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Integration of Beekeeping with the Concept of Smart Manufacturing

Abstract: Smart manufacturing encompasses various industries, including honey production on beekeeping farms. Modern technologies enable the resolution of complex and critical tasks in this field. This scientific article presents a method for integrating smart manufacturing into beekeeping. It describes the concept of digital control over processes inside hives, automation of hive management processes, monitoring, and problem forecasting. This, in turn, simplifies traditional beekeeping methods and improves both the vitality of bees and the productivity of honey production. Beekeepers of various levels, from amateurs to professionals managing large apiaries, are in great need of technologies that can enhance their efficiency. However, modern mass markets for beekeeping equipment, unfortunately, lack affordable solutions. Therefore, this problem remains relevant and requires attention in this field.

Keywords: Digitalisation, Automation, Smart manufacturing

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Introduction

Honey production is a complex and meticulous process that requires a high level of knowledge in this field and involves solving numerous complex tasks, such as: monitoring the condition of the bee colony includes necessary regular (weekly) inspections, fighting varroa mite infestations, predicting swarming, tracking queen presence, controlling colony growth/efficiency, and

preventing starvation. The generalization capacity in condition monitoring is therefore more preferable when compared with conventional methods [1]. The appliance of automated control procedures and targeted interventions against critical beehive conditions is the beekeeper's main concern and is carried out through periodic control checks of the entire apiary [2]. Beekeepers have to be there more often [3]. Human labor becomes more efficient with the use of smart manufacturing in beekeeping. Smart manufacturing is a general concept representing the deep integration of information technologies and advanced manufacturing technologies [4].

Physical labor is reduced, and with an increase in the number of beehives, human labor does not increase. Additionally, the time for visual inspection and diagnostics of hives on-site is shortened.

Materials and methods

The methodology involves selecting a combination of hardware and software and establishing a connection between automated tasks and the operator.

For data analysis in beekeeping, we use a SaaS (Figure 1) application that includes AI detections of frame photos, bee counts, queen and queen cups, varroa mites, frame cells, management of apiaries, hives, frames, and photos, an AI advisor, a mobile app, manual inspections, an inspection timeline, and re-training on user data. Therefore, to accurately analyze the impact of the environment on the state of the bee colony, it is necessary to use sensor devices with sufficient accuracy [5].

IoT sensors for beehives are integrated with hardware for transmitting infrequent telemetry data and are used to measure internal hive temperature, Figure 2. Enabling digital technologies (e.g., sensors and networks) are increasingly available, and with numerous digital products on the market (e.g., hive monitoring systems), beekeepers have started embracing digital beekeeping tools [6].



Figure 1. Data analytics SaaS app for beekeepers

In Figure 2, a web application for monitoring the temperature inside a beehive is shown. This application allows real-time temperature tracking as well as viewing recorded temperature data from previous days. The data is obtained from a temperature sensor installed inside the hive.

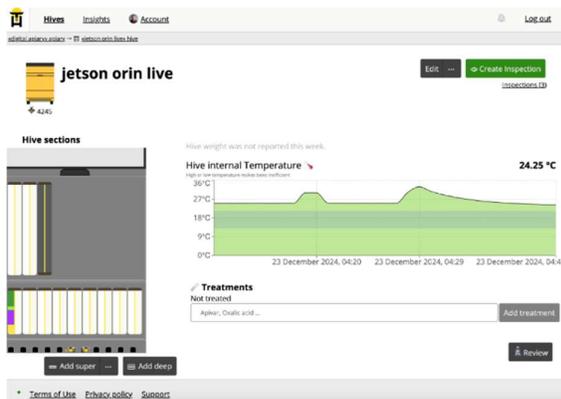


Figure 2: A Web Application for Monitoring the Temperature Inside a Beehive

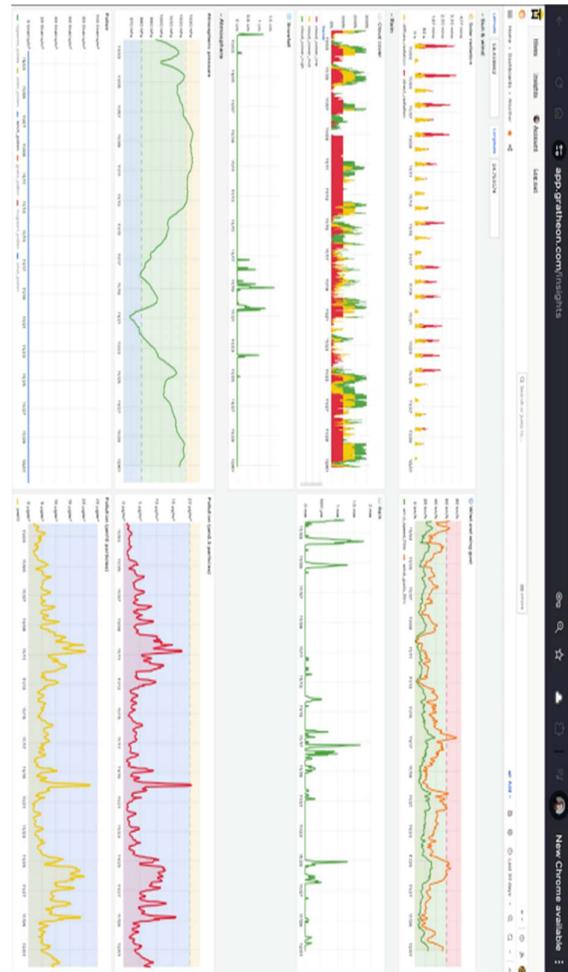


Figure 3: Weather Monitoring Display on the Web Application Page.

The temperature inside a beehive is a crucial factor for the bees' habitat. Extreme cold during winter, as well as excessively high or warm temperatures inside the hive, can significantly impact the bees. These temperature fluctuations may cause them to either perish or become ill, which in turn affects the honey yield.

With timely alerts about unfavorable temperature conditions inside the hive, provided through the web application, a beekeeper can promptly react to the situation and prevent excessive temperature increases or drops. This method is also highly convenient because temperature data collection occurs remotely.

The temperature is a very important parameter for bee colonies, as its detection can be used to identify different conditions in the hive, such as brood development, the pre-swarming condition, and, in general, the health status of the hive [7]. IoT sensors, also are used to measure humidity, atmospheric pressure, hive weight, CO₂ levels inside the hive, PM₂

pollution outside the hive, wind speed, and audio. Under this condition, how to improve the condition monitoring performance still needs to be studied [8].

In the web application displaying graphs (Figure 3) with information about the surrounding environment, various types of data are available, such as Sun & Wind, Wind and Wind Gust, Cloud Cover, Rain, Snowfall, Atmospheric Pressure, Pollution, and Pollen. Weather charts depend on the location.

Numerous algorithms can be used for feature extraction and analysis of bees' acoustic [9]. Putting a sensor inside a beehive to gather data from a colony is an advantage over being outside [10]. Due to various conditions, inspecting beehives using traditional manual and visual methods is highly limited. As a result, diagnosing the internal state of a hive with these methods is not as accurate or reliable compared to using technical devices and processing their data. Therefore, in an automated mode, we obtain crucial information through the identification, visualization, and signaling of the internal state and environmental conditions inside the beehive.

The web application enables plotting time series data in Grafana, performing analytics through graphs for identifying correlations and anomalies, and generating notifications. In that case, a web application will have the advantage of offering technical guidance without the need to establish a simulation environment [11].

Monitoring the entrance of a beehive is comprehensively performed using the Vision application and an IoT device (Figure 4). Camera used in the experiment: Mokose 4K with a resolution of 640x480 for logical output and for recording/streaming video to the cloud. Additionally, NVIDIA GStreamer API acceleration is used in the KV2 framework to reduce CPU load.

The Internet of Things (IoT) is an emerging technology to connect a myriad of devices to a data fusion center [12]. It includes video streaming and playback (Figure 5), counting incoming/outgoing bees, varroa mite detection, detecting seizures caused by pesticide exposure, monitoring pollen foraging activity, ant infestations, queen mating flights, theft alerts, and hornet attack notifications. To estimate the health status of a honey bee colony, beekeepers currently still largely rely on physical interventions, consisting of manually opening the hives and visually inspecting the colony for anomalies, such as, e.g., the presence of parasites or viruses, symptoms of diseases, and colony traits like queen and brood presence and status, colony and brood size, and honey and pollen storage [6].

The experiment using IoT was conducted on a private beekeeping apiary during the summer season when bees are in an active phase for collecting pollen.

A camera was installed above the entrance of the beehive, allowing for data collection, which serves as the basis for analysis and the diagnostic model.

The aforementioned results suggested that the diagnostic model had high degree of credibility and potent classification ability [13].



Figure 4. Hive entrance video monitoring / IoT device

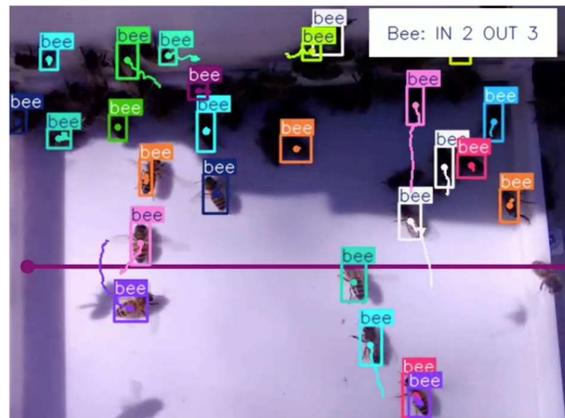


Figure 5. Video streaming & playback

In addition, smart beehives can include a frame extraction mechanism (Figure 6). This allows for the automatic extraction of a frame filled with honey, and in place of the removed frame, a new empty frame is inserted, which will later be filled with honey by the bees, just like the previous one.

After automatic extraction, the filled frame is also automatically directed to a device that extracts honey from the frames using a centrifugation method.

This method of honey frame extraction is effective because it subjects the bees to less stress compared to traditional frame removal. In the traditional, or manual, method, beekeepers disturb the entire hive and use

smoke throughout the beehive, affecting all the bees inside.

2 cameras to take photos of the frame for uploading to a web app, frame extraction for honey harvesting, frame movement across hives, and initially, a robot for a single colony. It moves on rails and also contains sensors for temperature, humidity, weight, and audio monitoring, as well as ventilation, automatic feeding, and anti-varroa mite treatment. The varroa mite disease is one of the most common causes of bee mortality [2].

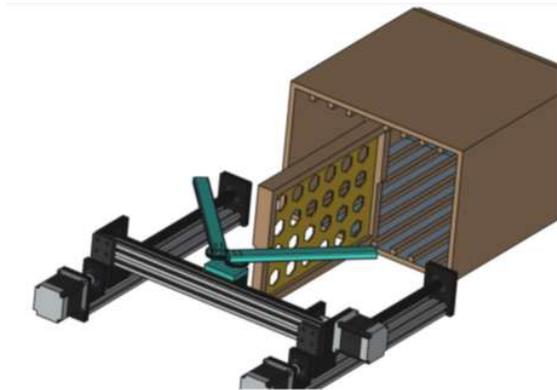


Figure 6. Frame extraction mechanism

In the future, it is possible to develop honey production using Smart manufactory on a larger scale, thanks to specialized containers in which the above-mentioned method will be used.

Conclusion

In the course of the study, a methodology was developed for the implementation and use of smart manufacturing technologies in beekeeping. Smart manufacturing necessitates a profound fusion of cutting-edge manufacturing technologies with sophisticated digitalization solutions [14]. The technology, consisting of data collection devices, software, and data transmission peripherals, has proven its suitability and efficiency in use. This enables the simplification of tasks in beekeeping while improving the quality and productivity of honey production. The future development of automated beekeeping management will simplify and improve traditional honey production on apiaries, taking into account the biological behavior of bees and the impact of the technical devices used on them.

Bibliography

- [1] Guangyao Zhang, Yi Wang, Yi Qin, Baoping Tang. Statistical distribution measures based on amplitude normalization for wind turbine generator bearing condition monitoring under variable speed conditions. 2025
- [2] Sotirios Kontogiannis. Beehive Smart Detector Device for the Detection of Critical Conditions That Utilize Edge Device Computations and Deep Learning Inferences. 2024
- [3] Marie Van Espen, James H. Williams, Fátima Alves, Yung Hung, Dirk C. de Graaf, Wim Verbeke. Beekeeping in Europe facing climate change: A mixed methods study on perceived impacts and the need to adapt according to stakeholders and beekeepers. 2023
- [4] Tianyi Gao, Lei Wang, Wenyan Song, Ying Cheng, Ying Zuo, Feng Xiang, Haijun Zhang, Fei Tao. Ten industrial software towards smart manufacturing. 2025
- [5] Yiyao Zheng, Xiaoyan Cao, Shaocong Xu, Shihui Guo, Rencai Huang, Yingjiao Li, Yijie Chen, Liulin Yang, Xiaoyu Cao, Zainura Idrus, Hongting Sun. Intelligent beehive monitoring system based on internet of things and colony state analysis. 2024
- [6] Wim Verbeke, Mariam Amadou Diallo, Coby van Dooremalen, Marten Schoonman, James H. Williams, Marie Van Espen, Marijke D’Haese, Dirk C. de Graaf. European beekeepers’ interest in digital monitoring technology adoption for improved beehive management. 2024
- [7] Pier Paolo Danieli , Nicola Francesco Addeo, Filippo Lazzari, Federico Manganello and Fulvia Bovera. Precision Beekeeping Systems: State of the Art, Pros and Cons, and Their Application as Tools for Advancing the Beekeeping Sector. 2024
- [8] Guangyao Zhang, Yi Wang, Yi Qin, Baoping Tang. Statistical distribution measures based on amplitude normalization for wind turbine generator bearing condition monitoring under variable speed conditions. 2025
- [9] Cassandra Uthoff, Masun Nabhan Homsy, Martin von Bergen. Acoustic and vibration monitoring of honeybee colonies for beekeeping-relevant aspects of presence of queen bee and swarming. 2023
- [10] Hugo Hadjur, Doreid Ammar, Laurent Lefevre. Toward an intelligent and efficient beehive: A survey of precision beekeeping systems and services. 2022
- [11] Yoshitaka Matsuzaki, Tetsunori Inoue, Masaya Kubota, Hiroki Matsumoto, Tomoyuki Sato, Hikari Sakamoto, Daisuke Naito. Web application of an integrated simulation for aquatic environment assessment in coastal and estuarine areas. 2024
- [12] Mingrui Zheng, Tianrui Feng and Tengjiao He. Max-Min Secrecy Rate for UAV-Assisted Energy Harvesting IoT Networks. 2025

[13] Jia Li, Xin Hou, Meng Zhao, Honglei Xie, Yue Su, Haowen Pan, Zongyu Yue, Zexu Zhang, Peng Liu. Establishment and validation of an immune-related genes diagnostic model and experimental validation of diagnostic biomarkers for autoimmune thyroiditis based on RNA-seq. 2025

[14] Jiewu Leng, Rongjie Li, Junxing Xie, Xueliang Zhou, Xiang Li, Qiang Liu, Xin Chen, Weiming Shen, Lihui Wang. Federated learning-empowered smart manufacturing and product lifecycle management: A review. 2025