APPLICATION OF WIRELESS SENSOR NETWORKS IN PRECISION APICULTURE

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Abstract. Wireless sensor networks are used in different fields. One of the fields, where such sensors can be used is apiculture for honey bee (*Apis Mellifera* L.) monitoring (for example, temperature and humidity data acquisition). This paper introduces a wireless sensor network system for bee colonies online monitoring. The developed wireless system consists of several wireless measurement nodes which transfer colony data to one main unit, which then sends the received data to the cloud database server. Users can see and analyze data using the developed Web system. To this moment temperature and humidity are monitored using the SHT15 sensor. Real time temperature and humidity monitoring of the bee colonies can provide the beekeeper with actual and timely data and information to help identify various states of the bee colonies. Due to the fact, that these sensor data are transmitted wirelessly, it is also easier for the beekeeper to set up such a system (there is no wiring needed).

Keywords: Precision Apiculture, Precision Beekeeping, bee colony monitoring, wireless sensors, wireless sensor networks.

Introduction

Honey bee monitoring has its roots in distant past. As mentioned by Meikle [1] in 1907 honey bee colony temperature data were gathered every hour for several days. Modern technologies have a significant impact on measuring and monitoring process improvements (more accurate sensors, data gathering technologies etc.) allowing to use different kinds of monitoring methods (from simple data observation on site to monitoring system with implemented data analysis [2]). These systems can use wires to transmit data or they can perform it wirelessly. The author Meikle [1] mentions wireless technology usage in agricultural sectors, with particular emphasis on apiculture, because of the advantage to use such sensors in remote locations.

Wireless sensor network can be described as a system that consists of spatially distributed autonomous sensor nodes. Wireless sensor networks can be applied almost in all branches. Sensors can be placed on earth, in air, in water, on objects, on vehicles and constructions [3].

Analyzing scientific literature it was found that application of wireless sensors and wireless systems in agriculture also are practically implemented. For example, Gomide developed a mobile field data acquisition system with the main aim to collect data about crop management [4]. Damas developed and tested a remotely controlled irrigation system using wireless sensors [5]. Cugati developed an automatized fertilizer system for tree crops [6]. Elsts developed a system for orchard monitoring using self-developed wireless nodes with the name SADmote [7]. It was found that with wireless sensors it is possible to monitor wild animals like lynxes [8]. Application of wireless systems for greenhouse microclimate and greenhouse crop monitoring is very common, there are many researches and systems developed in this area [9-16].

Precision Apiculture system can be implemented into the practice similar to Precision Agriculture approach completing three stages: data collection, data analysis and application of control action [17].

The wireless system can be used to constantly and remotely monitor bee colonies for several parameters. This monitoring system is a part of the whole Precision Apiculture (Precision Beekeeping) system. Precision Apiculture is recently defined as a scientific direction where Information Technologies (IT) and beekeeping are combined together, like this is done in Precision Agriculture. Precision Apiculture is defined as an apiary management strategy based on monitoring of individual bee colonies to minimize the resource consumption and maximize the productivity of bees [18; 19].

Usage of wireless solutions in the beekeeping branch is not developed very well. Nowadays, mainly wired systems are used for bee colony behavior monitoring [20; 21]. Some examples of wireless solutions in beekeeping are:

- temperature and humidity-controlled system fed by solar energy developed by Altun [22]. The principle of this system is to obtain and analyze temperature and humidity data using wireless sensor networks. To keep the temperature in the hive at the optimum level, a thermoelectric heating and cooling system was used. For data transmission two radio modems were used;

- open-source bee-hive monitoring system developed by Glyn and Clive Hudson [23]. The aim of this monitoring system is to compare the temperature data inside the honey bee colony cluster with temperatures obtained from different locations in the hive – outside the cluster, inside and outside the hive [23]. For data wireless transmission two Arduino devices and a radio frequency link was used;
- enthusiast, engineer, scientist and beekeeper Carl [24] developed a project called "PIC'n the Beehive". The main aim of his project was to develop a bee behavior and health monitoring platform (that acts like a research tool). The platform is based on PIC32 microcontroller with additional expansion boards. The microcontroller provides monitoring, data analysis and some control functions. There are several functions implemented in the system, like – temperature (hive base and top (inside, outside)), humidity, daylight and other data acquisition.

A scientific project with the title Application of Information Technologies in Precision Apiculture (acronym ITAPIC; homepage: www.itapic.eu) has started in August, 2013 and is funded within the ICT-AGRI 2012 call for transnational research projects. The ITAPIC project proposes implementation of Precision Agriculture technologies and methods in beekeeping. The main goal of the project is to identify different states of the bee colony and prevent colony losses. This paper introduces the developed wireless sensor system for honey bee colony online monitoring. The wireless system is developed within the ITAPIC project work package 1 "Development and testing of hive sensor hardware for audio, video, microclimate and environmental climate monitoring".

Nowadays, beekeepers can use a variety of technologies for monitoring colonies and wireless solutions also should be considered for practical use. Wireless sensor systems have an advantage over wired when it comes to installation. Wireless system installation does not require any wire management and can be used in remote locations as mentioned before. Despite the relatively small size of sensor network hardware components development of software for wireless systems is not trivial and is a complex task [25; 26].

The aim of this paper was to describe a developed wireless sensor network system for honey bee monitoring.

Materials and methods

Developing a wireless or wired system for honey bee colony online monitoring several approaches [2] and different hardware solutions for data storage, transferring and analysis can be considered. For example, all colony measurements can be directly transferred to the remote server, where data analysis and decision about the colony states can be made (Fig. 1).

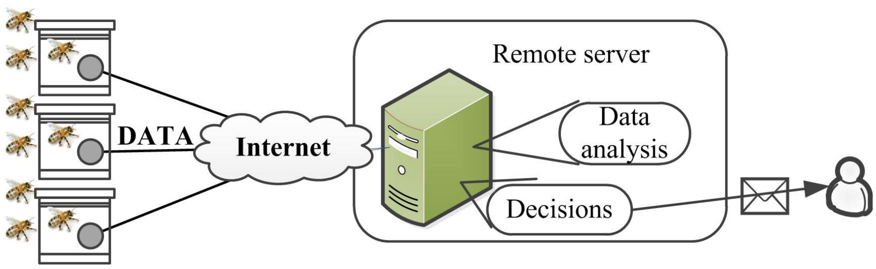

Fig. 1. **Concept of wireless/wired system for honey bee colony online monitoring**

Within the ITAPIC project, the developed wireless measurement system (Fig. 2) is based on the concept shown in Figure 1. The system is developed to monitor honey bee colony behavior by measuring different colony parameters. The monitored parameters depend on the sensors, which are placed on the measurement nodes. For now, temperature and humidity are measured using the SHT15 humidity and temperature sensor integrated circuit (IC). Communication with the SHT15 is ensured using a digital 2-wire interface. The relative humidity and temperature sensor parameters (see http://www.adafruit.com/datasheets/Sensirion_Humidity_SHT1x_Datasheet_V5.pdf) of the SHT15 are shown in Table 1. The SHT15 can be powered by an energy source that provides voltages from 2.4 to 5.5 V, and it consumes 3 mW when taking measurements.

Table 1

SHT15 IC parameters

Parameter	Condition	min	typ	max	Units
Relative humidity (RH) accuracy	typical	-	±2.0	-	%RH
RH response time	τ (63 %)	-	8	-	s
Temperature accuracy	typical	-	±0.3	-	ºC
Temp. response time	τ (63 %)	5	-	30	s
Temp. operating range	-	-40	-	+123.8	ºC

The main unit of the system (shown in Fig. 2) continuously receives data from the measurement nodes and when the data are received, transfers them to the cloud database server. Optionally a Secure Digital (SD) card can be placed on the main unit to store data locally for backup purposes. Local data storage is useful when the Internet connection is not stable, resulting in data transfer interrupted. The user can access data remotely by using the developed web interface. The web interface can be further developed based on the beekeepers needs and suggestions.

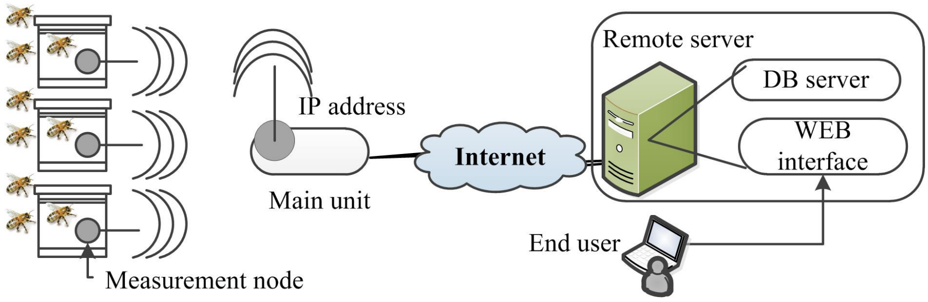

Fig. 2. **Wireless measurement system used in ITAPIC project** [2]

Data are transmitted in 433 MHz frequency.

The developed honey bee colony wireless monitoring system consists of three components:

- measurement node (Fig. 3-1) – a node is a system wireless element which is needed to make honey bee colony measurements [2]. The node consists of several integrated blocks: a low-power microcontroller, a wireless transceiver, on-board sensors and a power source. Different sensors can be connected to the measurement node. The developed node can use various energy sources, like 5 V batteries or solar energy. In case of solar power, the solar panel is charging lithium battery (Fig. 3-2). For battery saving purposes, the measurement node enters "sleep mode" and "wakes up" on predefined time intervals. In our case one minute interval is programmed. Atmega328P (see http://www.atmel.com/images/doc8161.pdf) microcontroller was used for nodes and a 433 MHz TWS-BS series radio frequency module (see http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Wireless/General/TWS-BS-3_433.92MHz_ASK_RF_Transmitter_Module_Data_Sheet.pdf) for data transmission;
- main unit (Fig. 3-3) for data transfer. The main unit is required to listen for measurement nodes and to transmit the received data to cloud database server. The unit consists of several integrated blocks: a low-power microcontroller, a wireless transceiver, peripheral extension connectors, an external storage device (optional) and a power source (5 V power adapter is used as energy source) [2]. Atmega328P microcontroller was used for the main unit. For communication a Wiznet W5100 Ethernet controller (see http://www.wiznet.co.kr/UpLoad_Files/ReferenceFiles/W5100_Datasheet_v1.2.2.pdf) and SYN470R ("antenna-in to data-out") (see http://www.gaily-gw.com/images/lxy/PDF/SYN470R.pdf) integrated circuit was used;
- remote database server. For data storage a cloud database service is used. Data from the measurement units are directly saved in cloud database for further analysis and demonstration. For easy access to the stored data an additional php Web system was developed. The web

system can be adjusted to the beekeepers needs by implementing different graphical elements for data demonstration or data analysis [2].

1 2 3

Fig. 3. **Wireless monitoring system elements:** 1 – measurement node; 2 – solar panel with lithium battery; 3 – main unit

For now, the system is implemented in Tokat, Turkey. The monitoring process started in summer of 2014. Eight hives were placed outdoors and equipped with measurement nodes. The measurement nodes were placed outside the hives into closed small boxes and covered with waterproof material. The main unit was placed in an empty hive. The monitoring system is working all the time and data are stored in SQL database. The weather conditions by the time the system was tested – average temperature in summer (2014) approx. +24 ºC; autumn (2014) approx. +14 ºC; winter (2015) approx. +5 ºC; average precipitation in summer (2014) 0.5 mm; autumn (2014) 1.1 mm; winter (2015) 0.7 mm.

The distances between the monitored hives were 5-10 m. The longest distance from the measurement node to the main unit was approximately 20 m.

Results and discussion

The developed wireless honey bee monitoring system was described. Currently the system is installed in 8 honey bee hives. Temperature and humidity data were obtained from the monitored hives. A web system (Fig. 4) was also developed to provide temperature and humidity data visualization. The web system provides:

- raw temperature and humidity data visualization for each hive;
- minimum, maximum, average visualization of temperature and humidity data for each hive.

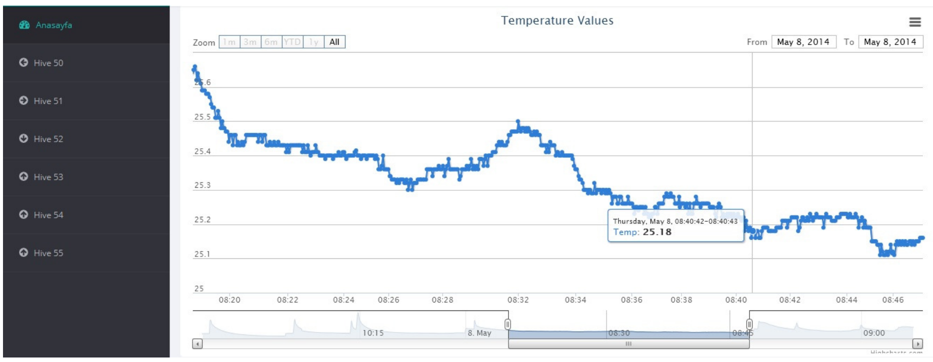

Fig. 4. **Web system interface for temperature data visualization**

The monitoring system was installed in summer of 2014 and is still working (early spring of 2015). At that moment rechargeable batteries were used as a power supply and powered the system elements (main unit, nodes) over a year without the need to charge.

One of the disadvantages of the wireless sensor network system is in relation with the power source for the nodes. If using batteries, it is necessary to keep track of whether the nodes are still working to prevent data loss.

The developed wireless system is consistent with the main fundamental requirements, mentioned by Krivanek [27], some of them are listed below:

- very low complexity of elementary sensors, associated with low power consumption and low-cost;
- high reliability of decision/estimation/measurement of the network as a whole;
- long network life-time for low maintenance and stand-alone operation.

In future it is planned to modify developed system hardware components by excluding the main unit from the system. This can be done by granting, that each measurement node will assign IP address using a simple wireless router. And the nodes will directly send data to the cloud database server.

Conclusions

1. The recently defined Precision Apiculture branch as a sub-branch of Precision Agriculture is still in developing stage. Nowadays, there are several wired and wireless systems developed to monitor several honey bee colonies parameters, but systems for honey bee colony data analysis still to be developed.
2. The described wireless system to this moment can be considered as a data collecting and demonstration system and in future it is planned to implement a data analysis and decision support module which will be used for bee colony state identification and recognition. The described system is implemented in Tokat, Turkey for bee colony monitoring.
3. Despite the fact that for battery saving purposes the measurement node can enter sleep mode, there is still a need for battery replacement after a certain battery life time. Therefore, regular control is needed to prevent data loss.
4. The developed wireless system for remote bee colony monitoring should minimize the manual inspection of colonies, and maximize the colony health.
5. Open issue for discussion – “Is there any effect of wireless data transmission on bee health?”

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ICT AGRI era-net SEVENTH FRAMEWORK PROGRAMME ITAPIC Application of Information Technologies in Precision Apiculture