

## **Modular sensory hardware and data processing solution for implementation of the precision beekeeping**

V. Komasilovs<sup>1</sup>, A. Zacepins<sup>1</sup>, A. Kviesis<sup>1</sup>, S. Fiedler<sup>2</sup> and S. Kirchner<sup>2</sup>

<sup>1</sup>Latvia University of Life Sciences and Technologies, Faculty of Information Technologies, Department of Computer Systems, Liela iela 2, LV-3001 Jelgava, Latvia

<sup>2</sup>University of Kassel, Department of Agricultural and Biosystems Engineering, Mönchebergstraße 19, DE34109 Kassel, Germany

\*Correspondence: [aleksejs.zacepins@llu.lv](mailto:aleksejs.zacepins@llu.lv)

**Abstract.** For successful implementation of the Precision Apiculture (Precision Beekeeping) approach, immense amount of bee colony data collection and processing using various hardware and software solutions is needed. This paper presents standalone wireless hardware system for bee colony main parameters monitoring (temperature, weight and sound). Monitoring system is based on Raspberry Pi 3 computer with connected sensors. Power supply is granted by the solar panel for reliable operation in places without constant source for power. For convenient data management cloud based data warehouse (DW) is proposed and developed for ease data storage and analysis. Proposed data warehouse is scalable and extendable and can be used for variety of other ready hardware solutions, using variety of data-in/data-out interfaces. The core of the data warehouse is designed to provide data processing flexibility and versatility, whereas data flow within the core is organized between data vaults in a controllable and reliable way. Our paper presents an approach for linking together hardware for bee colony real-time monitoring with cloud software for data processing and visualisation. Integrating specific algorithms and models to the system will help the beekeepers to remotely identify different states of their colonies, like swarming, brood rearing, death of the colony etc. and inform the beekeepers to make appropriate decisions/actions. This research work is carried out within the SAMS project, 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/>.

**Key words:** Precision beekeeping, data warehouse, bee colony monitoring.

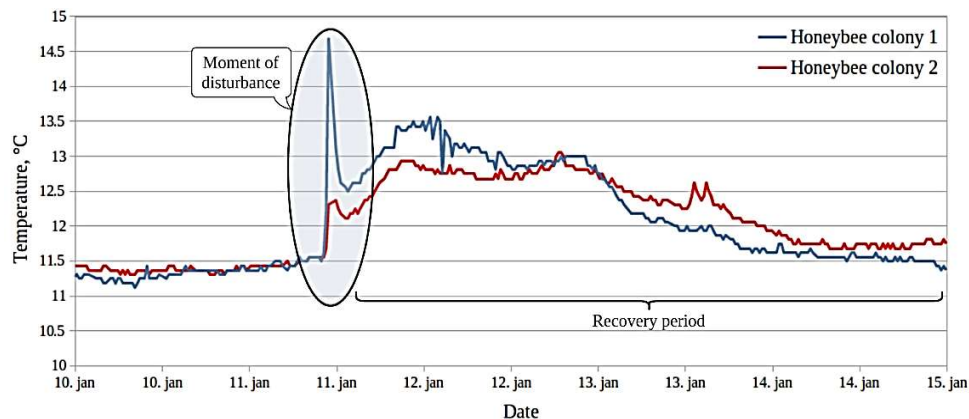
### **INTRODUCTION**

Bee health and sustainable beekeeping are a key for sustainable agriculture worldwide (Gallai et al., 2009; Kaplan, 2008). Risks of depleting honey production threatens livelihoods of beekeepers, but degradation of pollination power of suffering bee colonies threatens overall agricultural production and affects entire population. Approximately 75% of the crops, used for human feeding depends on pollination (Ollerton et al., 2011; Potts et al., 2016). The European honeybee *Apis mellifera* is the most economically valuable pollinator of agricultural crops worldwide. These insects can provide pollination generally to any fruit and vegetable, playing a crucial ecosystem service for agricultural food production and for wild plant diversity and conservation

(Bommarco et al., 2013; Klein et al., 2006). Many national and international projects like ITAPIC<sup>1</sup>, Swarmonitor<sup>2</sup>, Smartbees<sup>3</sup>, PoshBee<sup>4</sup> and others were implemented or are ongoing to study factors and parameters that may contribute to the bee health. In addition, several monitoring sensors have been developed for automatic beehive monitoring thus facilitating the development of the Precision Beekeeping (Meikle & Holst 2015). Precision Beekeeping is defined as an apiary management strategy based on the monitoring of individual bee colonies to minimise resource consumption and maximise the productivity of bees (Zacepins et al., 2015). Nevertheless, there still is a lack of a system which can be widely used and is very affordable for the end users (beekeepers).

Despite the fact there are number of implemented solutions for data collection about bee colonies, only few of them offer basic functionality for data analysis and decision making. This paper describes authors' developed bee colony hardware system for temperature, humidity, weight and sound monitoring linked together with a cloud data warehouse, specially designed for on-line data storage and close to real-time analysis and decision support actions. The proposed approach integrates two stages of the three-phase cycle of the Precision Beekeeping, including data collection and data analysis. Third phase – application of control actions, remains responsibility of the beekeeper. This phase, called also data utilization, usually involves the adjustment of important parameters and making the needed actions (Pentjuss et al., 2011). Author's approach can be integrated into a beekeeping practice to help the bees and pollination service they provide.

Research idea brings clear economic impact for the beekeepers. Proposed solution helps to remotely monitor bee colonies, recognize various states (for example normal, swarming, colony death) and minimise the necessity for on-site colony visits, therefore reducing beekeeper's spending on unneeded travelling to remote apiary. As well, bee colony health can be increased by minimising the number of beehive openings (see Fig. 1) (Stalidzans et al., 2017).



**Figure 1.** Temperature changes in the bee colony during manual hive weighing.

1 Application of Information Technologies in Precision Apiculture – <http://www.itapic.eu>

2 <http://www.swarmonitor.com>

3 Sustainable management of resilient bee populations – <http://www.smartbees-fp7.eu>

4 Pan-European assessment, monitoring, and mitigation of stressors on the health of bees – <http://www.poshbee.eu>

Every time when hive is opened and bee colony is inspected or any other manipulations with hive are done an additional stress is posed for the colony. Such stress can also be caused by manual weighting procedure.

In overall, developed approach facilitates optimization of operational beekeeping costs and minimises colony losses, increasing the profitability and stability of beekeeping.

This research is done within the SAMS<sup>5</sup> project. SAMS is a project funded by the European Union within the H2020-ICT-39-2016-2017 call. SAMS enhances international cooperation of ICT (Information and Communication Technologies) and sustainable agriculture between EU and developing countries in pursuit of the EU commitment to the UN Sustainable Development Goal “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”. SAMS proposes implementation of Precision Beekeeping by allowing active monitoring and remote sensing of bee colonies and beekeeping by developing appropriate ICT solutions supporting management of bee health and bee productivity and a role model for effective international cooperation. The outcome of the project will be a technologically enhanced beehive system and service including several components, like decision support system, advisory support tool, bee management business concept.

## **SENSORY HARDWARE FOR BEE COLONY MONITORING**

Many parameters of the bee colony can be monitored by the automated system, but not all of them can provide the beekeeper with valuable information. According to literature review and results of recent researches it is concluded, that system should measure temperature, humidity, weight and acoustic parameters of the colony. Temperature and humidity are the most commonly used metrics in precision beekeeping (Meikle & Holst 2015; Zacepins et al., 2015; Meikle et al., 2017). Hive weight is also a useful metric for monitoring the productivity of a colony with a correlation between honey production and different parameters of meteorological conditions (Fitzgerald et al., 2015; Ruan et al., 2017). In addition, monitoring of acoustics of bee colonies can be used for the prediction of e.g. swarming behaviour (Ferrari et al., 2008; Bencsik et al., 2011).

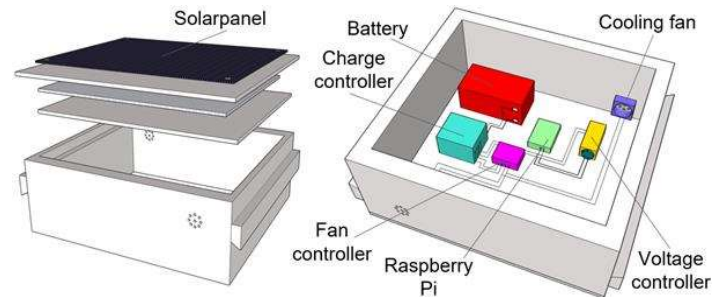
Developed system's architecture is based on proposed approach by (Kviesis & Zacepins 2015), where measurement node sends data to remote server via mobile network. According to the demands, a Raspberry Pi 3 (RPi) was used as Single-Board-Computer (SBC). The RPi was extended with a RPi-Shield-Audio Card and a microphone. A script addresses the sound card and converts the analog audio signals of the microphone. These signals are further broken down into their frequency components by means of a Fast Fourier Transformation (FFT). Using Wi-Fi and a mobile GSM router, the measured values are uploaded to a cloud server and deleted from the SBC memory. In case, radio transmission is not possible, the data remains on the device memory until a connection is established. Conversely, the SBC can also receive updates from the cloud server. Settings, such as the intervals of the data logger, can be changed by user from any computer with internet availability. In addition to the interval sizes for

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<sup>5</sup> International partnership on innovation in smart apiculture management services –<http://www.sams-project.eu>

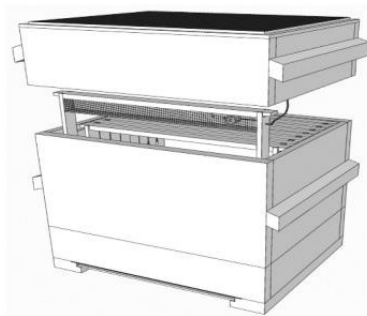
updates and uploads, variables that can be changed including the recording length of the audio signals and the sampling rate. The source codes will be available as open source on SAMS project website (<https://sams-project.eu/>).

The sensory hardware (see Fig. 2) is capable to obtain temperature data of the inside and outside temperature as well as weight data of the bee colony. A RPi capable sensor for temperature and a load cell in combination with an A/D converter is used for weight measurements. Additional sensors can be connected optionally.



**Figure 2.** Sensory hardware with casing, solar energy supply, single board computer and cooling.

Sensor placement in a modified broodframe is shown in Fig. 3, and the bee hive with installed monitoring system is demonstrated in Fig. 4.



**Figure 3.** Sensory placement in a modified broodframe connected with cable.

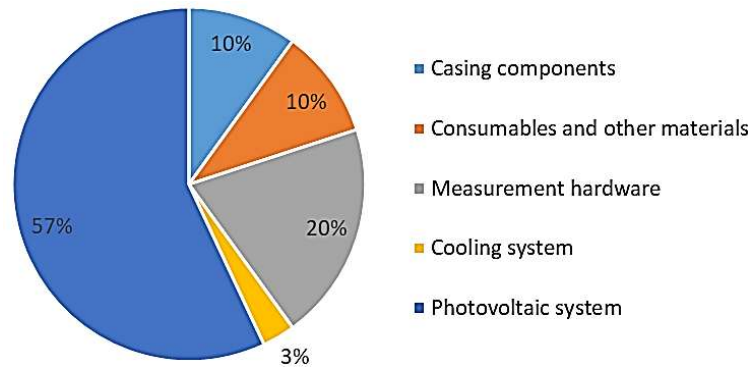


**Figure 4.** Bee hive with monitoring system prototype at the test site Witzenhausen of the University of Kassel.

In order to supply the system with electricity, a polycrystalline photovoltaic module with a system voltage of 12 V DC was used as a solar generator. To protect the battery from overcharging, a pulse-width modulated shunt controller with depth discharge protection was selected. To store energy a 12 V lead batteries with a capacity of 18 Ah was built in. For adequate ventilation, a temperature controller was installed in combination with two housing fans.

The energy consumption of the RPi depends on the specific sensor constellation. For the hardware configuration used here, the power consumption was less than 0.5 A. To reduce the consumption, the RPi can simply be started for the relevant measuring intervals using a time-controlled ‘power switch’. The component costs for the sensory system run to about 300 euros (see Fig. 5). If several sensor systems are used at one location, the power supply is designed to be shared. This reduces the specific costs

accordingly. Still it can be seen, that costs for granting power supply with alternative methods (photovoltaic system) is already expensive. System costs can be significantly decreased if the system is connected to the electrical grid available at the apiary. A honey chamber of a standard magazine hive for honey bees was selected as the casing for the hardware components. This is familiar to every beekeeper and can easily be placed on a beehive. In addition the construction principle can be transferred to magazine hives of other dimensions easily.



**Figure 5.** Cost distribution of the monitoring device. Complete system costs are about 300 euros.

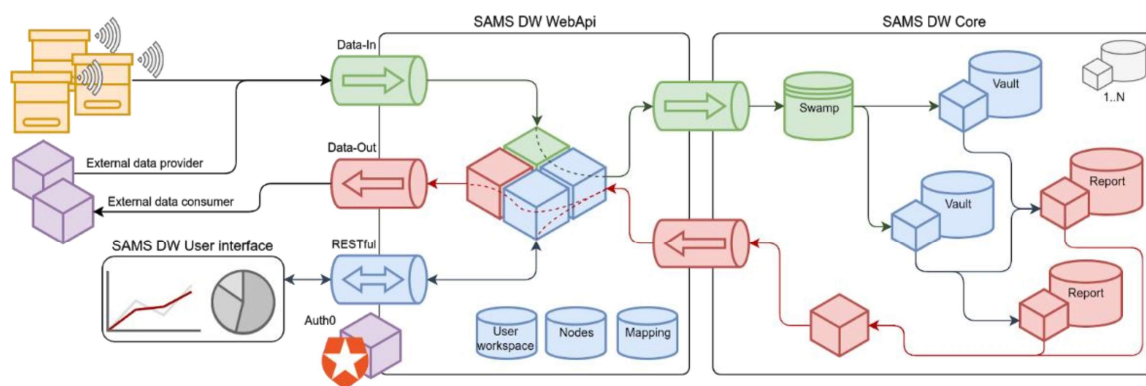
## DATA WAREHOUSE CONCEPT

Data warehouse (DW) can be considered as a universal system, which is able to operate with different data inputs and have flexible data processing algorithms.

By the definition data warehouse is like an intermediate layer between data provider systems and data consumer systems or end-users (Inmon, 2010). DW provides customizable facilities for data storage management, processing, analysis and output. The DW should be used to help beekeepers run the apiary more effectively by utilising higher amount of available data and accumulated data interpretation knowledge.

Authors suggest implementing DW as a cloud based data storage and processing unit with capabilities to combine different data sources like existing systems and available on-apiary generated data.

Architecture of the developed DW is demonstrated in Fig. 6. DW is capable to analyse data in the real-time or store it for future analysis.



**Figure 6.** Architecture of the developed data warehouse.

DW consists of three modules: a) Core – main data storage and processing unit; it receives data about various beekeeping objects in predefined format and distributes it through number of vaults and reports, which apply needed transformation to the data (e.g. aggregation, modelling, decision making); b) WebApi – intermediary unit between ‘outer world’ and DW Core; it provides number of HTTP interfaces for machine-to-machine interaction with external systems via Internet; main functions of the unit include request authentication and authorization, user private workspace management, data-in and data-out interface configuration and data conversion to/from DW Core supported formats; c) Graphical user interface – single-page web application provides user convenient way for managing the sources of incoming data (e.g. hives with monitoring devices) and getting insights into produced outputs (e.g. reports).

DW Data-in interface provides data input functionality for various data sources – it can be in a form of data files uploaded manually via user interface or via automated (scheduled) scripts, a bee colony measurement system configured, accordingly, to send data in accepted format, or third-party services, like weather station data.

Benefit of the DW is that data are processed almost immediately by involving different models for data aggregation and reporting. Modular architecture of the solution ensures isolation boundaries both for reliability reasons, maintenance and development considerations.

## LINKING REMOTE HARDWARE WITH CLOUD SOFTWARE

Remote hive monitoring systems (like Raspberry Pi based solution described previously in section ‘Sensory hardware for bee colony monitoring’) need special authentication mechanisms before sending data to the data warehouse. Since access to the Web API’s interfaces are protected by Auth0 authentication and authorization service, non-interactive Machine-to-Machine authentication flow is required (<https://auth0.com/docs/applications/machine-to-machine>). During such flow Auth0 service provides access token (a credential) that is issued to an authorized device and must be included into each HTTP request to DW endpoints. The access token has an expiration time (for example, 24 hours) and should be eventually renewed by the device. Remote measurement system is sending HTTP POST request to DW data-in interface, including authentication token within request header and JSON formatted data as a body of the request. A temperature and humidity HTTP POST example is shown below (where <token> is issued by Auth0 service and source IDs are arbitrary identifiers used for mapping incoming data to beekeeping objects like hives):

```
POST /api/data HTTP/1.1
```

```
Host: example.host.com:port
```

```
Authorization: Bearer <token>
```

```
Content-Type: application/json
```

```
[{"sourceId": "temp-id-123",  
  "values": [{"ts": "2018-10-10T23:06:00Z", "value": 33.2},  
             {"ts": "2018-10-10T23:07:00Z", "value": 33.5}],  
 {"sourceId": "hum-id-234",  
  "values": [{"ts": "2018-10-10T23:06:00Z", "value": 42.8}]}]
```

Upon receiving such request, it is validated against registered/allowed devices, and only then it is converted to appropriate format and sent to DW Core. Data processing involves various stages of pre-aggregation and actions performed by DW Core (see Fig. 6): temporary incoming data storing (swamp), data flow management, data vault activation, etc. Example of temperature measurements pre-aggregated into hourly record is shown below:

```
{ "_id" : "hive-549:2018101510",  
  "count" : 5,  
  "max" : 45.5,  
  "min" : 39.099998474121094,  
  "sum" : 213.39999771118164,  
  "values" : {  
    "15" : 44.400001525878906,  
    "17" : 45.5,  
    "20" : 41.599998474121094,  
    "23" : 39.099998474121094,  
    "27" : 42.79999923706055 } }
```

Described DW was implemented as a set of microservices and modules, built using Spring Boot 2.0 (back-end) and Angular 6 with Bootstrap 4 framework (front-end). MongoDB, a NoSQL database was used as a persistent storage for metadata and measurements.

Developed solution was approbated by building end-to-end data flow from hive prototype located in Witzenhausen, Germany to DW cloud service (physically hosted on servers in Jelgava, Latvia). In addition, for testing purposes room micro-climate monitoring hardware prototype was adapted to send temperature and humidity measurements to DW using the same data-in interfaces. Both devices are sending their measurements according to their schedules and become available in DW user interface in a form of quick overview of latest values as well as detailed parametrized reports. During implementation and testing period, several new versions of device and DW software were deployed. Modular architecture and flexible interfaces contributed to fast new feature development and deployment cycle.

## CONCLUSIONS

Development of the Precision Beekeeping direction is in active state nowadays, as many scientists and also industrial sector are heading toward development of solutions for improvement the management and monitoring of the apiary, minimising the beekeepers direct influence on the process.

Described systems and approach integrates two stages of the Precision Beekeeping, including data collection and data analysis. Third phase - application, remains still for the beekeeper.

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



The advantage of developed system is the possibility to detect abnormal behaviour of the colony at an early stage giving the beekeeper the chance to save their colonies.

At this moment system's prototype is used in experimental apiary in Germany, but in the future systems will be installed in apiaries in Ethiopia and Indonesia.

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