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Leveraging IoT Technologies for Smart Hive Management and Sustainable Beekeeping

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Povzetek. Precision beekeeping (PB) integrates digital tools into apiculture to optimize hive management, improve productivity, and enhance sustainability. The study explores the implementation of the Internet of Things (IoT) technologies in beekeeping. It presents a case study within the CODECS Horizon Europe project [1]. The case study which is related to beekeepers managing apiaries in remote locations highlights the need for remote monitoring systems. The key technological solutions include automated IoT-supported hive scales, refractometers for measuring the honey moisture content, and conductometers for assessing the honey conductivity. These tools enhance the economic, environmental, and social sustainability by reducing the labor, optimizing the honey production, and minimizing the carbon emissions from unnecessary travels. Results indicate that digital monitoring improves decision-making, reduces colony losses, and supports a data-driven approach to beekeeping, thus promoting sustainable agricultural practices.

Ključne besede: precision agriculture (PA), digitalisation, IoT sensors, sustainability, apiculture, beekeeping

Izkoriščanje tehnologij Interneta stvari (IoT) za pametno upravljanje panjev in trajnostno čebelarstvo

Natančno čebelarstvo (PB) vključuje digitalna orodja v čebelarstvo za optimizacijo upravljanja panjev, izboljšanje produktivnosti in krepitev trajnosti. Ta študija raziskuje uvedbo tehnologij Interneta stvari (IoT) v čebelarstvo ter predstavlja študijo primera v okviru projekta Horizon Europe CODECS. Študija primera se nanaša na čebelarja, ki upravlja čebelnjake na oddaljenih lokacijah, kar poudarja potrebo po sistemih za daljinsko spremljanje. Ključne tehnološke rešitve vključujejo avtomatizirane IoT-podprte tehtnice za panje, refraktometre za merjenje vsebnosti vlage v medu ter konduktometre za oceno prevodnosti medu. Ta orodja izboljšujejo ekonomsko, okoljsko in socialno trajnost z zmanjšanjem potrebe po fizičnem delu, optimizacijo proizvodnje medu in zmanjšanjem emisij ogljikovega dioksida zaradi nepotrebnih potovanj. Rezultati kažejo, da digitalno spremljanje izboljšuje sprejemanje odločitev, zmanjšuje izgube čebeljih kolonij ter podpira podatkovno usmerjen pristop k čebelarstvu, s čimer spodbuja trajnostne kmetijske prakse.

1 INTRODUCTION

Precision agriculture (PA), which uses the technology and data to optimize farming practices in terms of the resource use and crop production and advancing agriculture towards modernization, attracts interest from a diverse range of stakeholders, such as farmers and growers, agribusinesses, technology companies, researchers and academics, environmental and sustainability advocates, and governments and policy makers. The PA application extends to beekeeping, a crucial environmental field, giving rise to "precision beekeeping" (PB) or "precision apiculture". This management approach involves monitoring individual bee colonies to minimize the resource consumption and enhance the bee productivity. Bees play a pivotal role in ecology, through pollination of valuable crops and by supporting biodiversity via the conservation of wild plants. Also, bees serve as bioindicators, detecting the environmental pollution, either by radioactive substances, pesticides, or toxic metals [2].

Due to the climate changes and farmers' adaptation strategies, the honey bee populations are exposed to various anthropogenic stressors such as the pesticide exposure [3], changes in the land use [4], presence of metal trases and polycyclic aromatic hydrocarbons [5], diseases and pests [6], and inadequate beekeeping practices [7]. Both the individual and combined effects of these factors can severely impact the bee populations, leading to substantial colony losses [8].

2 SUSTAINABLE APICULTURE

For the sustainability of beekeeping, it is important to adopt practices that protect both the bees and the broader environment. Incorporating modern technologies like IoT sensors for continuous monitoring enables

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beekeepers to detect problems early and to take a timely action to maintain the hive health. These techniques help ensure a long-term health of bee colonies, support biodiversity, and contribute to the sustainability of agricultural ecosystems [9].

Traditional beekeeping techniques, which mainly depend on manual inspections, have been a staple of hive management for generations. However, they are time-consuming and fail to provide a continuous or real-time monitoring. As a result, early indicators of the hive health issues often go unnoticed, contributing to avoidable colony losses [10].

Digital technologies, particularly IoT sensors, have significantly transformed beekeeping practices by enabling a continuous monitoring of crucial hive parameters, including temperature, humidity, weight, pest detection and bee activity and behavior monitoring, such as the entrance activity and flight path tracking. These sensors transmit real-time data to cloud-based platforms, where AI algorithms process the information and provide beekeepers with actionable insights, helping them to optimize the hive management without physically disturbing the bees, thereby enhancing the health of the bee colonies and improving the pollination outcomes [11].

Adoption of the IoT technologies allows beekeepers to remotely track hive conditions, thereby increasing the efficiency and minimizing the reliance on physical inspections. By providing real-time data on environmental factors and hive health, these technologies enable an early intervention in response to the issues like the diseases or unfavorable weather, which may severely harm the colonies [12].

Smart beehive monitoring marks a transformative advancement in apiculture. Key innovations include 4G-connected hive scales for real-time weight tracking, environmental sensors to monitor the temperature, humidity, wind and air quality, sound sensors to detect hive health issues, sensors or cameras to detect pests and advanced data analytics to translate collected data into actionable insights. The monitoring is complemented by mobile and cloud platforms and applications enabling beekeepers to access the hive information remotely and conveniently. The use of the IoT technology optimizes the honey production, reduces the labor and supports the data-driven decision-making, also revolutionizing the apiary management for an enhanced sustainability and efficiency [13].

Following the above, the paper presents a case study using digital tools in apiculture. It demonstrates how this use enhances the hive management while contributing to the environmental, economic and social sustainability.

3 CASE STUDY

As part of the CODECS project [1], currently ongoing Horizon project, estimating the costs and benefits associated with farm digitalisation, we have established the Slovenian Living Lab Smart Villages Network an initiative that brings together farmers, researchers, technology providers, and government representatives to foster a "learning culture" through collaborative projects. It explores the use of digital technologies in agriculture. The Living Lab applies digital technology in viticulture and beekeeping to improve the environmental, economic, and social sustainability [14]. More about the use of the IoT sensors in viticulture can be found in [15]. The testing of the IoT-supported remote control of beehives, which has already started, has been seen a lot of attention of many beekeepers due to the changed environmental conditions.

The case study is related to a Slovenian beekeeper, Beekeeping Cesar (Slovenian: Čebelarstvo Cesar) [16], which represents a demo farm in this project of CODECS, who has his apiaries located at three remote locations across Slovenia. The first one is in Razvanje, a village south of Maribor, northeastern Slovenia (static apiary, near his home). The second is Pohorje, a mostly wooded, medium-high mountain area south of the Drava River in northeastern Slovenia (mobile apiary) The third one is located in the region of Prekmurje, in a village close to the Austrian border, called Sodišinci (mobile apiary). Therefore, there is a need of systems for remote control of the situation in the beehives. After conducting a research in collaboration with the beekeeper, we identified key challenges and explored existing technologies to address these issues. Based on the identified needs, we selected the most appropriate technological solutions [17].

The proposed technological solutions to the identified needs are:

- An automated measurement system to monitor the honey production and weather conditions in beehaves;
- A refractomter to measure the water content in the honey, and
- A cundoctometer to measure the honey electrical conductivity.

The main reasons to introduce the above technology are:

- Economic, to improve the farm profitability and management controlling the beekeeping process;
- Environmental, to lower the CO2 emissions by eliminating driving to the beehives locations to analyse the honey type;
- Social, to save the time and use it for other purposes.

3.1. An automated measurement system to monitor the honey production

The IoT-supported scale is an advanced beekeeping scale designed as an automated system for monitoring the honey production in beehives. This technological tool provides beekeepers with precise and continuous data, enabling efficient management of the hives. The system measures the weight of the beehive, which serves as a critical indicator of the honey production and overall hive activity. By tracking the weight fluctuations, the system provides an insight into the hive performance. It also records environmental parameters important for maintaining optimal hive conditions.

In our study, the IoT-supported scales (TCM-13A) [18] are placed under beehives on three different and remote apiaries (Figure 1). The IoT scales measure the weather parameters: rain, wind, nest temperature, external temperature, and relative humidity. The main feature of the scale is its ability to transmit the data in real time. Each scale has a SIM card because it uses GSM/GPRS in order to send daily SMS to the beekeepers' mobile phone. A mobile signal is needed only for sending SMS. Automated alerts notify the beekeeper about significant changes, such as rapid weight increases indicating the honey flow or decreases that may signal potential issues. The beekeeper sets the time of which the scale measures the climate data or calls the scale to get the current data immediately. The collected data can be further analyzed to support decision-making regarding the hive management.

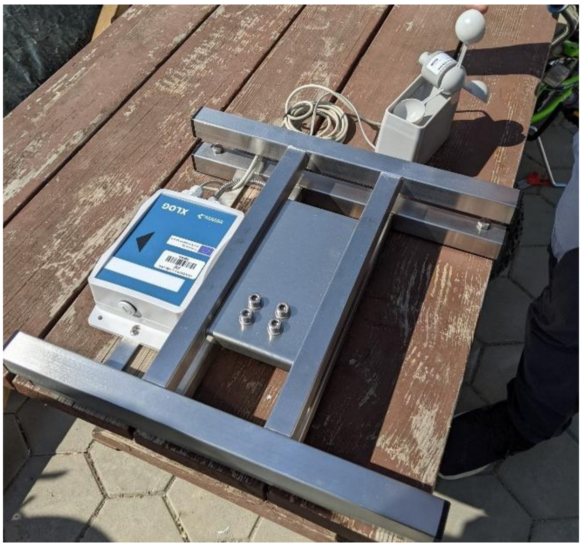

Figure 1. IoT scale.

The automated monitoring system significantly enhances the efficiency and precision of beekeeping practices. By reducing the need for manual inspections and providing early warnings of hive issues, the scale improves the hive productivity. Its ability to support remote monitoring further underscores its value in managing hives located in remote or hardly accessible areas.

3.2. Refractometer

The used refractometer (RHB-90 ATC) [19] shown in Figure 2 is used to measure the water content in the honey. This is crucial because honey with too much moisture can ferment and spoil, while honey with the proper moisture level will remain stable for a long-term storage.

Figure 2. Refractometer.

A beekeeper places a small sample of the honey on the refractometers' prism. By looking through the lens, he sees the percentage of the water content based on how light is refracted through the honey. Monitoring the water content ensures the honey is harvested at the right time, which is important for maintaining a high quality and preventing fermentation. With the help of this device, the beekeeper can do it instantly and on the spot.

3.3. Conductometer

The used conductometer (Combo pH/Conductivity/TDS Tester (High Range) - IC-HI98130) [20] measures the electric conductivity of the honey (Figure 3) to differentiate between different types of the honey, particularly the floral honey (from nectar) and the honeydew honey (from tree sap).

Figure 3. Conductometer.

The conductivity is determined by the presence of minerals and salts in the honey. The honeydew honey has a higher conductivity than the floral honey because it contains more minerals.

Beekeepers and honey producers use conductometers to classify the honey type (honeydew vs. floral), which affects the honey pricing and quality assessment. It's also used to ensure the honey meets certain regulatory or market standards, especially in Europe.

4 OUTCOMES

Prior to the adoption of the technological solutions, beekeeping practices were largely reliant on manual predictions and observations. The beekeeper would regularly consult the data from the National Weather Agency and the Austrian Weather Agency to assess the environmental conditions impacting the bees in remote locations. If significant weather changes were intuitively predicted, the beekeeper would physically visit the beehive site to evaluate the situation and address any urgent needs, such as feeding the bees, providing water, or collecting the honey. The process depended heavily on the beekeeper experience and intuition, often requiring frequent trips to the hives to ensure the well-being of the colonies. With the implementation of modern technological tools, the beekeeper practices have become more streamlined and data-driven. On a daily basis, the beekeeper now receives notifications via SMS, providing real-time updates on the environmental status of the bees in remote locations [17]. Figure 4 shows a mobile phone screenshot of an SMS containing the data for the measured parameters (e.g., time of the day, weight, temperature, humidity etc.) received from an IoT scale.

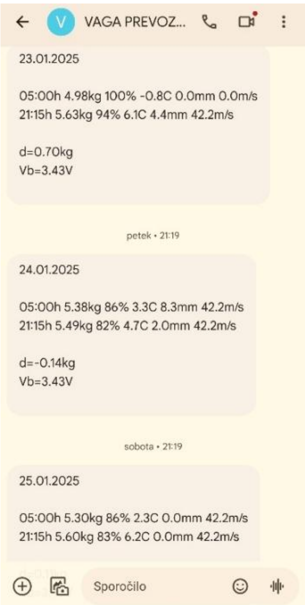

Figure 4. Data received from an IoT scale displayed on a mobile phone interface.

In case of significant weather changes or adverse conditions, a beekeeper can respond promptly by traveling to the hives to provide necessary resources. Moreover, the ability to request the current data from the hives at any time allows the beekeeper to monitor the well-being of the colonies remotely and make informed decisions about future management activities.

Previously, the beekeeper faced significant logistical challenges related to honey samplig as well, as their three apiary locations across Slovenia are remote and difficult to access. Honey sampling required traveling to the sites, collecting honey, and returning to a city for samplings analysis. With the introduction of refractometers and conductometers at these locations, analyses can now be performed directly on-site. This technology eliminates unnecessary travel, reduces manual inspections, and supports better hive health and productivity, improving efficiency and time management [17].

5 CONCLUSION

The integration of the IoT and digital tools in apiculture presents significant advantages for hive management, sustainability and productivity. The paper demonstrates how an automated monitoring systems reduces the manual labor and the number of unecessary travels to the apiaries, improves the data accuracy and enhances the efficiency of beekeeping practices. By implementing IoT-supported hive scales, refractometers and conductometers, beekeepers remotely monitor the hive conditions, optimize the honey production and minimize the environmental impact. It also highlights how these technologies contribute to sustainability by reducing carbon emissions, preventing colony losses, and improving overall management efficiency. As environmental challenges continue to impact the bee populations, adopting digital solutions is becoming increasingly important. Future research should focus on expanding the use of the IoT technologies across diverse beekeeping environments to further validate their effectiveness in enhancing apiculture sustainability.

REFERENCES

[1] Codecs | Maximising the CO-benefits of agricultural Digitalisation through conducive digital ECoSystems, https://www.horizoncodecs.eu/

[2] Zacepins, A., Stalidzans, E., & Meitalovs, J. (2012, July). Application of information technologies in precision apiculture. In *Proceedings of the 13th International Conference on Precision Agriculture* (ICPA 2012) (Vol. 7).

[3] Tsvetkov, N., Samson-Robert, O., Sood, K., Patel, H. S., Malena, D. A., Gajiwala, P. H., ... & Zayed, A. (2017). Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science, 356*(6345), 1395-1397. DOI: https://doi.org/10.1126/science.aam7470

[4] Otto, C. R., Roth, C. L., Carlson, B. L., & Smart, M. D. (2016). Land-use change reduces habitat suitability for supporting managed honey bee colonies in the Northern Great Plains. *Proceedings of the National Academy of Sciences, 113*(37), 10430-10435. DOI: https://doi.org/10.1073/pnas.1603481113

[5] Di Noi, A., Casini, S., Campani, T., Cai, G., & Caliani, I. (2021). Review on sublethal effects of environmental contaminants in honey bees (Apis mellifera), knowledge gaps and future perspectives. *International Journal of Environmental Research and Public Health*, *18*(4), 1863. DOI: https://doi.org/10.3390/ijerph18041863

[6] Pasho, D. J., Applegate, J. R., & Hopkins, D. I. (2021). Diseases and pests of honey bees (Apis mellifera). *Veterinary Clinics: Food Animal Practice*, *37*(3), 401-412. DOI: https://doi.org/10.1016/j.cvfa.2021.06.001

[7] Jacques, A., Laurent, M., Epilobee Consortium, Ribière-Chabert, M., Saussac, M., Bougeard, S., ... & Chauzat, M. P. (2017). A pan-European epidemiological study reveals honey bee colony survival depends on beekeeper education and disease control. *PLoS one*, *12*(3), e0172591. DOI: https://doi.org/10.1371/journal.pone.0172591

[8] Steinhauer, N., Kulhanek, K., Antúnez, K., Human, H., Chantawannakul, P., & Chauzat, M. P. (2018). Drivers of colony losses. *Current opinion in insect science*, *26*, 142-148. DOI: https://doi.org/10.1016/j.cois.2018.02.004

[9] Hunor, B., Bodor, Z., Keresztesi, Á., Gârbacea, G., György, D., Monica, M., ... & Szép, R. (2024). Advances in Beehive Monitoring Systems: Low-Cost Integrating Sensor Technology for Improved Apiculture Management. In *E3S Web of Conferences* (Vol. 589, p. 04001). EDP Sciences. DOI: https://doi.org/10.1051/e3sconf/202458904001

[10] Otto, C. R., Roth, C. L., Carlson, B. L., & Smart, M. D. (2016). Land-use change reduces habitat suitability for supporting managed honey bee colonies in the Northern Great Plains. *Proceedings of the National Academy of Sciences*, *113*(37), 10430-10435. DOI: https://doi.org/10.1073/pnas.1603481113

[11] Burma, Z. A. (2023). Digital transformation in beekeeping to carrying beehives into the future. *International Journal of Nature and Life Sciences*, *7*(2), 89-99. DOI: https://doi.org/10.47947/ijnls.1372420

[12] Pal, P., Sahu, M., & Juyal, R. (2022). Utilising Iot Technologies To Improve Beekeeping Through Remote Hive Monitoring. *Journal of Survey in Fisheries Sciences*, 367-372.

[13] Farmonaut. (n.d.). Revolutionizing Australian apiculture: Smart beehive monitoring with 4G-connected scales for precision hive management. Retrieved January 29, 2025, from https://farmonaut.com/australia/revolutionizing-australian-apiculture-smart-beehive-monitoring-with-4g-connected-scales-for-precision-hive-management/

[14] 4PDIH. (n.d.). Slovenian smart villages network. Retrieved January 29, 2025, from https://4pdih.com/en/slovenian-smart-villages-network/

[15] Stojanova, S., Duh, E. S., Kos, A., & Volk, M. (2024, November). Short Paper: IoT Applications in Viticulture: A Case Study on Sensor Network and Data-Driven Vineyard Management. In *2024 IEEE 10th World Forum on Internet of Things (WF-IoT)* (pp. 577-579). IEEE. DOI: https://doi.org/10.1109/WF-IoT62078.2024.10811426

[16] Medica-Cesar. (n.d.). Medica-Cesar. Retrieved January 29, 2025, from https://www.medica-cesar.si/

[17] Stojanova, S., Drobnič, F., Mali, L., & Superina, A. (2024). Socio-technical process modelling report (T3. 3.): IoT pilot setup in viticulture and beekeeping: living lab smart villages network Slovenia.

[18] AMES d.o.o. (n.d.). TCM 13 measurement station for honey collection control. Retrieved January 29, 2025, from https://www.ames.si/eng/cat/products/tcm_13_measurement_station_for_honey_collection_control/l:2

[19] DDMeter. (n.d.). RHB-32SG-1 ATC beer refractometer (0-32% Brix, wort SG 1.000-1.120). Retrieved January 29, 2025, from https://www.ddmeter.com/products/rhb-32sg-1-atc-beer-refractometer-0-32-brix-wortsg1000-1120-94

[20] Instrument Choice. (n.d.). HI98130 pH, conductivity & TDS tester. Retrieved January 29, 2025, from https://www.instrumentchoice.com.au/hi98130-ph-conductivity-tds-tester

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