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APPLICATION OF THE INTERNET OF THINGS IN PRECISION BEEKEEPING IN LATVIA

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ABSTRACT

Beekeeping is one of the traditional branches of agriculture and honeybees are very valuable economic insects, as they are the main pollinators in the world. Precision beekeeping is a sub-branch of the precision agriculture, which combines information and communication technologies with beekeeping and is aimed at managing an apiary more effectively to minimise the bee colony losses. Real-time, remote monitoring of the colonies applying information and communication technologies (ICT) can help the beekeepers to detect abnormalities and identify different states of the colony. One of the trending information technologies is the Internet of Things (IoT), which helps to link remotely located objects with the web services and data platforms. This research presents the IoT approach in precision beekeeping for the remote bee colony real-time monitoring system using the IoT SIM card for the data transfer. The approach is tested in a real apiary located in Platone, Latvia. Five systems were installed and used for bee colony temperature and weight monitoring. For the data management MQTT protocol and interactive visualization web application Grafana were used. As an IoT SIM card provider company 1NCE was selected, which provided SIM cards for the evaluation purposes. In addition, system power consumption and data volumes were evaluated within this research. It was evaluated that the system can operate up to 40 days before the need for the battery change or charge. IoT SIM cards worked properly. Using this approach beekeeper was able to remotely monitor the weight gain of the colonies and decide when to move the colonies to a new location.

Keywords: *Precision beekeeping, smart apiary, IoT, IoT sim card, HIVEOPOLIS.*

INTRODUCTION

Nowadays Cloud Computing and the Internet of Things (IoT) are the two trending points in the Internet field (Zacepins et al., 2017). IoT approach and methods can be applied in many branches and domains of human life including but not limited to medicine (Lu et al., 2021), transportation (Zantalis et al., 2019), agriculture (Farooq et al., 2019), etc. The IoT can be defined as a network of Internet enabled objects linked with web services that interact with these objects (Zhao et al., 2010). This concept can be applied also to the beekeeping sector, which allows to convert beehives as a physical thing into a data generating device that is connected to the Internet. With the increase of the number of such active devices connected to the Internet around the globe, the possibility to identify different bee colony states and predict upcoming potential issues is becoming a solvable task. Beekeeping is an important productive branch of agriculture dedicated to the breeding and maintenance of bees; in addition, bees play a fundamental environmental role (Patel et al., 2021). Bees are in charge of producing special and healthy food and products' such as wax, royal jelly, bee venom, honey, pollen and propolis (Souza Cunha et al., 2020; Flores et al., 2021). Currently, bee colonies are faced with various challenges such as climate change, pesticides, and land use changes (LeBuhn and Vargas Luna, 2021) and the IoT approach can help in minimising these impacts. IoT technology became relevant to the end users and massive practical implementations as the decline of sensor size, cost and energy consumption, allows the manufacturing of extremely small and inexpensive low-end devices and microchips. IoT can be applied in a beekeeping sector too for remote and real-time monitoring of honeybee colonies, extending the precision beekeeping (PB) approach. PB 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 (Zacepins et al., 2021; Zacepins et al., 2015). Remote colony monitoring and decision making minimizes the consumption of resources and stress in the colony (Kviesis et al. 2020). It is important to emphasize that processing the collected data, transforming it into information, and extracting information from the data are the essential operations within data science (Aydin and Aydin, 2022). There are some examples of the IoT application and implementation in the beekeeping (Debauche et al., 2018; Dineva and Atanasova, 2017; Kridi et al., 2016; Zabasta et al., 2019; Cejrowski et al., 2020). The aim of this paper is to describe a developed IoT system for honey bee colony temperature and weight monitoring, using the IoT SIM cards for data transmission. An IoT SIM card is a variation of traditional SIM cards used in personal mobile devices that have additional features designed specifically for IoT devices. These features include things like being more durable, secure, and flexible.

Today in the market there are plenty of options for the IoT SIM cards (https://www.emnify.com, https://1ot.com, https://1nce.com, https://www.hologram.io, https://www.simoniot.com, and others). For the end-user, the most important questions are price and data volume as well as if additional features are available, like remote control of activating/deactivating the card, transparent information about data usage, etc. Prices can differ based on a geographical region. Some companies have flexible data plans based on a consumed data volume and additional fee for the device itself, some companies have fixed prices with limited data amount and defined lifespan. Authors selected

the IoT SIM card from 1NCE (https://1nce.com) as they have an office in author's local country Latvia and agreed to provide several SIM cards for the practical experiments and evaluation. 1NCE is the global Tier-1 IoT carrier specialized in providing managed connectivity services for low bandwidth IoT applications.
IoT SIM cards work by establishing a connection to the host network and transferring data between the device and the IoT data platform. IoT SIMs and traditional SIMs perform the same primary function, which is keeping internet-enabled devices connected to the Internet, and technically use of traditional SIM cards is possible for this purpose. But the advantage of the IoT SIM providers have extra management features available for the end-users. On the top of the SIM there is a powerful and flexible BSS system (Business Support System) which allows to manage even very large numbers of cellular connections via 1NCE Portal or via API integration. It also has powerful data transformation tools to minimize payload from IoT devises and ensure minimal data consumption. Also, such SIM is able to connect multiple operators in each country – depending on availability with the global coverage.

MATERIAL AND METHODS

This section describes the approach, used monitoring devices and data transfer procedure methods used within this study.

Location description

This research and measurements were carried out in Platone, Latvia, GPS coordinates: 56°33'32.8"N 23°41'04.1"E, during the honeybee foraging period of 2022, starting from 19.05.2022. Apiary is surrounded by the winter oil seed rape (*Brassica napus L.*) fields. This is a 60–130 cm high annual herbaceous plant belonging to the family of cruciferous plants (*Brassicaceae*).

Apiary description

Five honey bee (*Apis mellifera*) colonies were placed for remote monitoring (Fig. 1). Colonies were placed in polyfoam hives with one section dimensions of 170 mm (height), 550 mm (width) and 450 mm (depth) for brood and for honey. All hives were put in the same location in an open environment with a distance of at least 1 m between hives in one row. Hives were with different number of frames starting from 10 and up to 40 frames. Weight and temperature (inside the hive and outside) of the colonies were continuously measured with the time interval of 30 minutes between two measurements by the automated bee colony scales, and two digital temperature sensors.

Figure 1. Apiary with five honeybee colonies

Monitoring device

All five colonies were equipped with bee colony monitoring systems based on the ESP8266 microchip inspired by the monitoring system developed within the SAMS project (Wakjira et al., 2021) and described in detail in another author publication (Zacepins et al., 2020). For weight monitoring, a single-point load cell Bosche H30A is used. For the bee colony temperature monitoring DS18S20 1-Wire® sensors were used. The accuracy and precision of the single-point load cell were empirically evaluated by (Kviesis et al., 2020). The precision of the scale measurement system (single-point load cell H30A together with the 24-bit HX711 A/D converter) was observed to be around 10g.

One temperature sensor (Dallas DS18S20) per colony was installed inside the hive above the hive body (brood frames) as suggested by Stalidzans and Berzonis (2013).

The monitoring system was powered by a Sony Li-ion 18650 3.7 V 3120 mAh battery. Additional GSM/GPRS module SIM800L was attached to the monitoring device for the IoT SIM card, which required additional power supply. For this purpose an extra Sony Li-ion 18650 3.7 V 3120 mAh battery was used per monitoring system. Data about the bee colony and battery charging status were collected every 30 minutes and sent to the remote data platform.

Data transfer approach

Schematic overview of the data transfer procedure is demonstrated in the figure below.

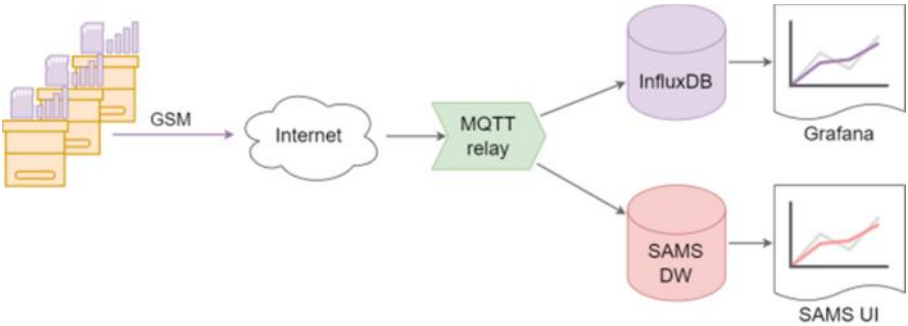

Figure 2. Architecture of the data transfer approach.

Five bee colony monitoring nodes are transferring data using the MQTT protocol. The MQTT broker coordinated the incoming and outgoing messages. Within this data transfer procedure, authors developed an “MQTT relay” component, which subscribes for specific data-in MQTT topics and carries out data storing routines upon the incoming messages. Two data platforms are used for data persistence: InfluxDB instance hosted on-premises and SAMS DW (Zacepins et al., 2020). Internet connectivity is ensured using IoT SIM cards provided by the 1NCE company. For the data observation multi-platform open source analytic and interactive visualization web application Grafana (https://grafana.com) is used to present data stored in InfluxDB, and SAMS UI for the SAMS DW stored data. The screenshots below (Fig. 3 and Fig. 4) demonstrate how the summary of one bee colony monitoring was shown to the beekeeper in real-time in both applications.

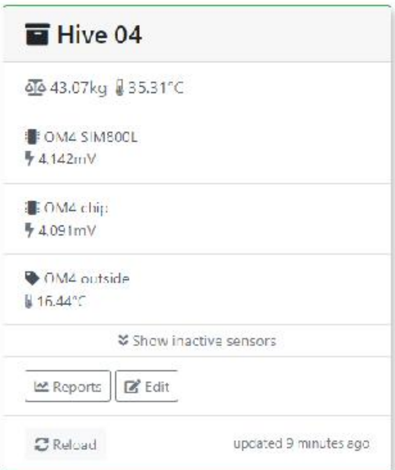

Figure 3. Summarized view in the SAMS UI.

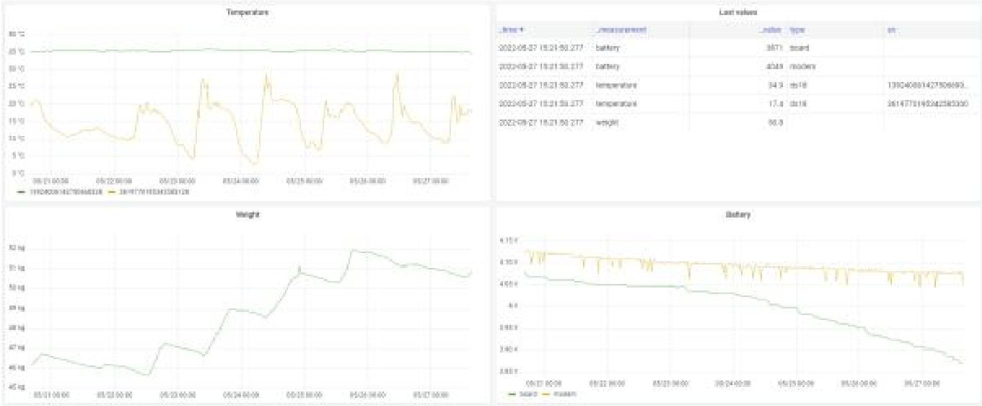

Figure 4. Detailed view in the Grafana UI.

RESULTS AND DISCUSSION

Data packet size

As the IoT SIM cards have limited data volumes, optimisation of the data packets sent to/from the data platform is crucial in the development process.

Data packet consists of several parts: bee colony measurement data itself and technical data defined by network protocols (such as handshake and security certificate exchange). The total overhead to establish a new TLS session is around 6500 bytes on average (http://netsekure.org/2010/03/tls-overhead). Different technical messages sent during the TLS session are: ClientHello, ServerHello, Certificate, ClientKeyExchange, ChangeCipherSpec, Finished. In the authors' case, the total overhead is equal to 6567 bytes. It should be mentioned that measurements data package itself is only 47 bytes, which is less than 1% of the whole data usage, and if data packets can be optimized by the developers, technical data defined by TCP, TLS and MQTT protocols cannot be affected.

There is an option to use data communication without TLS, then the total overhead is 668 bytes. But it is not recommended as in this case sensitive information from the monitoring nodes, like passwords, are transferred in plain text. One can use plain UDP packet with only reading data – plain binary. This can be sent to AWS via 1NCE Connectivity Suite and the SIM card can be used as a secure Authorization tool. In this case, plain UDP packet almost without any overhead after being received on AWS account with the serverless Lamda function can be securely transferred to any backend – with all the security protocols. This will ensure minimal payload data consumption from the cellular modem via mobile network. For better data usage tracking, 1NCE provides a web interface where users can observe and monitor data usage for all IoT SIM cards and individually for each SIM card.

Evaluation of the system battery life for the continuous monitoring

The bee colony monitoring system was powered by two Sony Li-ion 18650 3.7 V 3120 mAh batteries (one for the monitoring node, one for the SIM module). By summarizing the battery discharge dynamics, it was concluded that the monitoring system's daily battery drain is around 8.0 – 18.5 mV, where battery discharge for the SIM module is higher than for the monitoring module. Difference in discharge rate can be explained by the power consumption of the SIM module (peak current draw can reach ~2A during transmission burst mode and up to ~400mA during data mode (GPRS) (Shanghai SIMCom Wireless Solutions Ltd., 2015)) and the time needed for the module to connect to the cell tower, enable data mode and perform the data transfer procedure. It was evaluated that the system can operate up to 40 days before the need for the battery change or charge to avoid over-discharge and potential damage to the battery.

Costs estimation

Beekeepers are not willing to invest much in the digital solutions, thus the economic aspect of the system is very important and system costs should be as minimal as possible. The list of used system hardware components with approximate unit price are summarized in Table 1.

Table 1. The list of used system hardware components with unit price.

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
3	ESP8266 microchip including adapter plate	13.00
4	Temperature sensor DS18B20 (x2)	8.00
5	A/D converter OKYSTAR HX711	6.00
6	Additional components (PCB, wires, resistors, capacitors, connectors, etc.)	10.00
7	Rechargeable battery Sony Li-ion 18650 3.7 V 3120 mAh (x2)	18.00
8	SIM800L module	5.00
Monitoring node overall costs		160.00

The calculated costs for one monitoring system are 160.00 EUR (based on local prices in Latvia). System installation, maintenance, data storage, IoT sim card with appropriate data plan and usage of the web system is not considered in these calculations.

Analysis of bee colony data

Focus of this study was not on a comprehensive data analysis and the bee colony state and health recognition, but more on the approach of how to collect and transfer bee colony data to the endpoint. But for demonstration purposes authors would like to provide some charts visualizing bee colony temperature and weight dynamics of the monitored colonies indicating useful scenarios for the beekeeper. Data was collected from 19.05.2022 and the process is still ongoing.

By continuous weight monitoring it is possible to identify daily patterns of the bee activity during sunny days. Continuous monitoring of the honey bee colony weight allows beekeepers to identify daily patterns of their activity during sunny days. Based on the weight data, honey bee day can be split into 3 periods: nectar processing by reducing the water content during the night time; flying out for the foraging when ambient temperature reaches 8 and it is sunny; coming back with collected nectar (see Fig. 5).

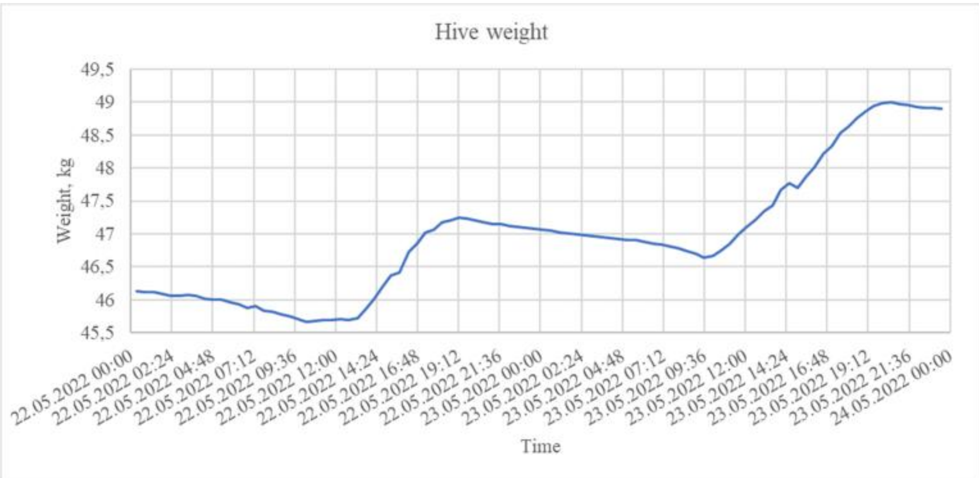

Figure 5. Daily routine of one honey bee colony during the sunny days.

By continuous temperature monitoring, conclusions can be made about the status of brood rearing in the colony during the summer period. To ensure the optimal development of brood, a honeybee colony needs to maintain its temperature within a certain range of values (thermoregulation), regardless of environmental changes in biotic and abiotic factors (Godeau et al., 2022).

Figure 6 below shows the temperature in colonies and indicates that optimal development of the brood is ensured, when temperature is between 34 and 36 .

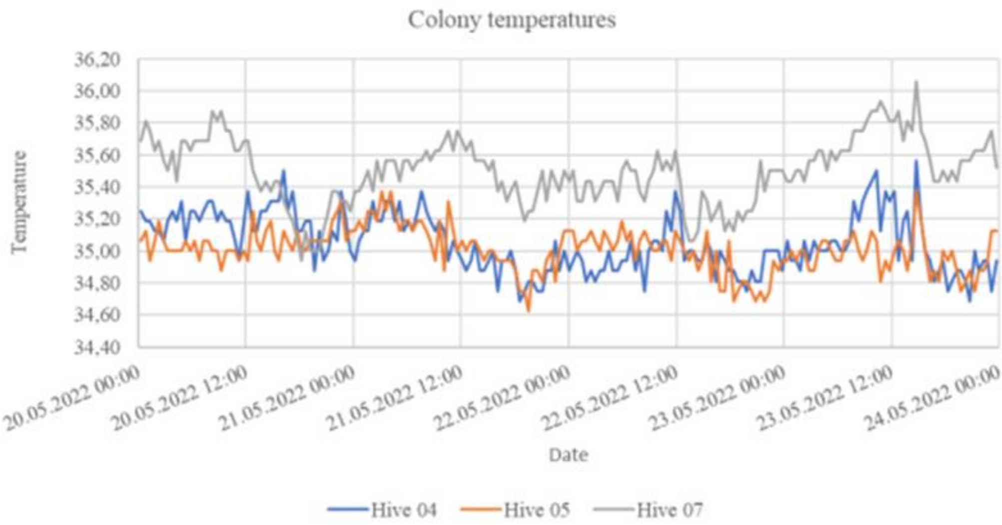

Figure 6. Temperature dynamics in some honeybee colonies.

CONCLUSIONS

Latest trends indicate an increasing correlation between the use of modern information and communication technologies with the successful development of beekeeping practice. New technologies enable beekeepers to make their business more efficient by reducing costs, minimising the number of on-site colony inspections. IoT solutions help to build-up the interaction between beekeepers and bee colonies. The ability to transfer data from a practically unlimited number of sensors over a long distance and the ability to analyse all the data in the cloud, makes the Internet of Things an indispensable technology to digitize beekeeping.

By using individual GSM/GPRS module per measurement node, the colony monitoring in the apiary becomes more distributed, decentralized and is not dependent on one central element (gateway, WiFi router) that allows data transmission to the cloud, therefore limiting the potential data loss of all connected nodes in case the central unit fails. One of the potential future research direction within this topic is the optimization of payload data from the cellular modem.

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