This is because the network adapts to movements, inclusion and even exclusion of nodes automatically - without the need to reconfigure them (Lent, 2008).

In a mesh network, the packet *jumps* from one node to another until it reaches its final destination. Thus, a node does not need to be visible - if it is within reach - for the data to be sent.

A technique to organize a mesh network is to utilize an *Interest Ad-hoc Network* (`Radnet`), which communicates through a protocol based on interests.

`Radnet` is a network model based on user interests and characteristics, and permits:

- a collaboration between the network nodes. The messages are delivered by *jumping* between the nodes;
- a routing based on user characteristics; and
- a message delivery approach to users who have the same interests.

`Radnet` belongs to the Publisher/Subscriber model, which is an asynchronous model that consists of a publisher node sending the messages to a certain interest and all the subscribers of that respective interest receiving them. Although some messages may not be delivered due to communication errors (Dutra, 2012).

The address of network devices and users is performed through the Active Prefix (Dutra et al., 2012), which is divided into two fields, namely: prefix; and interest.

The prefix, which represents user characteristics, is used as an Internet Protocol (`IP`) address. However, the difference is that the Prefix is linked to each application and not to the equipment. Unlike the `IP`, several users can have exactly the same prefix. The interest is a field that stores and represents an interest of the application.

The `Radnet` Protocol is responsible to forward the messages between the network devices (Dutra et al., 2010; Dutra and Amorim, 2010). A neighbor node can return a message that is being forwarded. Thus, the message can be received by a node that processed it. To avoid *reprocessing*, every message is inserted, at a certain time, into the hash table. Therefore, the table is consulted whenever a message is received.

The aforementioned protocol was developed for mobile and low-power applications. Its main features are: energy-saving; and sending packages indirectly to the receiver and through multiple nodes that have common interests. A mesh network adapts to node failures or removals. As a result, `Radnet` guarantees that the network will automatically configure itself if nodes are added or removed (Dutra et al., 2012).

It is worth highlighting that `Radnet` was developed with security in mind, attaining Active Prefix messages by either cryptographic signatures or passwords (Dutra et al., 2012). Based on these advantages, this protocol was chosen for our `PBIS`.

Computational Intelligence. `myBee` provides information about possible-future values of the monitored elements, which is performed by the Computational Intelligence. Basically, when the said functionality is triggered, the Stationary System activates artificial intelligence algorithms to estimate values of the monitored data, from the existing database. Whenever an inference is made, the data will be validated as soon as the system obtains it. If the inference is wrong, a warning is issued to the user.

Client/Server Side. The characteristics of the Stationary System architecture allow both clients and servers to be created. The former monitors the environment and sends the data to the server. The latter persists the data into a database and sends it to a remote computer or storage.

3.2 The Mobile System

The Mobile System has three objectives:

1. visualize the data monitored by the Stationary System;
2. provide data and statistics; and
3. provide notifications about undesirable behaviours.

The Mobile System architecture is composed of 2 layers: *Service* and *Management*. Figure 4 displays the layered-based architecture for the Mobile System platform.

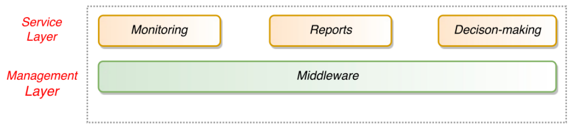


Figure 4: Mobile Architecture.

3.2.1 The Layers

Service Layer The Service Layer focuses on three aspects:

- **Monitoring:** consists in monitoring real-time data on a mobile device.
- **Reports:** provide information based on the collected data.
- **Decision-making:** permits user decisions based on reports.

Management Layer. The *management* layer is composed of a *middleware*, which connects the Mobile System and Stationary System.

3.2.2 The Implementation

The Mobile System consists of a Web interface to monitor the bee colonies. Figure 5 displays the Web System.

The Web System has the following functionality:

- displays the monitored data;
- generates graphs;
- provides reports;
- provides statistics;
- provides notifications; and
- provides future-behaviour statistics.

The system-visualization module graphically displays the collected data, allowing the user to select the time period. The report module provides detailed reports, including: description of each beehive, location, monitoring time and date. Both graphs and reports can be exported, with different extensions, and, thus, used separately.

The statistics module provides numeric values of the monitored data, which are: general mean, standard deviation, variance, minimum and maximum value. The first three can be viewed in reports, while the remaining two are displayed graphically.

The said functionality can be applied to each Stationary System individually. Thus, a single Mobile System is used to monitor all Stationary Systems installed on different beehives. It is worth mentioning that the Web System provides five data filters, which are applied when viewing the data, and they are:

- all data monitored thus far;
- data monitored between 12:00 AM and 6:00 AM (0h - 6h);
- data monitored between 6:00 AM and 12:00 PM (6h - 12h);
- data monitored between 12:00 PM and 6:00 PM (12h - 18h);
- data monitored between 6:00 PM and 12:00 AM (18h - 24h);

The notification module provides warnings to the user, indicating that the conditions of the bee colony are undesirable. Thus, the user can make appropriate decisions depending on the issued notifications.

Finally, the Web System provides the user with information estimated by the Computational Intelligence module that exists in the Stationary System.

4 CASE STUDY

Beekeeping is a sustainable activity that generates positive impacts on social, economic and environmental areas. This activity provides: income to beekeepers though the commercialization of their products; benefits to the environment through pollination, which favors the balance and maintenance of biodiversity (Camargo et al., 2002).

Controlling temperature and humidity is essential because biological processes can be modified and/or altered by high variations. Thus, it is important to implement technologies in order to maintain adequate beehive conditions.

Therefore, the objective of the case study is to monitor the internal temperature and humidity of the beehive corresponding to the *Apis Mellifera* species.

4.1 Experiment Area

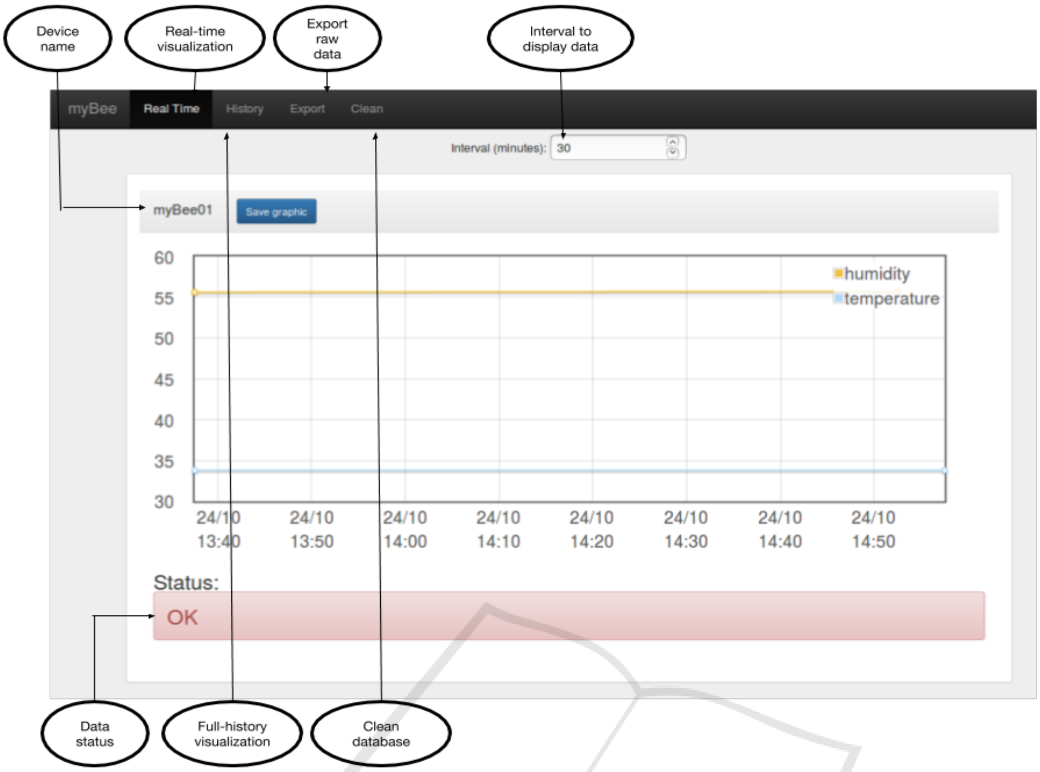
`myBee` is currently used in the *Experimental Farm of Iguatemi* (`EFI`), viewed in Figure 6. The `EFI` is located at a latitude of 23°25’ S; 51°57’ O, an altitude of 550 meters and area of 170 hectares. This location provides a suitable environment to develop projects on agriculture and animal husbandry.

The apiary is composed of 10 beehives, which are arranged in two types of boxes:

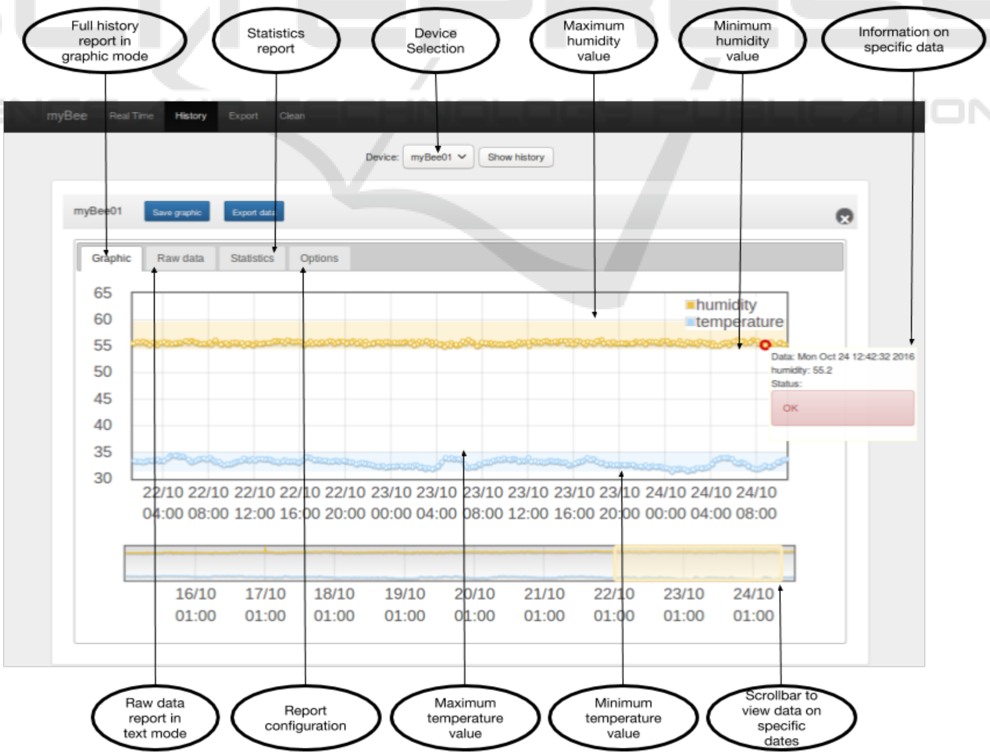
- Styrofoam and
- Wood.

Different materials are used in order to evaluate the conditions of the beehives, each with distinctive treatments.

The boxes were certified by the Forest Stewardship Council (FSC) and arranged in contrast to one another. These boxes were directly exposed to the weathering of the climate, reducing interference of



(a) Realtime



(b) History

Figure 5: The Web Interface.

Figure 6: Experimental Farm of Iguatemi, Source: Google Earth.

non-climatological factors in the experiment. The experiment area is surrounded by an eucalyptus plantation. The beehives were homogenized and standardized, being considered for: two combs, three with eggs and larvae, three with reserved food and two with alveolate wax (comple plaque), totalling 10 combs for each beehive. It was necessary to feed the bee colonies with water and sugar syrup in a 1:1 ratio during the standardization of the swarms (Camargo et al., 2002).

The placement of the Wooden and Styrofoam boxes can be visualized in Figure 7.

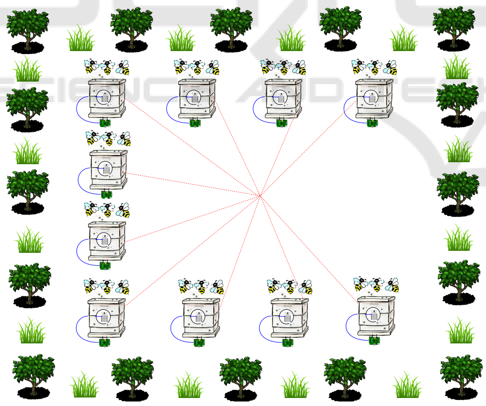


Figure 7: Apiary.

The red-dotted line represents data transmission. This means that each collected information is sent to every node, through `Radnet`, for backup purposes. In other words, this means that each Stationary System was implemented as a server. This data-redundancy guarantees that the data will be stored regardless of equipment failure.

4.2 Observations

This section presents data collected over a period of 10 days. The data was analyzed using the method of *Least Square* with the Statistical Analysis System. The adjusted averages were compared with Tukey's Test (P≤0.05).

Controlling the internal temperature is important for several reasons. Boyle-Makowski (1987), for example, stated that the colony's increased internal temperature has significant influence on bees and their forage throughout the day. It has been shown that, while worker bees can survive temperatures above 50°C (Coelho, 1991), temperatures above 36°C during an extended period of time can cause death or abnormal development of the *Apis mellifera* offspring (Winston, 1991).

The analysis of variance in Table 1 showed that there was a significant difference for each type of box, the materials and periods corresponding to both the temperature and relative humidity (P>0.05). There was a small contrast (P>0.05) between the relative humidity, whose average was 60% for the entire data-collection period.

Table 1: Average temperature and relative air humidity (*: significant (P<0.05); NS: not significant (P>0.05)).

Source of variation	**Degrees of Freedom**	**T°**	**UR**
Collections	1	0.45*	19.39^{NS}
Days (Collection)	10	0.08^{NS}	48.71*
Period	3	0.26*	176.98*
Material	1	0.29*	855.49*
Box (Material)	7	0.81*	615.77*
Residue	374	0.05	21.15
R^2	-	0.30	0.43
Coefficient of Variation (CV)	-	0.65	7.67

According to Southwick (1985) & Stabentheiner *et al.* (2003), endothermic heat production and site isolation allow bees to regulate the temperature of the breeding chamber within the range of 32-36uC.

The values described above corroborate with those obtained in Figure 8. Both materials did not interfere in the temperature homeostasis of the swarm, although a significant difference was acquired.

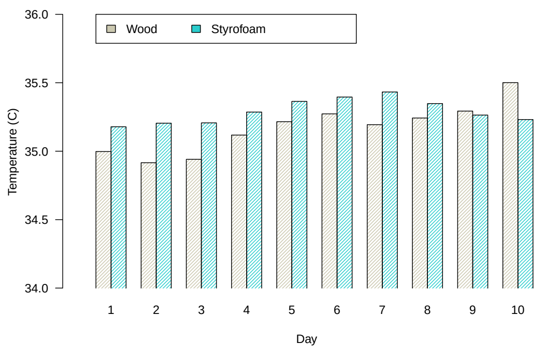


Figure 8: Temperature.

The humidity, as shown in Figure 9 was significant, obtaining a higher stability for swarms placed in a styrofoam box.

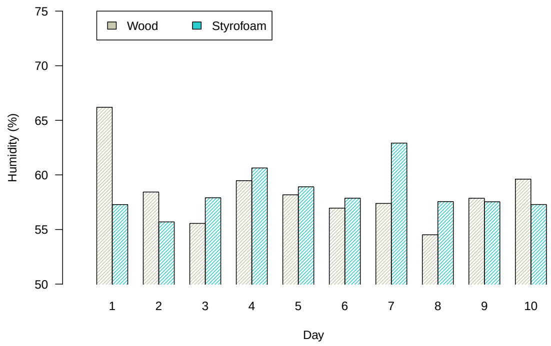


Figure 9: Humidity.

According to Seeley (2006), controlling the temperature of a beehive can be seen as one of the greatest innovations.

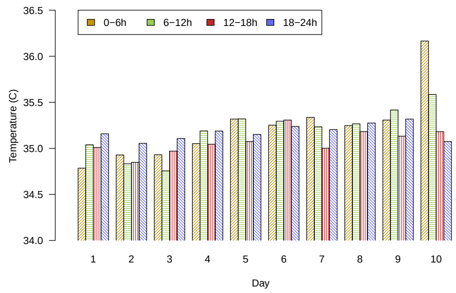
Honey bees, between the beginning of autumn and the end of winter (annual period of bee development), maintain the temperature in the middle of the beehive between 33 and 36°C, with an average of approximately 34, 5°C, and usually ranging at least than 1°C per day (Hess, 1926; Himmer, 1927).

The values obtained in the four periods of 6 hours/day, as shown in Figure 10 and 11, were within the values of homeostasis and showed that a higher temperature is expected during the night.

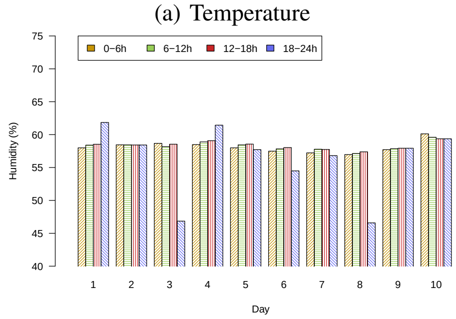
In terms of bees, thermoregulation is possible within certain limits. Body-warming occurs by absorbing heat from the environment. Thus, bees can raise their internal temperature above the ambient temperature. In addition, musculature contractions also contribute to heat-generation inside the body of the said insect. This thermoregulatory potential seems to emerge early in the worker bee's life, as they generate heat only after a few days of being born (Esch, 1976; Heinrich, 1975).

The analysis of variance showed that there was a significant different between the boxes, materials and periods for both air temperature and relative humidity (P>0.05).

There was a small contrast (P>0.05) between the relative humidity, whose average was 60% for the entire data-collection period.

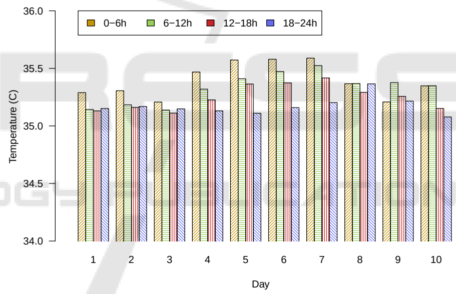


(a) Temperature

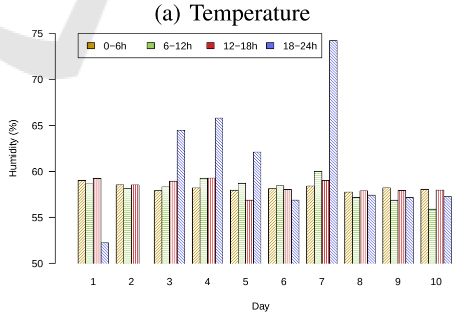


(b) Humidity

Figure 10: Wood.



(a) Temperature



(b) Humidity

Figure 11: Styrofoam.

4.3 Validation

An infrared camera-system was utilized to analyze the internal temperature of the beehive, as shown in Figure 12.

The use of such a strategy has two problems:

1. the use of infrared images is susceptible to a known error of 2%; and
2. the user plans to handle each beehive to identify its condition.

Comparing the data monitored by `myBee` with the

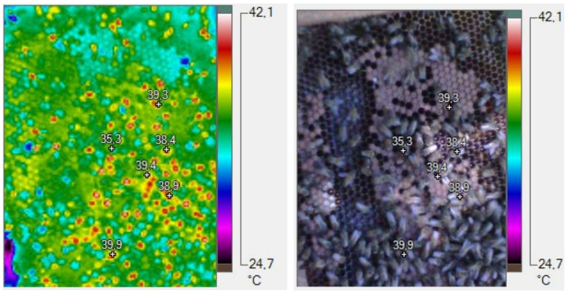


Figure 12: Infrared image of a part of the beehive.

data collected by the infrared camera, it is demonstrated that myBee has the following advantages:

- the data monitored by myBee are statistically the same as those obtained by the infrared camera;
- the collected data is not susceptible to an error percentage;
- there is no need to handle each beehive to identify its condition;
- there is no need to process the data to obtain reports and statistics;
- an unfavorable condition in the beehive is known in real time.

Using myBee in a real-world environment demonstrates its ability to monitor the conditions of the bee colony in order to perceive the alterations and to analyze the effects of environmental variables (temperature, humidity) on different boxes.

5 CONCLUSIONS

Currently, beekeeping provides an income of billions of dollars. Thus, efficiently maintaining bee colonies has become a goal for beekeepers. Temperature and humidity are among the environmental variables that affect the said area. Several techniques and technologies are used to capture, analyze and monitor bee colonies.

In order to monitor the said variables efficiently and in real-time, this paper describes myBee, which is a well-developed PBIS that supports beekeepers in maintaining their apiaries.

The evaluation of myBee in a real-world environment proves its efficiency in monitoring bee colonies, taking into consideration climatic alterations and the effects of different types of boxes.

A future challenge is to add sensors to the system in order to monitor and analyze sound and weight of the bee colony.

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