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CONCEPT SOLUTION OF AUTONOMOUS IOT SMART HIVE AND OPTIMIZATION OF ENERGY CONSUMPTION USING ARTIFICIAL INTELLIGENCE

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Abstract: *In this paper the authors present a conceptual solution for an autonomous smart beehive with a focus on energy efficiency; the hive's existence is based on artificial intelligence. The hive is equipped with an advanced system for monitoring the entry and exit of bees, as well as for collecting data on the weather inside and around the hive. Using an array of sensors controlled by Espressif ESP32 and Arduino Mega microcontroller boards, the hive continuously optimizes the operation of the ventilation system and other components, monitoring energy consumption and adapting to changing conditions. Special accents in the work are dedicated to the monitoring of the solar panel and, consequently, the capacity of the battery for independent power supply of the system, as well as the application of artificial intelligence to predict meteorological changes and optimize energy efficiency. This paper provides a comprehensive overview of the solutions and technologies that enable the autonomous and energy-efficient functioning of the Smart Hive.*

Keywords: *Smart hive, artificial intelligence, energy efficiency, solar energy, autonomous hive, sensors*

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1. Introduction

Beekeeping is one of the vital branches of agriculture and faces numerous challenges, including changing climate conditions and the global decline of bee populations. Given the enormous importance of bees for plant pollination and ecosystem preservation, the development of innovative technologies to monitor and support bees is becoming increasingly important. In this context, smart beehives represent an advanced solution that integrates the

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Internet of Things (IoT), artificial intelligence (AI) and sensor technologies to improve beekeeping practices (Andrijević et al., 2022; Ntavuzumunsi et al. 2021).

This paper presents a conceptual solution for a Smart Hive that relies on advanced technologies to enable beekeepers to better understand and monitor bee activities, as well as to optimize conditions inside the hive. The central part of the system is a digital monitoring system based on an Espressif ESP32 and an Arduino Mega microcontroller working together, with boards that allow continuous data collection on bee activity and environmental conditions. In addition, the hive is equipped with a system for monitoring weather conditions and parameters inside the hive, as well as a ventilation system that maintains optimal conditions for bees.

One of the key challenges in the development of the Smart hive is the optimization of energy consumption, especially in conditions where the solar panels are not fully efficient (Shah, 2017). In that aspect, this paper focuses on the application of AI to predict weather factors and optimize system energy consumption (Joshi, 2022). By combining data on weather conditions with information on bee activity and conditions inside the hive, the system can adjust the operation of ventilation and other components, in order to reduce energy consumption during periods of reduced insolation, thus extending the autonomy of the hive's operation (El-Said et al., 2024).

2. Challenges and approach to the problem

Beekeeping faces numerous challenges, including climate change, the emergence of diseases and pests, and the global decline of bee populations. The importance of bees for plant pollination and ecosystem preservation cannot be emphasized enough, and traditional beekeeping methods are often limited in effective monitoring and support of bees, especially in the context of rapid environmental changes (He et al., 2020; Andrijević et al., 2021; Pane et al., 2022; Al-Rajhi, 2022).

The introduction of Smart technologies in beekeeping, such as Smart hives, opens up the possibility of solving these challenges in an innovative way (Kuliukin & Reka, 2016; Andrijević et al., 2023). Smart hives use sensor technologies, the IoT and AI to enable beekeepers to better understand bee activities, monitor weather conditions and improve conditions inside the hive (Andrijević & Urošević, 2021; Zacepins et al., 2016). Such technological solutions enable beekeepers to react more quickly to changes in the environment and provide more effective bee care, which contributes to the preservation of the bee population and ecological balance.

The main goal of this paper is to present a conceptual solution for a smart beehive that relies on AI to optimize energy consumption. The focus of this work will be on the identification of key challenges in monitoring and supporting bees, as well as on the development of innovative technological solutions that will address these challenges in an efficient and sustainable manner.

In the continuation of the paper, the concept of the Smart Hive will be described in details, as well as the methodology of energy consumption optimization using AI.

3. System architecture

The architecture of the Smart Hive is designed to enable efficient monitoring and support of bees through the integration of sensor technologies, IoT and AI. The main goal of the system structure is to enable beekeepers to gain insight into bee activities, as well as the conditions inside and around the hive, so that they can react to changes and provide optimal conditions for the life of bees.

The central part of the system is the Arduino Mega microcontroller board, which functions as the main control and data acquisition unit. In parallel, the system uses the ESP32 module for wireless communication with other devices, as well as for collecting data on bee activities. Various sensors are used to monitor weather conditions and parameters inside the hive, including DHT22 for temperature and humidity measurement, BME280 for air pressure measurement, MAKS4466 and MAKS9814 for sound and frequency measurement, SV-420 for vibration measurement, MHRD for rain detection, MK135 and MICS5524 for measuring air quality, BH1750 for measuring light and VEML6075 for measuring ultraviolet (UV) and infrared (IR) radiation.

To optimize the conditions inside the hive, the system is equipped with a ventilation system that uses two-way fans. The fans are activated only when it is necessary to maintain certain parameters of temperature and humidity inside the hive, thus reducing energy consumption and increasing the autonomy of the system.

All collected data are sent to the Cloud platform where it is processed and analyzed using AI. AI is used to predict meteorological changes and to optimize the energy consumption of the system, in order to ensure the efficient functioning of the hive in different conditions.

Figure 1 shows the system architecture.

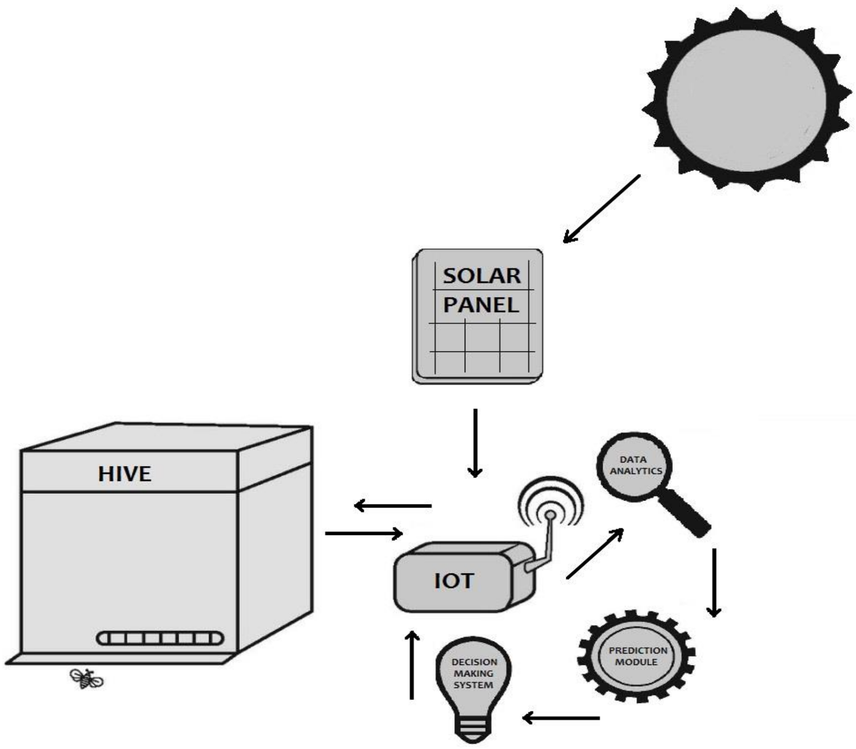

Figure 1. System architecture

Structure of the Smart Hive system is designed to enable beekeepers to respond quickly and efficiently to changes in the environment and provide bees with optimal living conditions, thereby contributing to the preservation of the bee population and ecological balance.

4. Energy consumption measurement

Measuring energy consumption in a smart hive system is a major aspect of optimizing its performance and ensuring efficient operation. However, due to the complexity and variety of components within the system, the measurement process is divided into several segments. This approach to the problem allows accurate measurement of the power consumption of each component individually and provides detailed insight into requirements such as powering the system as a whole.:

The reasons for splitting measurements are:

- **Component-specific analysis** - Each component in the smart beehive system has unique power requirements and operational characteristics. By measuring the energy consumption of each component individually, we can analyze their specific power needs and identify potential areas for optimization.
- **Optimization opportunities** - Dividing the measurement allows us to identify components or subsystems that may be consuming more energy than necessary. This information is valuable for optimizing the energy efficiency of the system and reducing overall power consumption.
- **Accurate energy budgeting** - By measuring the energy consumption of each component separately, it is possible create a more accurate energy budget for the entire system. This helps in designing effective power management strategies and ensuring the long-term sustainability of the smart beehive.
- **Performance monitoring** - The segmented approach to measurement enables monitoring of the performances of individual components over time. This information can be used to detect any anomalies or inefficiencies in the system and take corrective actions as needed.

Splitting the measurements of energy consumption into multiple segments allows for a more comprehensive analysis of the smart beehive system's power requirements.

a) General approach to the energy consumption measurement:

- Measuring the energy consumption of each component of the system (sensors, microcontrollers, ventilation) is done once during preparation, using voltage and current sensors to measure the maximum consumption of each component.
- The total energy consumption of the system is calculated as the sum of the energy consumption of all active components during a certain time interval.
- The formula for calculating the total energy consumption of the system is:

$$E_{total} = \sum_{i=1}^{n} P_i \cdot t \,. \tag{1}$$

where E_{total} is the detection energy consumption, P_i is the maximum energy consumption per time unit, and t is the duration of detection.

b) Bee movement detection (ESP32):

- Energy consumption for bee motion detection can be measured in time intervals when the motion detector is activated.
- The formula for calculating the energy consumption of bee movement detection system can be expressed as:

$$E_{detection} = P_{detection} \cdot t_{detection} \,. \tag{2}$$

where $E_{detection}$ is detection energy consumption, $P_{detection}$ is detection energy consumption per time unit, and $t_{detection}$ is the duration of detection.

c) Measurement of the energy consumption on Arduino Mega:

- The energy consumption of the sensors connected to Arduino Mega is measured in the time intervals when the sensors take measurements.
- The formula for sensor power consumption on the Arduino Mega is:

$$E_{sensors} = \sum_{i=1}^{m} P_{i,sensors} \cdot t_{sensors} \, . \quad (3)$$

where $E_{sensors}$ is the maximum energy consumption of the sensor, $P_{i,sensors}$ is the energy consumption of an individual sensor, and $t_{sensors}$ is the duration of sensor measurement.

d) Sending data via WiFi connection:

- Energy consumption for sending data via WiFi is measured in time intervals when the data is sent.
- The formula for calculating data transmission energy consumption is:

$$E_{wifi} = P_{wifi} \cdot t_{wifi} \, . \quad (4)$$

where E_{wifi} is the energy consumption of the WiFi connection, P_{wifi} is the energy consumption per unit of time for WiFi communication, and t_{wifi} is the duration of WiFi communication.

e) Ventilation and sensors on Arduino Mega with sending data via WiFi connection:

- The energy consumption of the ventilation and sensors on the Arduino Mega is measured in time intervals when they are activated.
- The formula for calculating energy consumption can be similar like the sensors formula, with the addition of energy consumption for WiFi communication:

$$E_{vent} = (\sum_{i=1}^{m} P_{i,sensors} + P_{vent}) \cdot t_{vent} + E_{wifi} \, . \quad (5)$$

where E_{vent} is the energy consumption of ventilation and sensors with WiFi communication, $P_{i,sensors}$ is the energy consumption of an individual sensor, P_{vent} is the energy consumption of ventilation, and t_{vent} is the duration of sensor measurement and ventilation operation.

By accurately measuring the energy consumption of each component and optimizing their usage, it is possible ensure the efficient operation of the smart beehive system while minimizing energy waste. This information is crucial for designing effective power management strategies and ensuring the long-term sustainability of the project.

4.1. Energy consumption of components

The **Table 1.** Below shows, the operating time for all components that would work constantly is set to 1 hour, while the operating time for sending data via WiFi connection is set to 20 seconds. This reflects more realistic system operating conditions.

Table 1. Energy consumption of components (according to the manufacturer's specification)

Component	Energy consumption (mA)	Operating voltage (V)	Work time (h)	Total energy consumption (mAh)
ESP32	80	3.3	1	80
Photoresistor	10	5	1	10
Sending data via WiFi	100	5	0.03	3
WiFi conection	150	5	0.03	4.5

Arduino Mega	50	5	1	50
RTC 3231	1	3.3	1	1
MicroSD module	2	3.3	1	2
Step down module	50	5	1	50
Relay	50	5	0.03	1.5
DHT22 Temperature & Humidity sensor	2	3.3	1	2
BME280 Pressure sensor	1	3.3	1	1
MAX4466 S & L	1	3.3	1	1
MAX9814 L & F	1	3.3	1	1
SW-420 Vibration	1	3.3	1	1
MHRD rain	1	3.3	1	1
MQ135 Gas & Air quality	1	3.3	1	1
MICS5524 Gas & Air quality	1	3.3	1	1
BH1750 Daylight & lx	1	3.3	1	1
VEML6075 UV & IR	1	3.3	1	1
Fan	1000	12	0.03	30

5. Application of AI in the optimization of energy consumption

As a part of the application of AI to optimize energy consumption, a module has been developed that uses Recurrent Neural Networks (RNN) to analyze time series data on weather conditions (temperature, humidity, amount and intensity of daylight), in order to predict weather factors that affect the amount of energy which will be collected by solar panels. This approach enables systematic analysis of weather data and prediction of future weather conditions, which contributes to efficient optimization of energy consumption.

Functioning of the RNN application module:

- **Data collection** - The system collects time series data on temperature, humidity, amount and intensity of light at regular time intervals.
- **RNN training** - The data is used to train the RNN to learn the complex relationships between weather factors and the energy efficiency of the system.
- **Prediction of weather factors** - Based on the trained RNNs, the system predicts the future values of weather factors for the next time interval.
- **Energy consumption optimization** - Based on predictive data, the system optimizes energy consumption, for example, adjusts the operation of fans in the hive or activates/deactivates certain sensors according to the predicted weather conditions in order to reduce energy consumption.

Mathematical model of RNN:

RNN can be represented by a mathematical model that takes into account time series of data to predict future values. Let it x_t time series of data, a h_t the hidden state of the RNN at the moment *t*. The function of RNN can be defined as:

$$h_t = \tanh(W_{ih}x_t + W_{hh}h_{t-1} + b_h) \quad (6)$$

where W_{ih} and W_{hh} are the weights, b_h the bias, and $tanh$ is the tangent hyperbolic of the activation function.

Advantages of applying artificial intelligence:

- **Efficiency** - The use of artificial intelligence allows the system to respond efficiently to changing weather conditions, leading to optimization of energy consumption.
- **Automation** - The system automatically adjusts its activities according to the predicted weather conditions, which reduces the need for manual management.
- **Sustainability** - Reducing energy consumption contributes to the sustainable operation of the system and reducing the impact on the environment.

The application of AI (especially RNN) in optimizing the energy consumption of the bee monitoring system and weather conditions in the hive is an efficient and sustainable approach. This module allows the system to intelligently manage its resources based on predicted weather factors, resulting in more efficient energy use and improved system performance.

6. Conclusion

The analysis of the smart beehive system's energy consumption underscores the critical importance of optimizing energy usage for sustainable operation. Leveraging AI to forecast weather conditions and optimize system performance holds immense potential for reducing energy consumption and enhancing overall efficiency.

The utilization of solar panels to power the system emerges as a highly effective approach to ensuring its independent and sustainable energy supply. Through meticulous calculations of the energy requirements of all system components, we can precisely determine the solar panel and battery capacity needed for optimal power provision.

This study delves into the intricate challenge of energy optimization in smart beehives, focusing on the integration of microcontrollers, sensor modules, AI and ecological principles. The inquiry revolves around efficiently utilizing energy to monitor bees and environmental conditions within the hive, aiming to optimize honey production and preserve bee colonies.

The structural framework and conceptual solution involve the integration of diverse sensors and microcontrollers for monitoring environmental parameters and hive conditions. Furthermore, the application of RNN for weather forecasting and energy consumption optimization plays a pivotal role. This amalgamation of technologies enables systematic data monitoring and analysis, facilitating effective energy consumption optimization.

The research findings underscore the significant impact of AI, particularly RNN, in enhancing the efficiency of monitoring bees and hive conditions. The implementation of this solution necessitates further data collection, optimization model refinement, and rigorous testing to validate its efficacy and sustainability.

Moving forward, in authors plan is to publish research findings and solution in a subsequent paper, following data collection and optimization model development. This paper marks the initial step in the exploration of information technology and AI applications in beekeeping with the overarching goal of enhancing practices and safeguarding bee colonies.

References

Al-Rajhi, M. (2022). Warming Beehives with Solar Energy Stored in Water. Türkiye Tarımsal Araştırmalar Dergisi, 9(3), 286-294.

Andrijević, N., Radivojević, V., Radaković, D., Milovanović, D., Suljović, S. (2023). Conceptual model of a system for optimizing the temperature and humidity of honeybee hives using artificial intelligence. Scientific and Professional Conference with International Participation Politehnika, Belgrade, pp. 1266-1269.

Andrijević, N., Urošević, V. (2021). Concept of Adaptive Smart IoT Technology for Application in Smart Agriculture. Scientific and Professional Conference with International Participation Politehnika, pp. 749.

Andrijević, N., Urošević, V. (2021). Development of a System for Continuous Monitoring of the State of the Bee Society. YU-INFO conference 2021, pp. 123–126.

Andrijević, N., Urošević, V. (2022). Development of software for control of beehive ecosystem with alarm. YU-INFO conference 2022, pp. 173–175.

Andrijević, N., Urošević, V., Arsic, B., Herceg, D., Savić, B. (2022). IoT Monitoring and Prediction Modeling of Honeybee Activity with Alarm. Electronics, 11(5), 783.

El-Sayed, A. S., Al-Rajhi, M. A. I., & Sharobeem, Y. F. (2024). Development of an automatic solar powered honey bee feeding system in a movable multi shelves apiary. Journal of Apicultural Research, 63(1), 18-31.

He, W., Zhang, S., Hu, Z., Zhang, J., Liu, X., Yu, C., & Yu, H. (2020). Field experimental study on a novel beehive integrated with solar thermal/photovoltaic system. Solar Energy, 201, 682-692.

http://www.pveurope.eu/installation/solar-beehive-protecting-bees-solar-energy (28.02.2024.)

http://www.sustainablebusinesstoolkit.com/solar-beehive/ (28.02.2024.)

http://www.thermosolarhive.com/en/ (28.02.2024.)

Joshi, D. B. (2022). Design and Implementation of Sustainable Smart Beehive Monitoring. University of California, Riverside.

Kulyukin, V., & Reka, S. K. (2016). A computer vision algorithm for omnidirectional bee counting at langstroth beehive entrances. In Proceedings of the International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV) (p. 229).

Ntawuzumunsi, E., Kumaran, S., & Sibomana, L. (2021). Self-Powered Smart Beehive Monitoring and Control System (SBMaCS). Sensors, 21(10), 3522.

Pane, S. B., Nuraini, C., & Syam, F. H. (2022). BeeHive Co-Working with Green Architecture Approach. In The International Conference on Education, Social Sciences and Technology (ICESST), 1(1), pp. 178-187.

Shah K. (2017). Power analysis of continuous data capture in beepi, a solarpowered multi-sensor electronic beehive monitoring system for langstroth beehives. Utah state university Logan, Utah.

Zacepins, A., Kviesis, A., Ahrendt, P., Richter, U., Tekin, S., & Durgun, M. (2016). Beekeeping in the future - Smart apiary management. In 2016 17th International Carpathian Control Conference (ICCC), pp. 808-812.