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AUTOMATED SYSTEM FOR BEE COLONY WEIGHT MONITORING

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ABSTRACT

Real time, continuous and remote monitoring of the honeybee colonies with application of information and communication technologies (ICT) is becoming increasingly frequent in industry and in a scientific research. Combination of ICT and beekeeping led to the development of the Precision Beekeeping approach. Successful implementation of the Precision Beekeeping system includes development of the bee colony monitoring hardware solution and computer software for data collection and further analysis. This paper describes developed and implemented bee colony monitoring unit for weight and temperature monitoring. Bee colony weight is one of the key metrics of the strength of a colony. Changes in weight can reflect the productivity rate of the colony, as well as its health and state. Developed monitoring system is based on Raspberry Pi Zero W single board computer with several connected sensors for bee colony temperature and environmental parameter monitoring. Weight is measured using single point load cell with possibility to measure weight up to 200kg, which is enough for the beehive measurements. Data transfer from the remote bee colony is provided by the external 3G router. For data storage and analysis cloud-based data warehouse is developed. Collected data is accessible in the web system with user friendly interface for data visualisation and reporting. Within this research scale calibration process is described and accuracy of the weighting is evaluated and possible challenges are discussed. Described monitoring system is developed within the Horizon 2020 project SAMS, which is funded by the European Union within the H2020-ICT-39-2016-2017 call. To find out more visit the project website https://sams-project.eu/.

Keywords: *Precision Beekeeping, Precision Apiculture, weight monitoring, bee colony monitoring, SAMS project*.

INTRODUCTION

Insects are the main pollinators for agricultural and horticultural plants (Kremen, Williams, & Thorp, 2002; Partap, 2011). Up to 79% of the human food supply today is dependent on pollination, and the honey bee is the most widespread and active pollinator animal worldwide (Bradbear, 2009; Breeze, Bailey, Balcombe, & Potts, 2011). Besides the important aspect of pollination, honey bees also produce a variety of valuable bee products like honey, beeswax, pollen and etc. which also leads to an economic benefit for the beekeeper (Crane, 1990). Recently Precision Beekeeping (Precision Apiculture) has been defined, as apiary management strategy based on individual bee colony monitoring (Aleksejs Zacepins, Brusbardis, Meitalovs, & Stalidzans, 2015). Within the Precision Beekeeping hardware and software solutions should be developed and implemented to assist the beekeeper by providing real-time data and decisions about the bee colonies and their states. The monitoring of honeybee colonies over long periods of time can result in long-term data for better analysis and understanding of the colony behaviour (Lecocq, Kryger, Vejsnæs, & Jensen, 2015; Odoux et al., 2014; Simon-Delso et al., 2014).

Behaviour and state of bee colonies can be monitored by use of temperature, humidity, acoustic, video, weight and other sensors (W. G. Meikle & Holst, 2015). Continuous monitoring of those parameters is becoming feasible for most beekeepers as the cost and size of the end devices decrease while their precision and capacity increase. Additional benefit of the remote monitoring of colonies is in minimising the number of local manual colony inspections as frequent, physical inspections of bee colonies interferes bees and can cause additional stress, that negatively affects the whole colony productivity (Komasilovs, Zacepins, Kviesis, Fiedler, & Kirchner, 2019; Zabasta, Zhiravetska, Kunicina, & Kondratjevs, 2019). As well implementation of the bee colony monitoring solutions provides economical benefit for the beekeepers, taking into account that every inspection of the remote apiary adds additional transportation costs to the beekeepers (W. G. Meikle & Holst, 2015; Zetterman, 2018).

Bee hive weight provides one of the most important kinds of data beekeeper can have about the colonies (Fitzgerald, Edwards-Murphy, Wright, Whelan, & Popovici, 2015). Automated weight systems can supply the beekeeper with important information on several important events from the honey bee colonies (Buchmann & Thoenes, 1990; McLellan, 1977; W. Meikle, Hoist, & Mercadier, 2006). Weight is related to such important activities of the bee colony like starting of nectar collection, resource consumption by the colony indicating the need of additional feeding. Weight data shows the beekeepers when to add supers or start a honey harvesting. Commercial beekeepers can use beehive scales to save unnecessary visits to the apiary when they do long-distance migration (Human & Brodschneider, 2013).

Idea of weighing of the bee colonies is not new, since the 1950s it is suggested to use weight as an indication of health and productivity (McLellan, 1977), and today there are a big number of ready commercial and homemade solutions for this purpose available for the beekeepers (Human & Brodschneider, 2013). One major difference among different vendors and systems is the number of load cells in the product, which may be one, two, or four, but any of these arrangements will work. https://colonymonitoring.com/current-sensors/ summarised many vendors and their products in one place. Besides the commercial products many handmade systems are available too. As well some scientifically used solutions are described in many publications (Cecchi et al., 2019; Fitzgerald et al., 2015; Gil-Lebrero et al., 2016; Ochoa, Gutierrez, & Rodriguez, 2019; Sengul Dogan, Erhan Akbal, 2017; Terenzi, Cecchi, Spinsante, Orcioni, & Piazza, 2019; Zabasta et al., 2019; A. Zacepins, Pecka, Osadcuks, Kviesis, & Engel, 2017).

Additional value of the bee colony monitoring is an option to geographically distribute and install of automated electronic scales (Lecocq et al., 2015), then share the collected data with other beekeepers to inform about the start of the nectar flow in different geographical regions. There are several such initiatives found in the web (list is not full and there are many more such systems):

- 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, Esaias, Wolfe, Nickeson, & Ma, 2008).
- https://www.beeandmegmbh.com/global-map-bee-hives - some of the beehive worldwide made public by the BeeAndme for scientific, collaborative or information purposes.
- http://mybees.buzz/ – this Web system shows data about main bee colony parameter changes from different Nordic countries, including Denmark, Sweden, Norway, Latvia and Estonia. System is developed by the Danish Beekeepers Association.
- svari.strops.lv – this Web systems shows data from several bee colonies located in Latvia using the Capaz monitoring system. System is developed by the Latvian Beekeeping Association.

The aim of this paper is to describe the developed honey bee colony weight monitoring system for weight and temperature measurements using one load cell, as load cells become a standard in bee colony weighing systems and Raspberry Pi Zero (Arduino, ESP?) computer.

Development of the bee colony weigh monitoring system is done within the Horizon 2020 project SAMS. A combined biological, sociological and technical approach is made within the SAMS - Smart Apiculture Management Services - project (https://sams-project.eu/).

DEVELOPED SYSTEM FOR WEIGHT AND TEMPERATURE MONITORING

Inapplicability for outdoor conditions of continuously loaded general purpose electronic scales and sometimes the high costs of the available commercial solutions limits their application in Precision Beekeeping. Manual weighing of the colonies is possible, but too laborious to perform frequently and also procedure of lifting the hive and putting on the scales makes addition disturbance to the bee colony (Stalidzans et al., 2017). So still there is an open possibilities and open market for development of affordable and reliable solution for the automated bee colony weighting.

Authors of this research developed prototype of honeybee colony weight monitoring system based on single point load cell (BOSCHE Wagetechnik Single point load cell H30A, https://www.bosche.eu/en/scale-components/load-cells/single-point-load-cell/single-point-load-cell-h30a) with max load of 200kg and Raspberry Pi Zero W single board computer. In addition, two sensors are added to the system for bee colony temperature and environmental humidity and temperature monitoring. For getting the weight data analogue/digital converter HX711 is used. At this stage system is powered by standard 220V power supply, but in the future, it is planned to implement power management from renewable energy sources (e.g. solar power) and additional battery for energy storage. As well for data sending to the remote server wi-fi network (provided by the 3G router) is used, but it can be easily substituted by mobile network adding additional module to the Raspberry Pi directly or even using modern data transfer technologies, like LoRaWAN (A Zacepins et al., 2018) or other. At this moment system is assembled using the breadboard, but after testing separate printed circuit board with casing will be designed and manufactured. Developed system's architecture is based on proposed approach by (Kviesis & Zacepins, 2015) where individual measurement node sends monitoring data to the remote server via wireless or mobile network.

Load cell is mounted between two metal plates (10cm x 15cm), and then metal plates are screwed to the plywood plates (50cm x 50cm) as described in the load cell manual. Beehive can be placed directly on the platform or some additional wooden planks can be used. Mounting of the load cell is shown in Figure 1.

Economic aspect is very crucial for the beekeepers, therefore system costs should be as minimal as possible. In authors case costs for system components and additional materials are summarised in Table 1.

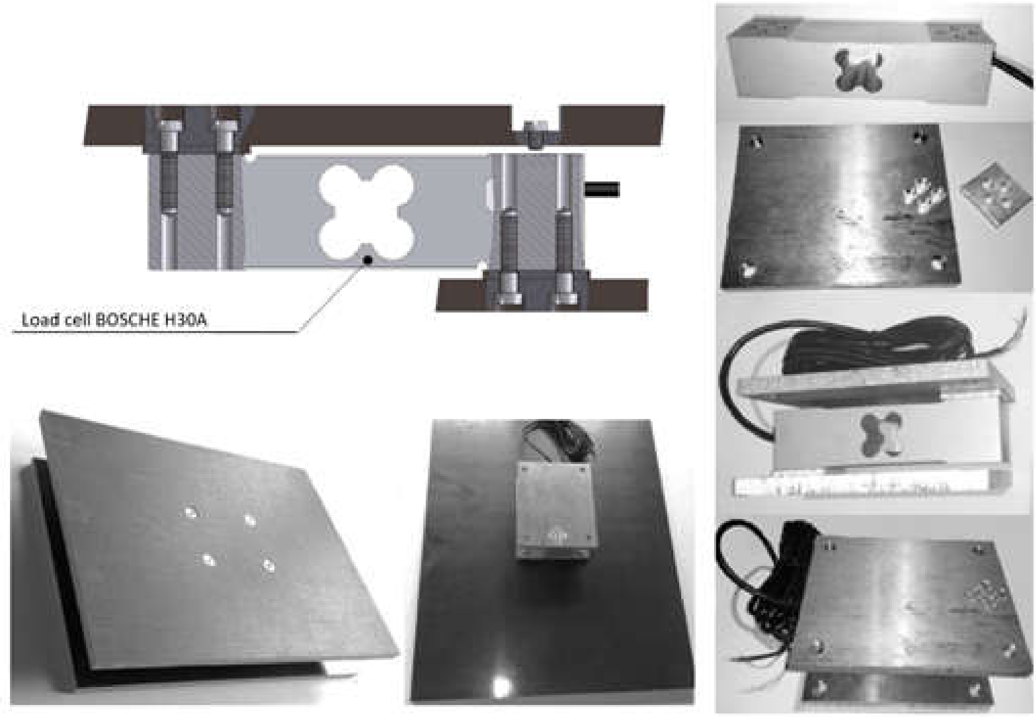

Figure 1. Load cell assembling process

Table 1. System components with unit costs

Nr.	Name of the component	Cost (in EUR)
1	BOSCHE Wagetechnik Single point load cell H30A (200kg)	50.00
2	Platform for load cell	50.00
2.1	Plywood	*14.00*
2.2	Metal plate	*14.00*
2.3	Screws	*2.00*
2.4	Assembling costs	*20.00*
3	Raspberry Pi Zero W + SD card	22.00
4	Temperature sensor DS18B20	4.00
5	Humidity and temperature sensor DHT22	7.00
6	A/D converter Sparkfun HX711	11.00
7	3G router Huawei E5330	37.00
8	Additional components (breadboard, wires, connectors, etc.)	10.00

The costs for one developed system are 191.00 EUR. System installation, maintenance, data storage, SIM card with appropriate data plan and usage of the web system is not taken into account in those calculations. As well some components are optional, like 3G router can be dismissed if there are Wi-Fi connection at the site.

Measurement intervals can be configured individually based on required information that should be gained from the system. In authors case, as system is powered from central power network measurement can happen more frequently that it would be needed in real situation. In authors case measurements are performed each 2 minutes.

Sensitivity tolerance of the chosen load cell is ±0.2 mV/V, which gives measurement error of ±1 g, nevertheless calibration with standard weight is necessary. This resolution is more than enough for the beekeepers, because during the active summer period hive weight changes can achieve 1-3 kg during the day.

LOAD CELL CALIBRATION PROCESS

For precise weight measurements load cell should be calibrated before placing the beehive on it. Calibration technically means to determine the difference between the scale readout and the actual weight on the weighing platform to determine accuracy. Calibration was performed placing an object with known weight on a scales, making several weightings and getting the needed offset and scale factor values.

For scales precision evaluation weighting experiment with known weights (5kg, 7.853 kg, 10kg, 17,853kg metal weight) using three physical weights of 5kg, 5kg and 7.853kg was performed in the laboratory. Ten measurements each two minutes was performed. Weights were placed at the centre of the scale platform. Overview of the test measurements are summarised in Table 2 below:

Table 2. Overview of the test weighing measurements

Id of the experiment	Known weight (g)	Average (from 10 readings) reading from the scales (g)	Error (g)	STDEV (g)	Error (%)
EXP-1	0	4,5	4,5	1,51	-
EXP-1	5000	5001,9	1,9	0,99	0,038
EXP-1	7853	7856	3	0,94	0,038
EXP-1	10000	10001	1	1,15	0,010
EXP-1	17853	17857,5	4,5	1,18	0,025

One of the possible problems with scales precision when using single point load cell could be when object is placed not in the centre but in some corner of the platform. To evaluate this, additional experiments are performed placing weights at different locations on the scale platform and making once again ten measurements each two minutes. Overview of the test measurements are summarised in Table 3 below:

Table 3. Overview of the test weighing measurements placing weights at different locations

Id of the experiment	Known weight (g)	Average (from 10 readings) reading from the scales (g)	Error (g)	STDEV (g)	Error (%)
EXP-2	17853	17848,9	-4,1	1,10	-0,023
EXP-3	17853	17864,4	11,4	0,84	0,064
EXP-4	17853	17877,1	24,1	1,52	0,135
EXP-5	17853	17858,1	5,1	1,45	0,029
EXP-6	17853	17855,9	2,9	0,88	0,016

Experiment set-up and location of weights is shown in Figure 2 below:

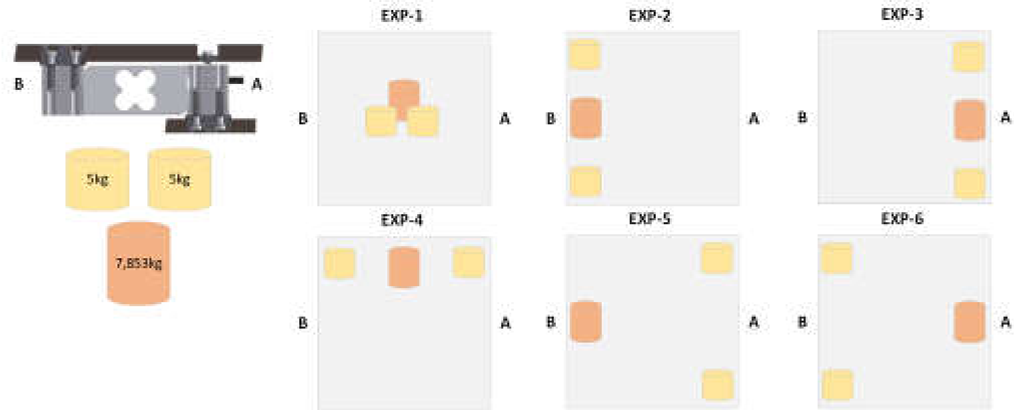

Figure 2. Location of weight on a scale platform during the weighting experiment

Analysing the measurements, it can be seen that there are minor changes in values depending on the placement of weight on a scale platform, but those can be considered as insignificant, as error is less than 1 %.

During the experiments it is found that any physical operation with scales, like lifting, changing its location affects the weighting values. Therefore, it needed to perform taring procedure each time scales are transported to a new location. For the beekeepers it is mean additional operation to perform before initial bee hive weighting. To make this process more user-friendly authors developed a physical interface for scale taring operation. Basically, additional button is connected to the system and when it is pressed system make taring operation.

Another issue found during lab experiments is weight fluctuation in relation to environmental temperature. With increase of the temperature weight is decreasing (see Fig. 3). Authors made a conclusion that A/D converter is affected by the temperature changes. It is confirmed by heating the A/D converter by the electric heater and monitoring the weight change.

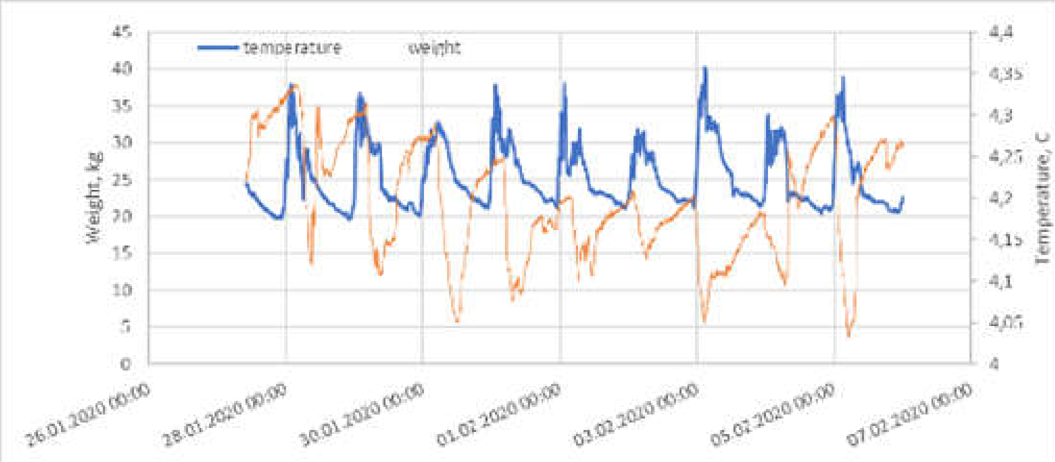

Figure 3. Relation of the weight measurements with environmental temperature

FIELD TESTS WITH DEVELOPED SYSTEM

After calibration, tests and experiments in laboratory system was installed in real environment to monitor two bee colonies during the passive wintering period. Practical experiments were conducted in the bee colony wintering building made from metal sandwich panels (Stalidzans et al., 2017) in the LLU apiary in Strazdu iela, Jelgava, Latvia. Colonies were placed in the wintering building on 21.01.2020. Figure 4 below demonstrates real placement of the developed system:

Figure 4. Installation of the system in real environment

For the measurement storage and analysis data management solution was developed. Authors called it data warehouse (DW). DW is developed with main aim to help beekeepers run the apiary more effectively by utilising higher amount of available data and accumulated data interpretation knowledge. DW architecture is developed considering flexibility and extensibility. Within the DW data visualisation is possible. Figure 5. below demonstrates chart with weight dynamic of the bee colonies:

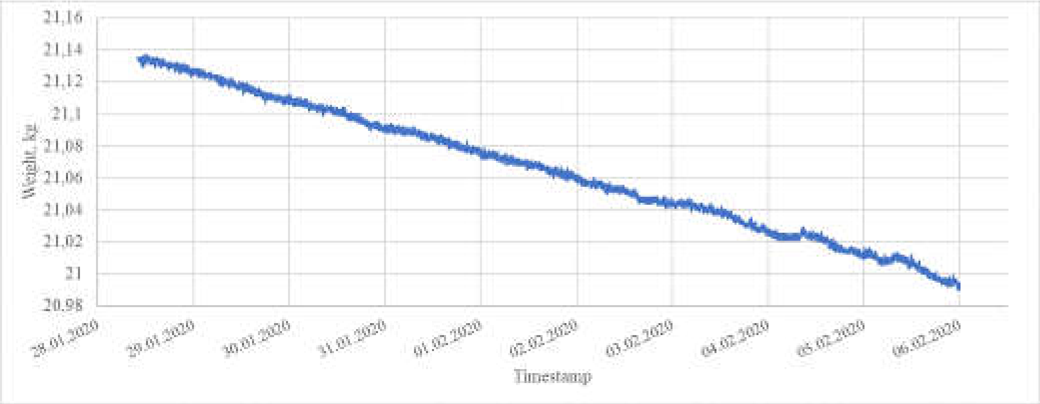

Figure 5. Weight dynamic of one bee colony

CONCLUSIONS

Continuous and real time monitoring of the bee colony main parameters like weight and temperature becomes a standard procedure in the beekeeping practice and acts as a first stage in implementation of the Precision Beekeeping approach.

Weight monitoring of at least one reference colony at the apiary can help to identify periods of the nectar flow and predict the colony foraging activity.

Developed system should be used to minimise the number of manual bee colony inspections, which should lead to the minimisation of stress to the bee colony.

Proposed honey bee weight and temperature monitoring system uses one load cell for weight measurements, very accurate (± 0.4 °C) two temperature sensors and Raspberry Pi for data collection from the sensors and transferring it to the remote data warehouse. In a future system can be set up also in a remote area, when alternative power supply and mobile network capabilities will be integrated.

Developed system could also be extended with additional functionality adding new sensors for example for detection of hive openings, or detection of other disturbances (e.g, hives can be damaged by animals).

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