HONEY BEE COLONY MONITORING WITH IMPLEMENTED DECISION SUPPORT SYSTEM

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Abstract. In this article honey bee monitoring with implemented decision support system for wintering period is described. A 1-wire temperature sensor system for honey bee monitoring was developed, where data can be demonstrated on a developed computer application and on a Web page. To analyze and interpret the gathered data, a decision support system was implemented in the previously mentioned computer application. The decision support system analyzes data when requested by the user. The system consists of three defined rules, such as detection of significant temperature variations between different honey bee colonies in the same apiary, possibility of brood rearing detection, possibility of colony death detection. The analyzed data showed that in some colonies the average temperature was significantly different than the average temperature of all colonies, meaning that attention to these colonies needs to be paid. After those hives were inspected, it was concluded that the temperature difference was due to their movement closer to the sensor. The described system is developed within the ITAPIC (Application of Information Technologies in Precision Apiculture) project.

Keywords: Precision Beekeeping, honey bee monitoring, decision support system, 1-wire temperature sensors.

Introduction

Honey bee (*Apis mellifera* L.) monitoring has become very important. One of the reasons is that bees are in crisis situation caused by different diseases and a phenomenon called colony collapse disorder (CCD) [1]. Honey bee colony state detection is also essential [2]. Thus, there is a need for continuous bee colony monitoring in order to store data, which could then be used for further analysis, for finding correlations between the data and bee activities.

Without data analysis, sensor data (e. g., temperature) do not provide all the information that is needed. The raw data show temperature at a specific time, but it is not sufficient to get a fast and convenient insight about the temperature fluctuations. It is claimed [3], that currently beekeepers or persons associated with beekeeping analyse raw data, using software like Microsoft Excel or similar. Although, there are a number of studies that include individual honey bee colony data analyses including development of decision support algorithms or rules mentioned by [2], aiming to detect different states [4-8] of honey bee colony and several studies that include decision support systems (DSS) or expert systems (ES) in the field related to beekeeping. However, these systems were not used for individual honey bee colony data analysis.

As it is stated in literature [2], the DSS can be adapted to beekeeping for automatic analysis and different data, obtained from individual colonies and/or whole apiary, interpretation. By using different algorithms and rules, DSS application can reduce time needed for colony data analyses, provide beekeepers with, e.g., detected bee colony state, decision or warning about abnormal situation, resulting in beekeeper's apiary management improvement. Thus, DSS can be considered as a notable part in Precision Beekeeping (PB) [9].

In this study we propose a honey bee temperature monitoring system with DSS for wintering period that analyses/interprets temperature measurements and provides beekeepers with information about the possible honey bee colony state (death of colony, brood rearing and detection of significant temperature difference between colonies) on the beekeeper's request.

The aim of this paper is to describe the developed system for honey bee monitoring with implemented decision support for different colony state detection.

Materials and methods

1. System architecture and set up for honey bee monitoring

The developed monitoring system is based on the approach (Fig. 1) that is described in the article [10] where data from sensors are obtained using Raspberry Pi model B. This device was decided to use, because in future it is planned to combine temperature monitoring with sound and video. For temperature measurements, DS18S20 1-Wire digital thermometers were used. These sensors use only one wire for data transmission and can be powered form +3.0 V to +5.5 V; the operating temperature range is -55 ºC to +125 ºC, thermometer error ±0.5 ºC at -10 ºC to +85 ºC and ±2 ºC at -55 ºC to +125 ºC (see http://datasheets.maximintegrated.com/en/ds/DS18S20.pdf).

Sensors were placed inside the hive above the frames. The sensors were connected with each other and with the Raspberry Pi using a telephone networking cable and cable adapter (2 in 1 splitter – RJ11 connector 6P4C Extender Adaptor) as connectors.

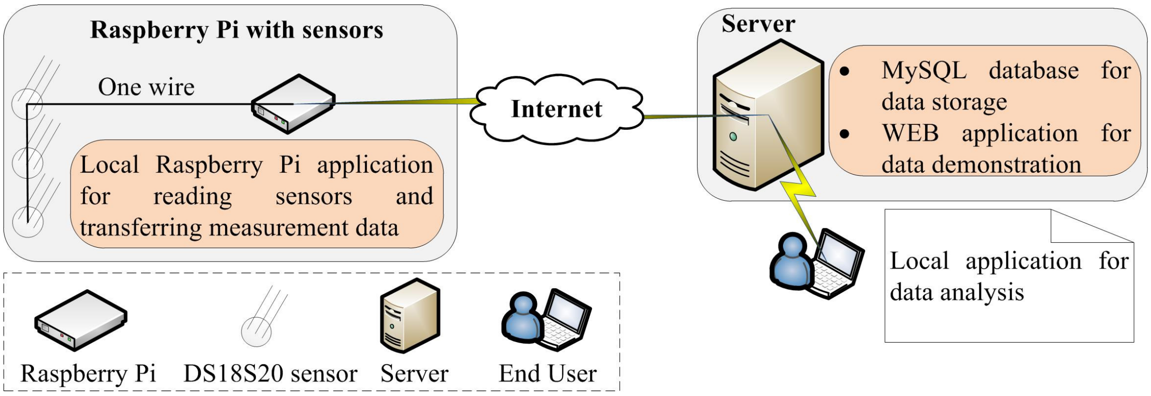

Fig. 1. **System architecture used for honey bee monitoring** [10]

To obtain data from 1-Wire network, corresponding driver modules were enabled on the Raspberry Pi. The device was programmed using Python programming language. As mentioned by [10], the connected sensor count should be taken into account, because by default the maximum count of connecting sensors are 10. In our case, the sensor count exceeded the predefined maximum, therefore Raspberry Pi's firmware and kernel were upgraded.

The obtained data were sent to a remote database. A development package, called XAMPP, was used for data storing and demonstration on Web. XAMPP (which consists of Apache Web server, MySQL database, PHP and Perl (see https://www.apachefriends.org/about.html) was set up on Ubuntu 12.04 LTS operating system.

The costs for components of such temperature monitoring system are shown in Table 1.

Table 1

Costs for one honey bee temperature monitoring system components

Component	Quantitiy	Unit	Price (EUR)*
Raspberry Pi device	1	Piece	58.00
Power supply for Raspberry Pi	1	Piece	5.00
Wire (small coil cable for telephone 4/4)	1	m	0.15
DS18S20 digital thermometer	1	Piece	2.89
RJ11 connector (6P4C)	1	Piece	0.14
RJ11 connector 6P4C Extender Adaptor	1	Piece	1.15
Ribbon cable with connector	1	Piece	1.50

Note: * – the prices may differ;

The monitoring system costs depend on the sensor count and wire length between the hives. Also the component delivery expenses are not taken into account, as well as the installation costs. The costs for such monitoring system can be calculated using formulas (1-4):

$$W_{Costs} = \left(s_{count} \cdot \left(s_{length} + s_{between}\right) - s_{between} + first_{length}\right) \cdot cable_{price} \tag{1}$$

where W_{Costs} – wire costs, EUR;

s_{count} – sensor (DS18S20) count, pieces;

s_{length} – wire length for sensors, m;

$s_{between}$ – wire length between sensors, m;

$first_{length}$ – wire length from Raspberry Pi device to the first sensor, m;

$cable_{price}$ – price of the wire, EUR per m.

$$C_{Costs} = (3 \cdot s_{count} - 1) \cdot rj11_{price} \tag{2}$$

where C_{Costs} – connector (RJ11) costs, EUR;
s_{count} – sensor (DS18S20) count, pieces;
$rj11_{price}$ – connector (RJ11) price, EUR per piece.

$$S_{Costs} = s_{count} \cdot (s_{price} + sCon_{price}) \tag{3}$$

where S_{Costs} – sensor (DS18S20) with 6P4C Extender Adaptors costs, EUR;
s_{count} – sensor count, pieces;
s_{price} – sensor price, EUR per piece;
$sCon_{price}$ – 6P4C Extender Adaptor price, EUR per piece;

$$FullCosts = W_{Costs} + C_{Costs} + S_{Costs} + RPi_{Price} + RPiPS_{Price} + RibClb_{Price} \tag{4}$$

where $FullCosts$ – sum of all costs for the monitoring system, EUR;
W_{Costs} – wire costs, EUR;
C_{Costs} – connector costs, EUR;
S_{Costs} – sensor with 6P4C Extender Adaptors costs, EUR;
RPi_{Price} – Raspberry Pi device price, EUR;
$RPiPS_{Price}$ – Raspberry Pi device power supply price, EUR;
$RibCbl_{Price}$ – price of the ribbon cable with connector, EUR.

The costs for one such system in our case were approximately 120 EUR. Two systems of such approach were developed before winter and therefore set up in Strazdu iela 1, Jelgava, Latvia, for honey bee monitoring. The first system monitored ten honey bee colonies inside (inside group – IG) the wintering building, the second system monitored ten honey bee hives outside (outside group – OG) the wintering building. Temperature data were obtained every 20 minutes. Each system monitored ambient temperature as well.

2. Data demonstration

The collected data can be demonstrated on a local desktop application and on a Web page.

Desktop application was developed to keep track of the temperatures in the hives. The application ensures data visualization for all installed sensors, providing the user with an option to view maximum, minimum, average and median temperatures by day. In order to determine „bad" data, Chauvenet's Criterion calculation was implemented. In this desktop application a decision support system was implemented as well.

The functionality of the developed Web system is similar to the desktop application. The user can select devices and then sensors, associated with the specified device. Data for chosen sensors can be displayed by a selected period.

Web system was programmed using PHP server-side scripting language and is run in XAMPP server.

3. Decision support system

By [2], DSS can analyze and interpret various data, e.g., temperature, weight, audio etc., resulting in bee colony state detection. Several bee colony states can be distinguished: intensive nectar flow, death of colony, swarming, broodless, queenless and others.

In our study, we defined three decision support rules that are based on [2] for honey bee colony state detection during the wintering period:

- specific colonies, that need attention, due to the significant temperature difference;
- possible colony death;
- possible brooding.

The implemented rules can be divided in two groups, as described by [2]: individual rules (analysis is based on single colony data) (second and third rule) and differential rules (analysis is based on more than one colony (e.g., in one apiary) data) (first rule).

Based on the defined rules, DSS informs the beekeeper if one of the states is detected and gives a decision to inspect these colonies. But the main decision maker still remains the beekeeper, therefore it is upon him to decide, if the provided decision is applicable.

3.1. First rule – temperature difference

The first defined rule compares last temperature data of each individual colony with the average temperature from all colonies in the wintering building. If the temperature difference between a single colony and the whole average is greater by a specific number (determined by the beekeeper), then the beekeeper is informed that this specific colony should be inspected. In our study, the value of temperature difference was set to ±5 ºC.

3.2. Second rule – honey bee colony death detection

Second rule in the decision support system detects possible death of a single colony. The developed algorithm is based on the last temperature data comparison between the temperature inside the hive and the ambient temperature. If the temperature inside the hive is almost equal (with slight difference) with the ambient temperature, besides, the ambient temperature is below some previously defined value (e. g., +7 ºC in our case), then it should be considered, that the colony in the hive is dead.

3.3. Third rule – honey bee brood rearing process detection

The system's third rule determines if there is a possible brooding inside the hive. Brooding is characterized by significant temperature growth (inside the colony cluster, the temperature reaches approximately +35 ºC) [2]. Although the sensor is not in the middle of the colony cluster the temperature growth inside the hive can still be determined.

Different methods can be used to determine increase of temperature. One of the methods is to compare the most recently gathered temperature value with the previously defined threshold – if the temperature is greater than the defined value, it should be considered that there could be possible brooding. However, this method is not accurate, because it does not show the temperature trend, and the temperature increase could be due to some environmental factors. Therefore, in our study we also determined the temperature trend by taking into account the data for the last two hours. These data were then approximated by applying the least square approach. The trend was characterized by four positions – increasing, decreasing, constant and fluctuating.

As a result, the DSS provided information about the last gathered data and the temperature trend for each colony, thus the beekeeper has to decide if inspection is necessary, by taking into account the provided data interpretations.

Results and discussion

The honey bee monitoring system consisting of 1-Wire sensor network and Raspberry Pi device was described. The decision support system was implemented in the desktop application, when requested, the system provides the user with information about honey bee colonies and a decision to inspect the colony in specific situations. Since the monitoring systems are still ongoing, in this paper data were collected for the wintering period, as it is an important period in the bee annual cycle.

It was observed, that the temperature in some honey bee colony hives differed (Fig. 2) (more than ±5 ºC) from the average temperature of all colony hives. In this situation, the implemented decision support indicated the need for inspection. After inspection it was concluded that the temperature rise was due to the honey bee colony movement closer to the sensor.

During the wintering period (from 9th December to 9th March):

- in some cases DSS did warn about some colonies (e.g., colony No. 2 (OG-2) and colony No. 5 (OG-5)) (Fig. 2), where temperature differed from average of all colonies – manual inspections concluded that in those cases, bees were close to the sensor or bees were far from the sensor;
- DSS did not warn about any possible colony death – in manual inspections on 9th March, it was concluded there were no dead honey bee colonies;

- DSS did warn about possible brooding – manual inspections concluded that also in these cases the bee cluster was close to the sensor

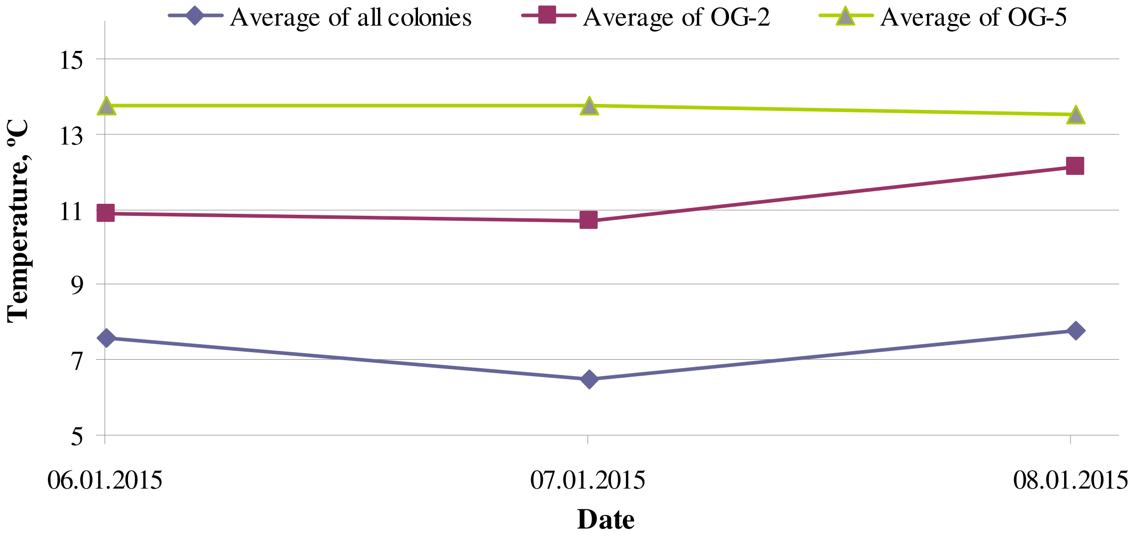

Fig. 2. **Single colony (OG-2, OG-5) average temperature and average of all colonies**

For some outside group colonies large temperature spikes were observed (Fig. 3) that could be caused by car noise, construction work or other environmental factors. When these spikes were detected, DSS warned about the need of inspection and showed a fluctuating temperature trend.

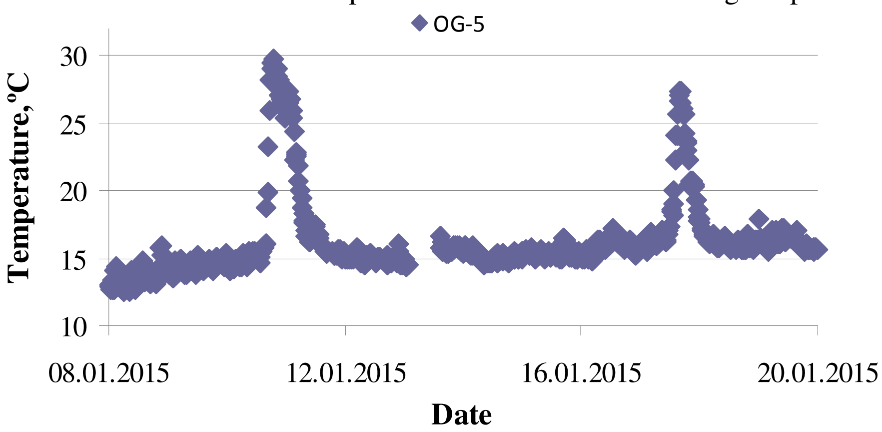

Fig. 3. **Detected temperature spikes**

Manual inspections on 9th of March for OG proved that in hives where temperatures were high (over 20 ^{0}C) bee clusters were close to the sensor. Table 2 represents temperatures in hives and cluster placement (closer, farther to sensor).

Table 2

Outside group bee cluster position relative to sensor

Hive	Temperature, °C	Position
OG-1	28	Close
OG-2	25	Close
OG-3	20	Close
OG-4	23	Close
OG-5	30	Close
OG-6	11	Farther
OG-7	22	Close
OG-8	24	Close
OG-9	27	Close
OG-10	21	Close

Conclusions

1. The decision support system in honey bee colony monitoring can be used as a data analyzer and interpreter, but the main decision is still up to the beekeeper.
2. The honey bee colony size and cluster emplacement need to be taken into account, because it is one of the factors that impacts the temperature difference between a specific hive and the average temperature of all hives.
3. Environmental factors may disturb bees, resulting temperature rise.
4. It is planned to improve the DSS, so it could perform as an automatic decision provider, without a need for beekeepers request.
5. It is also planned to add video and audio monitoring to the Raspberry Pi device.

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