APPLICATION OF TEMPERATURE MEASUREMENTS FOR BEE COLONY MONITORING: A REVIEW

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Abstract. Precision Beekeeping (Precision Apiculture) like Precision Agriculture can be considered as a three-phase cycle, where the first stage – data acquisition plays a big role. Sensing technologies can be applied in Precision Apiculture to measure various bee colony parameters in a real time. Constant and real time information on bee colony conditions would be a key to study new diseases like colony collapse disorder and to develop new beekeeping tools to improve the hive management and make it more efficient. Nowadays, a number of individual bee colony related parameters currently can be continuously measured: temperature by temperature sensors or infrared imaging, air humidity, gas content, sound, vibration of hive, counting of outgoing and incoming bees, video observation and weighing. But temperature measurements seem to be the simplest and the cheapest way to monitor bee colonies. The aim of this paper is to review some practical implementations of temperature measurements for the bee colony monitoring. Temperature measurements can provide a beekeeper with actual and real time data and information about the bee colony behaviour. Based on temperature information beekeepers can detect such colony events like increased food consumption, start of brood rearing, recognition of the pre-swarming state or death of the bee colony. For implementation of temperature measurements various technologies and methods can be applied: measurements by loggers, development of wired networks or even usage of wireless sensors.

Keywords: Precision Beekeeping, bee colony temperature measurements, bee colony monitoring.

Introduction

Beekeeping is a production branch of the agriculture. Honeybees are very important economical insects not only for pollination of crops, but also for their valuable products. Bees are gathering nectar and pollen from plants and trees. A part of it bees are using to maintain their own life, but the other part is used for production of beekeeping products, like wax, propolis, queen milk, bee venom, apilarnil, etc. These products are used either directly as human food (honey) or as a raw material for an impressive number of medicinal, cosmetic, pastry produces, etc.

In apiculture, one of the major problems is to monitor honeybee colonies for their health, population, other biological activities indicating production of honeybee products and environmental conditions affecting the colony health. Beside honeybee diseases, Varroa destructor infestation and pesticides, one of the most common problems in apiculture is colony losses because of food shortage in hives, queen loss, and loss of broad by unusual alteration in environmental conditions such as temperature, humidity and the length of the winter season.

Nowadays, rapid improvements in temperature, sound measurement systems and information technologies overall allow economically feasible applications in beekeeping. Continuous data capture and analysis can be used to monitor individual bee hives and the data can be adapted for individual bee colony maintenance.

Usage of ICT in apiculture mainly can increase the beekeepers' knowledge about behavior of individual bee colonies and improve the efficiency of beekeeping by bringing it to the next technological level. Usage and combination of ICT in beekeeping allow defining self-sufficient subdirection of Precision Agriculture like Precision Beekeeping. Precision Beekeeping (PB) or Precision Apiculture is an apiary management strategy based on the monitoring of individual bee colonies to minimize the resource consumption and maximize the productivity [1].

The main task of the PB is to develop real time on-line tools for continuous monitoring and control the bee behavior using the individual access to the objects avoiding exposure of bees to additional stress or unproductive activities. It is not possible and also not needed to monitor each and every bee individually, and that is why PB object is a bee colony [1].

Similar to Precision Agriculture also Precision Beekeeping can be considered as a three-phase cycle (data acquisition, data analysis and application), where the first phase – data acquisition has an important role. Then, based on the measured data and taking into account the expert knowledge it becomes possible to conclude about the bee colony behavior and developing process [1].

In the annual cycle of bee colony development passive wintering and active periods can be distinguished. They can be characterized more precisely [2-4]. And in each of them temperature measurements can be used with different aims to improve the collaboration between the beekeeper and the bees. In summer period it is important to detect the preswarming, broodless, queenless and other states of a bee colony. So far, mostly automatic preswarming state detection systems have been developed. Swarming is a natural mechanism of proliferation of bee colonies. Swarming is a highly stochastic process which depends on genetic and other peculiarities of a particular bee colony [5; 6]. As a result of swarming a part of the bee colony leaves the existing hive and establishes a new colony in a new place at least several kilometers away from the previous place of living making serious damages of the beekeepers' plans. There are no direct indications of preswarming conditions that would be clearly visible for a beekeeper without opening the hive. So, the best option to detect this process is to apply Precision Apiculture methods to individual colonies. During the passive wintering period temperature measurements can be applied for detection of events like increased food consumption, start of brood rearing or death of the whole colony [7; 8].

Various IT tools and technics can be applied for individual bee colony monitoring. Currently, practical experiments and measurements were done with temperature by temperature sensors or infrared imaging, air humidity, gas content, sound, vibration of hive, counting of outgoing and incoming bees, video observation and weighing. But this paper is devoted to the applications of the existing temperature measurements and systems for automatic monitoring of the bee colonies to determine the state and needs of individual bee colonies.

Application of bee colony temperature measurements

Honey bees have one important feature; they can regulate temperature inside the hive. During the cold time bees can heat themselves, but when it is hot they stimulate the air exchange in the hive. Temperature in the bee hive is not divided evenly, in the bee ball it is higher and changes less than temperature near the hive walls [9].

Temperature measurements of bee colonies have the longest history. Nowadays, bee colony temperature measurements seem to be the simplest and cheapest way to monitor bee colonies. There are made many researches and practical experiments with the temperature measurement of the bee colonies and many scientists tried to understand the bee behavior features depending on environmental parameters.

The low costs of data collection, processing and data transfer of temperature measurement systems facilitate application of temperature measurements in beekeeping.

Monitoring of the bee colony temperature can be performed using various methods and technologies.

1. Manual temperature measurements, measurements by different loggers and iButtons

In the previous 20th century, when information technologies were not widely available, measurements of the bee colony temperature were done manually using thermocouples and later special temperature loggers or iButtons were used.

One of the first practical experiments was made by W.E.Dunham in 1926, when he used eight thermocouples, which were placed into one hive in different places. Each hour temperature measurements were made and manually fixed. He concluded that temperature fluctuations in the bee ball are not so high, comparing to temperature in the empty places of the hive. Also he found out that during the active brood rearing state temperature in the bee ball is increased up to +30 ºC. And already at that time a conclusion was made that temperature has the highest effect on bees than other environmental parameters [10].

Fahrenholz in 1989 made the research, when the bee hive temperature at the center, the periphery and the entrance of a honey bee colony was continuously determined during the summer season and the broodless time in winter. During the measurements the bee colony temperature change dependence on the environmental temperature was monitored, as well heat production in the hive was measured. During the summer season the temperature in the brood nest averages 35.5 ºC with brief excursions up to 37.0 ºC and down to 33.8 ºC. Increasing environmental temperatures resulted in linear increases in the temperature of the hive entrance, its periphery and its center. The temperature in the center of an overwintering cluster is maintained at an average value of 21.3 ºC (min 12.0 ºC, max 33.5 ºC). With rising ambient temperatures the central temperature of a winter cluster drops whereas the peripheral temperature increases slightly. With decreasing external temperatures the peripheral temperature is lowered by a small amount while the cluster center temperature is raised. Linear relationships are observed between the central and the ambient temperature and between the central temperature and the temperature difference of the peripheral and the ambient temperatures [11].

Chuda-Mickiewicz and Prabucki made a research and observed how the bees nest is moving during the wintering time in dependence on environmental temperature. As a result it was concluded that a bee colony wintering in a hive with a cold set of frames does not shift its thermal center in a significant way. Clear vertical and horizontal movements of the center are observed permanently within the same byway between the combs. At minus outdoor temperature, the thermal center constantly remains in the same place not showing any movements. At plus outer temperature, the thermal center displays movements within one bee way between the combs. The temperature of the cluster is subjected to the influence of the outer temperature. The cluster of wintering bees behaves the same in cold and warm structures of the brood nest [12].

Some experiments were made by inserting many temperature sensors into one hive, while all measurement data were displayed on the sensor screen, which was placed outside the hive. But it seems to be not so very convenient solution, because the temperature data were not automatically stored for further analysis [13].

2. Wired sensor networks for temperature measurements

With the rapid development of IT and ICT it has become possible to develop whole sensor networks for temperature measurements. One wire sensor networks are popular, when it is possible to store all measurements in PC database for further data analysis.

A complicated practical experiment was held in Riga, Latvia in 2000, when E. Stalidzans monitored temperature changes in individual bee hives during the whole year. The aim of the measurements was to observe the bee colony temperature changes, and to define the bee colony activity states in the Latvian climate conditions. Small DS18S20digital sensors were used for the measurements and they were placed under the pillow above the bee nest. The measurements were made at 15 minutes interval. As a result, six bee activity states were defined [14].

One more research was made in Rumania by Vornica and Olah. The aim of that work was to present a monitoring system conceived and achieved by means of the most recent software and hardware products attachable to a bee family, having in view the nonstop supervising of the climate conditions of the environment (temperature, humidity and dew point), respectively their influence on the conditions in the beehive. The aim of monitoring was to find some undesirable influences as well as to achieve proper developing conditions for the bee families, by proper intervention. In order to monitor they have proposed to measure nonstop and to register, by means of sensors, the temperature and relative humidity around the beehive, respectively, to measure and register the variations of the same parameters in different zones inside the beehive by means of three movable sensors [15].

Another research was held in Jelgava, Latvia in 2008, when J. Meitalovs developed automatic 1-wire measurement and monitoring system in order to find out the features of microclimate changes that would allow detecting the preswarming condition of the colony. The beehive observation system consisted of: control subsystem, measuring (temperature and relative humidity) subsystem and video recording subsystem [16].

The author of this paper also did practical experiments obtaining the bee hive temperature measurements in closed environment created in the wintering building. In this building up to 30 bee hives were placed. Each hive was equipped with a small digital temperature sensor. All sensors were sequentially connected with the Temp08 interface device, while it was connected with the end PC using the COM port. All data from the sensors were transmitted to the PC database. Based on the temperature data it is possible to conclude if the bee colony is in a passive/inactive state, if the brood rearing process has started and if the bee colony is still alive. This information is very useful for the beekeeper, because it is needed to monitor the brood rearing process, and if this process has started too early it is needed to slow down or stop this process. Premature start of bee breeding in winter can cause high energy consumption of the bee colony that, in turn, can lead to a possible death of that colony. That is the main risk factor during the wintering in the special building [7].

3. Remote monitoring of bee colony temperature changes

When it became easy to implement bee colony temperature measurements, development of pc based systems began to ease the access to the measured data and to give the opportunity for beekeepers to monitor their own bee colonies in real time. WEB systems started to be implemented for visualization of measurements.

One transnational bee colony monitoring system has been delivered and operates as an international network including bee colonies in Denmark, Sweden, Norway, Latvia and Germany [17].

One more web system is developed by the authors of this paper to easy access all bee colony temperature measurements. The main idea is that a beekeeper from any place, where there is the Internet coverage could connect to the web server and check the temperature in the hives. As beekeepers usually are not very experienced in using PC applications, the WEB interface should be as simple as possible, without any possibility to make any wrong actions. Web system is developed using the ASP.Net technology and divided in several modules. The first module – actual information about the bee colony temperature (last measurements for all sensors). The second module – option for detailed analysis of the bee colony temperature with an option to graphically demonstrate average, minimal or maximal temperatures for the hive. The third module – an option for administration and modifying information in configuration file [18].

4. Infrared imaging

Monitoring of the bee colony temperature can be done not only with the small sensors, but also with application of the infrared imaging [19-21]. The infrared imaging can give data about heat distribution of a single colony or a group of colonies. Still they reflect the real temperature less accurately as in fact just the hive surface temperature is measured. The costs are much higher compared to temperature sensors.

The thermal imaging method was used by Eskov and Toboev to monitor thermal processes in the inter-comb bee clusters and temperature of different body parts during the wintering period. The temperature of different body parts was found to depend on the localization of bees in the nest and the external temperature. The dependence of the thermoregulatory activity of bees on the external temperature fluctuations decreased during wintering. The trends of distribution of thermal fields in clusters of wintering bees are revealed [22].

Also Long-wave infrared imaging was used by Shaw for non-invasive assessment of the internal population of honey bee colonies. The radiometrically calibrated camera signal is related to the number of frames that are populated by bees inside each hive. This enables rapid measurement of population without opening the hive, which disturbs the bees and can endanger the queen. The best results were obtained just before sunrise, when there is maximum thermal contrast between the hive and the background. This technique can be important for bee hive monitoring or for applications requiring frequent hive assessment, such as the use of bees for detecting chemicals or explosives [21].

5. Wireless solutions for bee colony temperature measurements

Nowadays, wireless sensors and wireless solutions for different object monitoring tasks and data acquisition have become more popular. But unfortunately, in beekeeping the authors of the paper found only one example of wireless system prototype for bee colony observation [23]. The main components of wireless networking system are listed below.

- Beehive circuit: it is flexible, super slim, with built-in Li-Po charger. External solar panels are used to provide energy for the circuit.
- Sensors: temperature and humidity sensors.
- Zigbee circuit for wireless communication.
- Embedded computer.
- Software.

- Database: the system uses MYSQL.

But it is clear that wireless solutions and application of wireless sensors will be developing and its usage in beekeeping will increase in the near future.

Conclusions

A number of colony level related parameters currently can be continuously measured: temperature by temperature sensors or infrared imaging, air humidity, gas content, sound, vibration of hive, counting of outgoing and incoming bees, video observation and weighing, but temperature measurements seem to be the simplest and the cheapest way to monitor bee colonies.

The aim of this paper was to review various practical implementations of temperature measurement systems in the beekeeping practice.

Accuracy of the temperature sensors used for bee colony measurements is not the crucial point, because temperature changes are monitored, not the actual values.

Temperature measurement systems can provide beekeepers with actual and real time data and information about the bee colony behavior. Based on this information beekeepers can make important conclusions and in case of need perform some additional actions.

Implementing the temperature measurement system it is needed to choose its type (wired or wireless) and choose the energy source for the system.

Acknowledgment

Academic study and publication financed by the project „Support for doctoral studies in LUA" / 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017/ agreement Nr. 04.4-08/EF2.PD.56.

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