IoT-Based Smart Beehive Monitoring System

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Abstract*— In recent years, there has been an alarming decline in bee populations both globally and in Sri Lanka, severely impacting ecosystems and agriculture worldwide. Traditional methods in Sri Lankan beekeeping are often time-consuming and less efficient, making hive management and health assessment challenging. This paper introduces a smart IoT-based beehive monitoring system tailored to the Sri Lankan beekeeping industry. The system integrates various sensors to measure key hive parameters, such as temperature, humidity, and weight, offering beekeepers a user-friendly web interface for real-time monitoring of hive conditions. It also provides insights into hive management aspects, including feeding needs, optimal harvesting times, and abnormal temperature detection within the hive. This paper highlights the initial steps towards implementing a robust IoT-based beehive monitoring system, acknowledging its current limitations. By addressing these limitations in the future, the authors aim to develop a more effective and efficient monitoring method for Sri Lankan beekeepers, saving time and enhancing the productivity and health of bee colonies.

Keywords*— *beekeeping in Sri Lanka, IoT-based beehive monitoring, smart beehives, hive health monitoring

I. INTRODUCTION

Albert Einstein once famously remarked that if bees were to disappear from the earth's surface, humanity would have only four years left to live. The statement is meant to point out the importance of bees to the ecosystem and, in essence, the interdependence of life here on Earth [1]. Needless to say, bees are indeed nature's unsung heroes, and their role in sustaining life on Earth cannot be overemphasized [2].

Their central role is as pollinators. For plant pollination, bees have no rivals, and without them, many species of flowers, fruits, and vegetables would lose their only means of reproduction [3]. Without bees, many plants would be unable to reproduce, leading to a cascading effect on entire ecosystems and ultimately threatening food security for humans and other animals [2].

Besides playing an important ecological role, bees also produce some important resources humans exploit in apiculture. Perhaps the most popular of all bee products is honey; though being a delicious and healthy food ingredient, it is also successfully applied in many medicinal and therapeutic fields [4]. Apart from honey, various other products such as beeswax, royal jelly, bee pollen, and propolis are cultivated in beekeeping for cosmetic and medical use [5].

The beekeeping industry represents a thriving sector within Sri Lanka's agricultural landscape, offering significant potential for both economic growth and environmental stewardship [6]. With its multifaceted benefits, this industry can contribute substantially to the nation's development.

However, in Sri Lanka currently, beekeepers monitor their hives manually, which causes several challenges for the beekeepers and bees. Regular manual monitoring of hives is often time-consuming, inefficient, and risky, as beekeepers may get stung while inspecting hives [7]. Additionally, many beekeepers overlook regular hive monitoring due to their busy schedules [8]. Traditional manual monitoring can also make it difficult to gather reliable information about the health of the bee colony and often ignore important environmental factors like temperature and humidity [9]. As a result, the quality and quantity of honey can suffer due to insufficient monitoring of hive conditions, and these manual methods can be intrusive, causing stress to the bees [7], [8].

Therefore, there is a pressing need for non-intrusive methods to monitor beehives remotely and accurately, benefiting both beekeepers and bees.

This paper outlines the initial steps taken to implement a smart IoT-based beehive monitoring system. The primary focus is on enhancing traditional beekeeping practices by integrating cutting-edge technology to provide real-time insights into hive conditions.

The system includes various hive inside and outside sensors to monitor crucial parameters such as inside and outside temperatures, inside and outside humidities, inside air quality, rainfall and hive weight. This project is designed to ensure a reliable and scalable wireless communication infrastructure that would allow seamless data transfer from the beehive to the cloud database. After that, the stored data is retrieved by a Flask server for further analysis.

The end goal is to empower Sri Lankan beekeepers with a user-friendly web dashboard that offers both real-time and historical data, enabling informed decision-making for optimal hive management and the well-being of bee colonies.

This section introduces the implemented IoT-based Smart Beehive Monitoring System. Section 2 reviews some of the previous work conducted on IOT-based beehive monitoring. Section 3 describes the methodology of the work: sensor integration and calibration, cloud database, data retrieval and analysis, and the web application. Section 4 presents the research outcome and summarizes the findings of the study. Section 5 discusses the limitations of the study and points out areas for further research.

II. Related work

The integration of IoT in beekeeping has garnered significant interest, with researchers exploring various sensor devices such as temperature, humidity, and weight sensors to monitor beehive conditions. IoT devices collect real-time data crucial for effective beehive management. Numerous studies have focused on smart beehive monitoring systems based on IoT technology.

For instance, [9] conducted a study in Malaysia where a system utilizing LoRa technology was developed to monitor hive conditions, including temperature and humidity. Similarly, [10] in Latvia utilized an IoT approach and the Arrowhead framework to create an autonomous beekeeping system prototype, providing data on the temperature, weight, and humidity of the hive. These studies, along with others, primarily emphasize real-time monitoring of collected data.

In Mexico, [11] implemented a system capable of sending alerts to beekeepers when the temperature exceeded a predefined threshold, aiding in prompt responses to temperature fluctuations. Additionally, [12] utilized bee sound samples, along with temperature and humidity data, to predict swarming in the early stages, highlighting the significance of temperature and sound analysis in swarm prediction.

Several studies [13], [14], [15], [16]have utilized load cells for hive weight measurement, which can be a direct indicator of honey production and colony size. However, most research has focused primarily on analyzing seasonal patterns in hive weight changes. One study analyzed daily weight variations in beehives and found a significant difference in daily weight changes during the winter and summer months [16].

[17] employed the Support Vector Machine (SVM) algorithm to detect the presence of the queen in the hive using audio samples supplemented with temperature and humidity levels. However, it was noted that a new SVM classification model had to be created each time the queen was changed. Furthermore, the utilization of bee sounds to detect the presence of the bee queen is further discussed in [18], [19].

Comprehensive research by [16], [20] delved into utilizing inside temperature, inside humidity, weight, sounds, and CO2 level values to predict hive health using artificial intelligence. These studies provided valuable insights into leveraging AI to enhance beekeeping practices and ensure optimal hive conditions.

Furthermore, one research study focuses on determining feeding needs based on the feeder syrup level [21]. In contrast, the implemented system experiments using rainfall data to determine the feeding requirement.

Previous research lacks the utilization of web or mobile applications for beehive monitoring, except for a few research studies with limited features [9], which only focuses on displaying live data. In this study, a web application was developed to monitor live and historical data inside the hive, environmental conditions outside the hive, and to get insights into feeding needs, optimal harvesting times, and abnormal temperatures inside the hive.

In the context of similar projects in Sri Lanka, it's important to note that beekeeping in the country is predominantly conducted on a small scale. Therefore, there is a noticeable lack of research conducted on IOT-based beehive monitoring in Sri Lanka and many other South Asian countries [20].

By introducing IoT-based monitoring tailored to the needs of Sri Lankan beekeepers, the developed system stands as an innovative solution in an emerging field. The developed system stands as a pioneering effort to utilize sensor-based technology for Sri Lankan beekeeping industry.

III. Methodology

A. *Sensor Integration and Calibration*

The developed IOT project consists of a total of five sensors. These include two DHT22 sensors (one placed outside the hive and one inside it), a rainfall sensor, a 15 Kg load cell with an HX711 amplifier, and an MQ135 air quality sensor. These sensors are placed at various places inside and outside the hive to get valuable insights into the hive as well as environmental factors.

The load cell needed proper calibration to ensure accurate weight readings. Calibration was performed after mounting the load cell on a metal frame, which was attached to two wooden frames on either side. The top wooden frame was designed to be wide enough to securely hold the beehive.

Figure 1 shows the load cell which was mounted properly as discussed above.

Fig. 1.15 kg load cell mounted on a custom metal frame, which was attached to two wooden frames on both sides.

All the sensors are connected to the ESP32 microcontroller. The microcontroller is uploaded with a C++ code in order to get readings from the sensors and send the received sensor readings to the cloud database.

Figure 2 shows the circuit diagram of the developed system. Figure 3 shows the block diagram of the developed system. Figure 4 shows how the implemented sensor hardware setup is attached to a non-functional beehive for testing purposes.

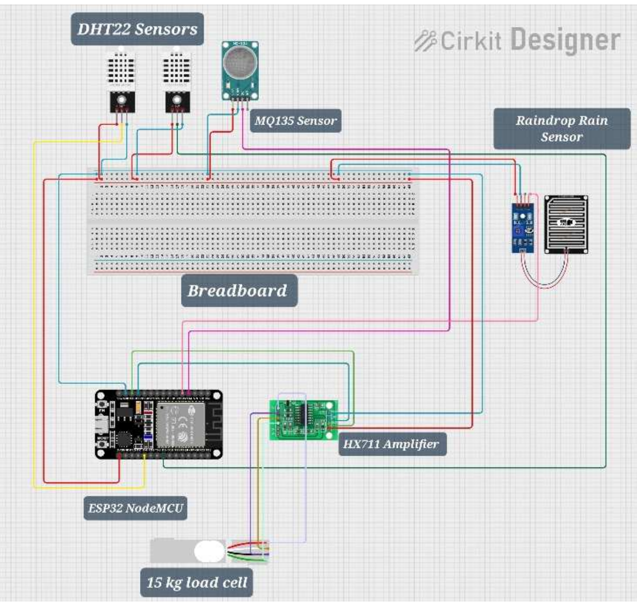

Fig. 2. The circuit diagram of developed system

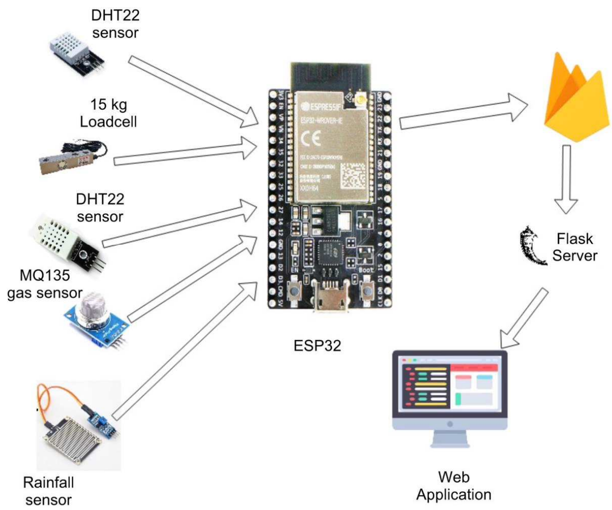

Fig. 3 . The block diagram of developed system

Fig. 4. Hardware setup is attached to non-functional beehive

The ESP32, along with its integrated sensors, are powered by a custom power supply setup, which includes two 3.7V, 4800 mA lithium-ion batteries connected to a battery pack, continuously recharged by a solar panel via a 2S 18650 Battery Charger with Charge Protection Module.

B. Communication and the Cloud Database

The ESP32 is programmed to utilize Wi-Fi for transmitting retrieved data to a Firebase real-time cloud database.

The ESP32 communicates with the Firebase RTDB server using TCP/IP to establish a reliable connection for data transmission. This ensures that data sent from the ESP32 to the Firebase server is delivered in the correct order and without errors, guaranteeing the integrity of the communication.

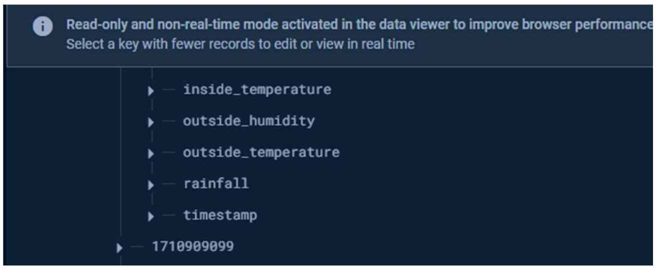

Fig. 5. A screenshot depicting how the sensor readings are stored in the Firebase real-time database

C. Data Retrieval and Analysis

A Flask server, hosted locally, acts as the middleware responsible for retrieving data from the cloud database. Upon retrieval, the Flask server performs comprehensive data analysis to determine the need for feeding, predict the optimal time for honey harvesting, and assess whether the hive's internal temperature levels are abnormal.

The Flask server retrieves rainfall records from the database for the past two hours and calculates their average. This average value is crucial for determining the necessity of feeding within the beehive ecosystem. During heavy rainfall, bees are confined to the hive and unable to forage, increasing their reliance on stored honey. To mitigate potential honey depletion, beekeepers need to manually feed the bees. The system can automatically determine the need for feeding when the average rainfall exceeds a certain threshold during daytime hours.

Additionally, the Flask server calculates the average of the five most recent weight values from the real-time database. If this average weight exceeds the predefined threshold, it indicates an optimal time to harvest.

From past research studies [22] conducted on similar projects, it has been revealed that in a healthy hive under normal weather conditions, bees maintain a stable inner hive temperature typically ranging from 26°C to 38°C. Therefore, if the hive inside temperature is out of this range, it indicates abnormal temperature inside the hive. This abnormal temperature may be an indication of possible issues such as diseases, or pests or stress. Thus, the system is capable of providing insights into hive health by considering variations in internal hive temperature.

D. Web User Interface

Once the analysis is complete, the Flask server renders the analyzed data in HTML format, creating dynamic web pages for the web user interface (UI). The Flask server serves as the central hub for data retrieval, analysis, and distribution, ensuring seamless integration between the cloud database and the web UI.

The application offers intuitive visualizations of real-time data from both inside and outside the hive, along with historical trends displayed in graphs. Additionally, it informs users whether the hive is ready for harvesting, if feeding is necessary, and if abnormal temperature is detected in the hive.

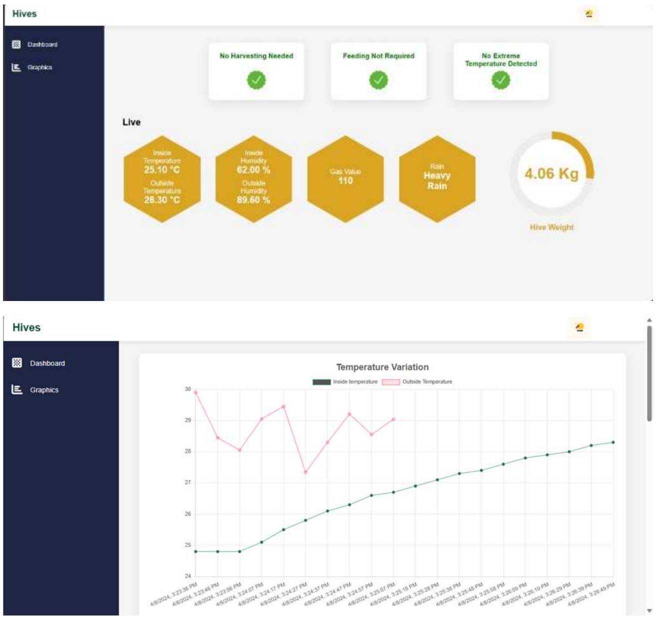

Fig. 6. Screenshots of the developed web UIs

IV. Results and Findings

Extensive testing, including unit, integration, and system tests, confirmed the successful functionality of the developed system. All proposed objectives, including feeding requirement analysis, harvest time prediction, and checking for abnormal hive temperature, were achieved. The system effectively captures sensor data using the ESP32 microcontroller and transmits it to a cloud database via Wi-Fi. This data is retrieved by the Flask server for analysis and the real-time data along with analyzed data is then presented in a user-friendly manner on the web interface.

Testing was conducted by placing a weight greater than the threshold value (8 kg) on the load cell frame to check if it triggers the "harvest ready" alert on the Web User Interface (UI). The result was as expected: for weights of 8 kg or more, the web dashboard displayed a "ready to harvest" message, while weights below this threshold showed a "no harvesting needed" message, as depicted in Figure 7.

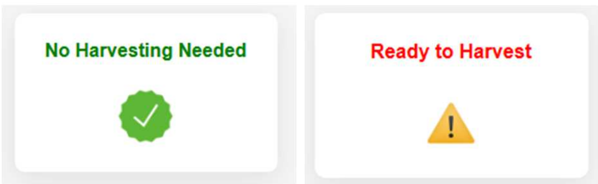

Fig. 7. An image depicting the different content displayed on the web UI based on the weight value.

Similarly, testing was conducted by manually adding water to the rain pad during the daytime. The results were as expected: when the average rainfall value over the past 2 hours exceeds the specified threshold, a message indicating a need for feeding is displayed on the UI. Otherwise, a message indicating that no feeding is required is shown, as depicted in Figure 8.

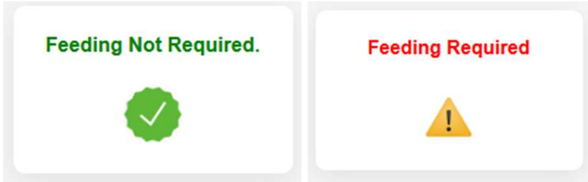

Fig. 8. An image depicting the different content displayed on the web UI based on the average rainfall value.

Furthermore, testing was conducted by manually exposing the DHT22 sensor to both colder and hotter temperatures to check if the system could detect abnormal temperatures and display the result on the Web UI. This feature also worked as expected, displaying a message indicating "extreme temperature detected" when the sensor was exposed to temperatures outside the specified range discussed in the Methodology section above. The results obtained are shown in Figure 9.

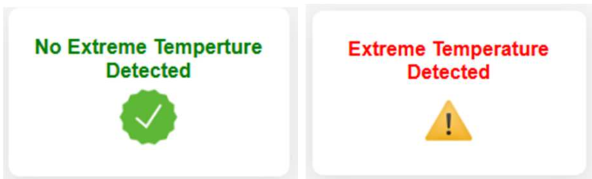

Fig. 9. An image depicting the different content displayed on the web UI based on the hive inside temperature value.

The implemented system was deployed on a beehive at a beekeeper's house in Rajagiriya, where data was collected every minute for a duration of 17 hours.

Fig. 10. An image depicting how the IOT device is deployed on a beehive at the beekeeper's house in Rajagiriya.

It was observed that despite fluctuations in external temperature and humidity, bees tend to maintain an optimal temperature and humidity inside the hive. This phenomenon, discussed in various papers [23], [24], [25], is achieved through various behaviors of bees such as clustering, fanning, and other activities. Our research confirms this observation, as shown in Figure 11 and Figure 12.

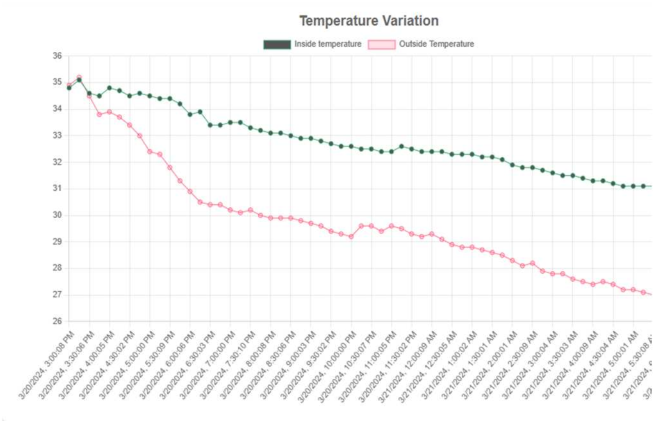

Fig. 11. Screenshot depicting how inside and outside temperature changes over time in the beehive

As shown in above Figure 11, within the 17 hours that the IoT device was placed in the hive, the bees maintained an inside temperature between 31°C and 35°C.

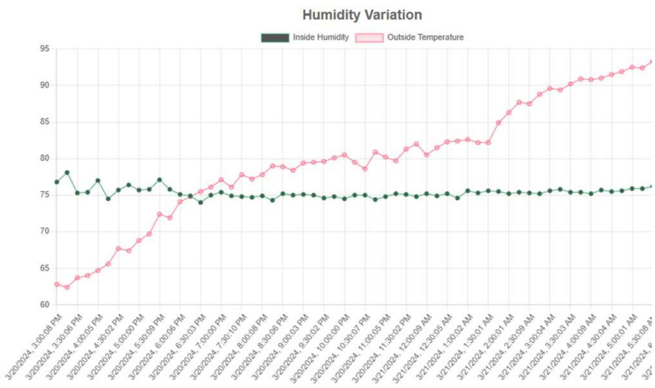

Fig. 12. Screenshot depicting how inside and outside humidity changes over time in the beehive

Furthermore, as shown in above Figure 12, despite the outside humidity fluctuating between 60% and 95% RH, the bees maintained an inside humidity of around 75%.

V. Conclusion and Future Work

To sum up, the conducted research study yielded good results as it confirmed the knowledge from previous research and contributed more to the field of IoT-based smart beehive monitoring. It introduced successful novel improvements, such as determining feeding needs using rainfall data and determining harvest time using weight data.

Building on the successes achieved in this project, future expansions are planned to find solutions to overcome the limitations experienced during this research study along with adding some additional features.

Determining the need for feeding based on rainfall data and the time of the day alone might not be sufficient in a real-world scenario, where the frequency and the amount the bees need to be fed varies depending on other conditions as well. This includes the weight of the hive, where the daily weight gain may provide insights into nectar availability. Therefore, lack of daily weight gain during summer times indicates less availability of food sources and flowering plants, therefore the feeding frequency and amount should be increased. Therefore in the future analyzing the weight gain and other possible parameters along with the rainfall data and time of the day, a more robust algorithm to determine the feeding needs of the bees will be implemented.

Furthermore, the current system tracks the overall weight of the beehive to determine the optimal time for harvesting using the data obtained from the load cell. However, the current system lacks the features to track the daily honey gathering or loss amount and forecast honey gathering trends using weight data. These limitations will be addressed in the future, as more features will be added to accomplish the above-mentioned tasks.

Apart from resolving the limitations in the current study, future studies will also aim to implement advanced technologies to predict swarming events through sound analysis, detect the presence of the bee queen within the hive, and track the intricate foraging activities of the colony.

Additionally, the authors propose leveraging image processing techniques to identify and manage threats such as hornet intrusions and enhancing hive security. Furthermore, the project will focus on implementing innovative methods for early detection and management of varroa mites, a significant threat to bee health.

Apart from the web application, the research will be further expanded to provide a user-friendly mobile application for beekeepers to monitor the hives remotely.

These advancements will not only deepen the understanding of bee behavior but also contribute to the sustainable management and conservation of bee populations in Sri Lanka.

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