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Solution for automated bee colony weight monitoring

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Abstract. Future of the traditional beekeeping is to implement Precision Beekeeping approach and implement different automated and smart apiary monitoring systems for remote and optimised bee colony management. Behaviour of the bee colony can be monitored by the use of temperature, humidity, acoustic, video and weight systems. Each measurement system can give its own additional value for recognition of bee colony state. It is useful for the beekeeper to have at least one control colony with weight system equipped in the apiary. The hive scales is an important tool which gives assessment if food consumption has been high and whether there is a need for feeding. In most countries it is important to know how long the winter storage is, in addition it gives a very good indication of periods without any nectar flow. This paper presents conceptual design and prototype of honey bee colony weight monitoring system with GSM/GPRS external interface for packet-based communication with remote server. The central module with scales is placed on one of the hives and consists of temperature sensor, 4 strain gauge load cells for weighting purposes, RF and GSM/GPRS modules, photovoltaic cell array, battery, charge controller and minimal user interface for operational status signalling. The system allows sensor data logging to local storage and periodic data transfer to a remote server for further data analysis in different user applications. Data processing back-end component serves GET requests coming from remote measurement device, performs identification and raw data conversion using configuration stored in database.

Key words: precision apiculture (precision beekeeping), weight monitoring, smart apiary, internet of things.

INTRODUCTION

Recently Precision Beekeeping (Precision Apiculture) scientific sub-branch of Precision Agriculture has been defined (Zacepins et al., 2015). For implementation of PB various technical and measurement systems can be developed. Behaviour and state of bee colony can be monitored by use of temperature, humidity, acoustic, video, weight and other sensors. Each measurement system can give own additional value for recognition of bee colony state. For example, using temperature measurements death, broodless, brood rearing states can be easily detected. It is also clear that monitoring of bee colony weight is significant as well: it is very important for the beekeeper to have at least one control colony with weight system equipped. Electronic hive scales can easily

supply the beekeeper / scientist with important information on several important events from honey bee colonies' life cycles (Buchmann & Thoenes, 1990; McLellan, 1977; Meikle et al., 2006). Long-term sensor data analysis and data fusion could also be used to assess development of bee colony.

Very often it is difficult to judge what is going on in honey bee colonies. The hive scale is an important tool and gives a good assessment if food consumption has been high over a longer period and whether there is a need for feeding. In most countries, it is essential to know how long the winter storage period is since it will tell if spring feeding of carbohydrates is needed. In addition, it gives a very good assessment of periods without any flow in the summertime and hence can warn of starvation danger. Finally, it gives a very good evaluation of how intense the nectar flow is, in other words, if there is a need to provide the colonies with additional supplies. Commercial beekeepers use hive scales to save unnecessary visits to the apiary when they do long-distance migration (Human & Brodschneider, 2013).

The weight of an inhabited hive (i.e., the sum of the weight of the box, combs with food stores and the bees) can be measured to monitor the different states of the colonies or to identify several colony events:

- the occurrence of nectar flow during the foraging season (start and end of nectar flow) or daily gain in nectar stores (Meikle et al., 2008; Okada et al., 2012; Human & Brodschneider, 2013);
- consumption of food during non-foraging periods (Seeley & Visscher, 1985);
- the occurrence of swarming events through a decrease in the hive weight (Meikle et al., 2008; Linton, 2012);
- estimating the number of foragers (Linton, 2012).

Important advantages of weight systems are: weighing is fast, requires little training and is not disruptive to the colony so it can be done at any time of year. There are two ways of measuring the weight of the colony: first, automatic measurements can be made using industrial scales, which allows for the continuous measurement of the bee colony weight; and second, simpler scales can be used to take measurements manually.

Weather influence should be taken into account because wooden boxes absorb moisture and thereby bias weight measurements (Meikle et al., 2008). The use of Styrofoam boxes is recommended for more accurate weighing. In the case of wooden hives, it is recommended that the changes in weight of an empty hive (with frames and honey but no bees) are taken into account to clarify the mass changes due to environmental effects such as humidity and wind.

Aim of this research is to develop conceptual design and prototype of honey bee colony weight monitoring system with GSM/GPRS external interface for packet-based communication with remote server. As well financial aspect is taken into consideration, so system should be economically feasible and return of investment coefficient should be high. This system is mainly intended for individual and small scale agricultural beekeepers which have up to 100 bee colonies. Novelty of authors approach is design of scales, optimised data transmission for energy-saving purposes and usage of solar power for system operation even in remote areas.

Review of existing solutions for bee colony weighting

Bee colony weighting is not new and number of dedicated industrial and homemade weighing systems for beekeeping (Human & Brodschneider, 2013), including Beewise (BeeWise, 2013), BeeWatch (BeeWatch, 2013) and CAPAZ (Beehive scale, 2013), indicate the applicability of this approach. Some hive scales also measure wind velocity or sun hours. A state of the art hive scale is designed to automatically transmit these data either directly via internet, to the beekeepers cell phone or to personal computer software. Systems can be used in remote monitoring of hives by communicating weight values using SMS technology accessible from any mobile phone. Due to their relatively high price, the continuous scales used in these systems are not of much interest to beekeepers. In addition, the resolution for measurements made using Beewise and CAPAZ is only 100 g, which is not sufficient for monitoring colonies during the passive state (winter period) when nectar is not harvested and the daily changes in mass do not exceed 100 g.

Other interesting solutions for bee colony weight monitoring are: Hivemind project – Firstly funded on Kick-starter campaign the Hivemind project is a nifty little box designed to remotely track how much honey is in beehives (http://hivemind.co.nz/scales#bottomboard). It uses satellite data transition to send data to Hivemind server. Arnia hive scales – Another commercial product – Arnia remote hive monitoring system which have many monitoring options (http://www.arnia.co.uk/hive-scales/). One of them is hive weight monitoring. Arnia hive scales enables option to remotely monitor how much honey is in bee hives. The hive scales integrate with Arnia hive monitoring system and it is possible to compare hive weight data with colony activity and weather conditions which is an invaluable aid for colony management. Beehive scale XLOG bee – is a SMS/GPRS remote monitoring system that enables data collection from beehives in chosen interval (http://www.microel.hr/products/gprs-sms-beehive-scale-xlog-bee). Data readings are stored in internal memory and sent via SMS/e-mail message directly to beekeeper's mobile phone or via TCP/IP protocol over GPRS data transfer to the server (optionally). In addition to regular measuring reports, special alarm messages are sent immediately in case of alarm situation (beehive theft, sudden increase or decrease in hives weight, overload of the beehive, low battery etc.) to the beekeeper's mobile phone, e-mail address and to the server.

There are also available some homemade systems for continuous bee colony weight monitoring. One solution combines together bathroom scales, instrumentation amplifier, and ATtiny85 microcontroller making a device that could weigh beehive and report the measurements. It is very inexpensive (40–50 USD) for the parts [http://makingthingswork.wordpress.com/].

Another homemade beehive scaling system is based on the simple luggage scale that cost 16 USD (http://www.instructables.com/id/Build-a-scale-to-weigh-bee-hives/). Total costs of such system are under 50 USD. The maximum range of such scales is about 56.7 kg – less than a lot of bee hives. It measures the hive by only lifting one side – and assumed that weight in the hive is more or less centrally distributed. It has a loss in accuracy but maximum range is extended to about 113.4 kg. Disadvantage of such system is that it does not have any data storage or transmission system. Real data can be

only seen on scales monitor. Such system is not designed for automation systems developing. It needs to be manually used to make the measurement.

Several interesting initiatives have been set up to determine the nectar flow and share the information with other beekeepers that use Web systems, demonstrating the interest in the exchange of information among beekeepers:

- http://biavl.volatus.de/bsm0/BSM.html# – this Web system monitors colonies from different Nordic countries, including Denmark, Sweden, Norway, Latvia and Germany (Honningmeteret, 2012);
- http://www.vdrb.ch/service/waagvlker.html – this open website enables all users to see colony mass changes in Switzerland;
- http://honeybeenet.gsfc.nasa.gov – the NASA Goddard Space Flight Centre has initiated a project in which the daily weighing of hives by volunteer beekeepers are merged with satellite data (Nightingale et al., 2008).
- http://mybees.buzz/ – this Web system shows data about bee colonies from different Nordic countries, including Denmark, Sweden, Norway, Latvia

Developed automated weighting system

The high costs and inapplicability for outdoor conditions of continuously loaded general purpose electronic scales limit their application. Moreover, the manual weighing of colonies with required frequency is too laborious to perform at the industrial scale. So it is an open market for development of cheap and reliable solutions for automated bee colony monitoring.

Authors of this research developed conceptual design and prototype of honeybee colony weight monitoring system with GSM/GPRS external interface for packet-based communication with remote server. System is based on one main module, which is placed on the hive and consists of temperature sensor, 4 strain gauge load cells for weighting purposes, RF transceiver and GSM/GPRS modules, photovoltaic cell array, battery, charge controller and minimal user interface for operational status signalling. The system allows sensor data logging to local storage and periodic data transfer to a remote server for further data analysis in different user applications. RF transceiver is used to communicate with other sensor nodes to gather and present their data to remote server as well. The automated weighting system presented in this article is part of precision beekeeping system (Zacepins et al., 2017).

As usually beekeepers place their colonies outside the living regions (in open fields, in forests) advantage of authors proposed system is that it can be located in any place where mobile communication network is enabled and there is no need for classic power supply, because it uses the batteries and solar power.

The automated weighting system uses four load cell based sensors (Fig. 1). Total hive weight is calculated by adding 4 force vectors. Rated load of each cell is 50 kg, therefore total maximum weight of hive is 200 kg. The sensors are equipped with round funnel-shaped trays to help position feet of hive in proper position relative to load cell. None to minimum modifications are necessary to construction of bee hive.

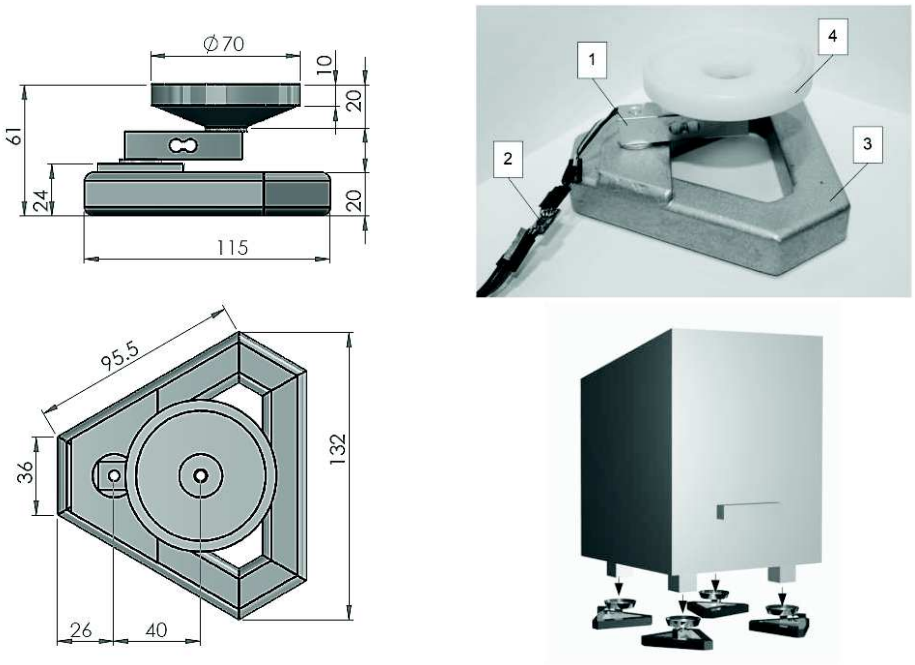

Figure 1. Concept and prototype of beehive automated weighting system sensor: 1 – load cell; 2 – AD converter; 3 – base frame; 4 – hive feet tray.

In order to minimize costs of load cell measurement circuits, analog front-end is positioned right at the each scales module. Signal from strain gauge bridge is measured and converted to digital form using MCP3421 18–bit ADC with I2C digital interface. Digital interface allows lossless data transfer to central logging device use low cost wires. MCP3421 has built-in 8x gain amplifier and voltage reference, therefore minimum external components are necessary. Measurement resolution is 32 g for one load cell, nevertheless calibration with etalon weight for each sensor is necessary. This resolution is enough for beekeepers, because during the active summer period hive weight changes starting from 1 kg up to 10 kg.

Weight measurement is performed with 1 s interval, data is then used by central module to calculate moving average value with 10 minutes step after which the calculated value along with local and remote (if any wireless sensor is used on other hives) temperature measurements are sent to cloud data server.

System components with approximate unit price are summarized (Table 1) below.

Table 1. System components with approximate unit price

Nr.	Name of the component	Quantity (pieces)	Price per piece (EUR)
1	Central data logging module (Zacepins et al. 2017)	1	53.50
2	50 kg Micro Load Cell	4	10.00
3	Base frame	4	7.00
4	MCP3421A0T on PCB and wires	4	2.50
		Total	131.50

The costs for one such system in authors case were approximately 131.50 EUR. System installation, maintenance, data storage, SIM card with appropriate data plan and usage of web system is not taken into account in those calculations.

This developed system can be easily upgraded and extended for example by temperature measurements of the whole apiary, proposed solution for this can be find in other author publication (Zacepins et al., 2017).

Weight data transfer procedure

Measurements from remote measurement node were transmitted to remote server using A6 GSM GPRS module, thus the data could be accessed by using a user-friendly Web application (Fig. 2). Successful operation of the mentioned A6 module requires mobile phone SIM card with data plan. Collected data could not only be used by beekeepers, but also could be accessible by agricultural institutions in order to evaluate overall honey production in the region.

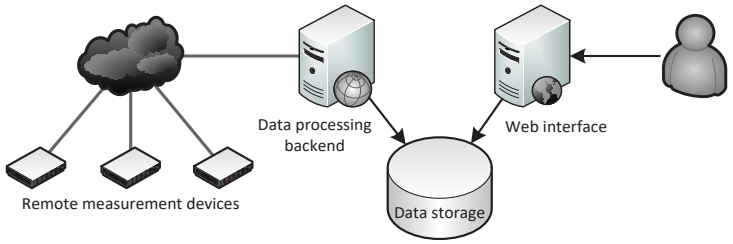

Figure 2. Concept of developed system architecture.

Hypertext Transfer Protocol (HTTP) and GET method are used to send data to server. Transmitted message consists of weight measurement data combined with central module ID, battery and PV voltage status. On server side PHP script retrieves the message, performs data processing and stores measurement information to database (Fig. 3). Data processing includes identification and raw data conversion (in order to save central module resources and power). Also using configurations stored in database allows changing measurement device parameters without accessing hardware (e.g. calibration parameters of load cell).

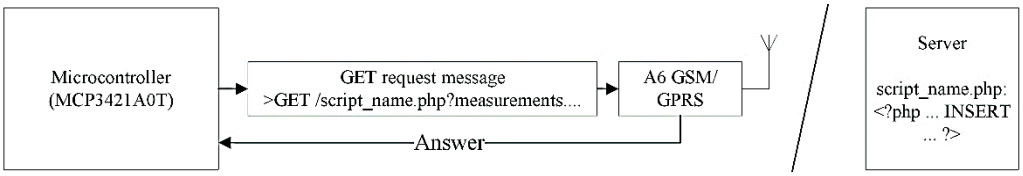

Figure 3. Schematic representation of measurement transmission.

Example of the GET method is shown below:
GET/script_name.php?type=c&devid=1&b=3500&pv=2500&t0=80&w0=2210&w1=2205&w2=2200&w3=2190
After the script is executed, results can be viewed in the developed Web application.

Practical experiments and measurements of bee colony weight

At the beginning, developed system prototype was tested in bee colony wintering building made from metal sandwich panels (Zacepins & Stalidzans, 2012). Unfortunately, it was observed, that data transmission was not stable at all and there was constant GPRS signal loss. Then system was tested in another bee wintering building, which is built from wood. Real system installation can be seen in Fig. 4. It was needed to use additional wood planks to grant stability and balance for the beehive. Measurement results for 30 minute period with 50 sec data transfer intervals are shown in Fig. 5:

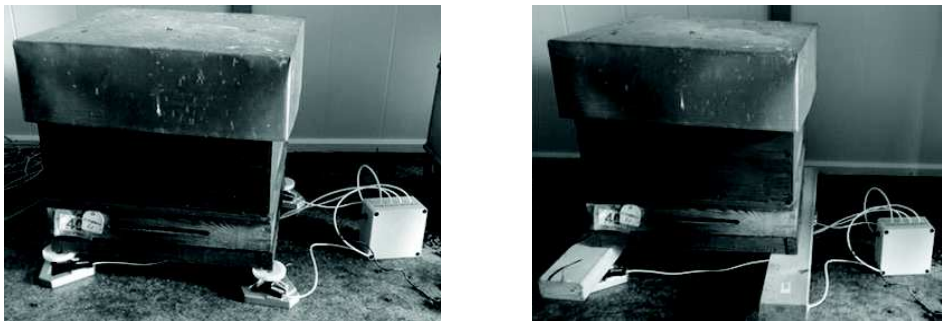

Figure 4. Installation of weight measurement system for beehive monitoring.

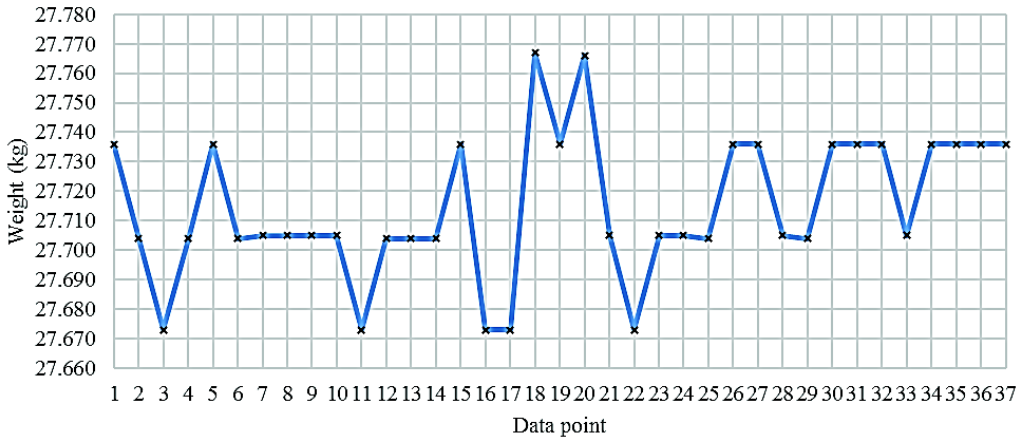

Figure 5. Measured bee colony weight data set.

As measurement period is only 30 minutes, there should be no weight change, but observing the data, some weight fluctuations occurred. Making some basic analysis it can be concluded, that average weight value is 27.715 kg with statistical variance of 587 g. This can be explained by fact, that measurement resolution for one load cell is 32 g, so measurement results can variate maximum by 128 g. This scale precision is enough for monitoring nectar flow during active summer period, but can not be used during the passive winter period, where weight change is less than 128 g.

CONCLUSIONS

Continuous and real time monitoring of bee colony parameters have become a common tool not only for research but also for practical beekeeping as electronic components become easier to deploy and maintain, owing to small, accurate, and robustly designed sensors. Monitoring hive weight allow beekeepers to observe hive health, and during pollination, those data could provide a record of quality control.

Precision Beekeeping is still in developing stage, but already there are various bee colony weight monitoring systems available.

Proposed honey bee weight monitoring system uses 4 load cells for weight measurements, very accurate (± 0.4 °C) temperature sensor and GSM/GPRS external interface for packet-based communication with remote server. Such a system can be set up also in a remote areas, since the main module is energetically self-sufficient and communicates with the database over cell network.

Weight data are sent to the cloud server in a 10-minute interval (containing measurements of weight, temperature and battery level).

For better precision of the weight system, measurement resolution for each load cell should be decreased from existing 32 g to detect weight changes during passive winter period.

Weighing honey bee hives hourly or even more often, using scales, shows data on hive growth and activity, provides precise information on timing and size of different colony events such as swarming, and permits researchers or beekeepers to control for weight changes due to foraging and rainfall.

Described system could also be extended with functionality for hive theft detection or detection of other disturbances (e.g, hives can be damaged by animals).

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