Journal of Agricultural Machinery

Homepage: https://jame.um.ac.ir

Research Article
Vol. 15, No. 1, Spring 2025, p. 47-63

IoT Stingless Bee Colony Monitoring System

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Received: 07 January 2024 Revised: 14 March 2024 Accepted: 06 April 2024 Available Online: 15 February 2025	**How to cite this article:** Arendela, R. J., Ebora, R. A., Arboleda, E., Ramos, J. L. M., Bono, M., & Dimero, D. (2025). IoT Stingless Bee Colony Monitoring System. *Journal of Agricultural Machinery, 15*(1), 47-63. https://doi.org/10.22067/jam.2024.86261.1222

Abstract

The IoT monitoring system for stingless bee colonies aims to provide real-time information about temperature, humidity, and hive weight in response to the issue of colony collapse disorder (CCD) caused by human intervention in beekeeping. It also aims to improve the current monitoring methods for the bees more effectively and efficiently. The monitoring system features a water-cooling control system to maintain an optimal temperature for Tetragonula Biroi (Stingless Bees). The system also includes a user dashboard for remote monitoring and alerts the beekeeper when it is time to harvest. It’s primarily built around the ESP8266-MOD microcontroller, with an Arduino Mega 2560 R3 for the water valve control system. Data were collected from a DHT22 sensor for temperature and humidity, and load cells connected to an HX711 amplifier for hive weight. The system was tested by comparing samples from the system and actual measuring instruments using MAPE for two months, and it demonstrated 98.74% and 97.89% accuracy for surrounding temperature and humidity, respectively. An accuracy of 95.92% for the weight scale and 93% for the water valve control system was also obtained. Hives equipped with the IoT system gained 3.414% more weight than those without it, indicating that the project succeeded in achieving its objectives.

Keywords: Environmental parameters, Hive weight, IoT monitoring system, Remote monitoring, Stingless bee colony

Introduction

The stingless bees known as "Kiwot" are similar in size to ants but share many characteristics with honeybees, excluding the absence of a stinger. These bees play a crucial role in primary healthcare by producing medicinal hive products like honey, propolis, and beebread (Kwapong, Aidoo, Combey, & Karikari 2010). According to research conducted by the National Library of Medicine, it was asserted that the application of propolis can expedite the healing process of cold sores compared to not receiving any treatment (Sforcin, 2016). Carcinogens contained in honey are proven to fight cancer development with the ability to mitigate toxicity through antioxidant properties in honey (Afrin *et al.*, 2019). Beekeeping, also known as Apiculture, has ancient origins, as evidenced by prehistoric art depicting humans harvesting honey from bee colonies. In the early days of beekeeping, honey and wax were the primary products obtained from hives. However, in contemporary times, honey production is viewed as a secondary outcome of the western honeybee (*Apis mellifera*),

https://doi.org/10.22067/jam.2024.86261.1222

whose most crucial role is pollinating plants. Today, up to 79% of the global food supply relies on pollination, making the honeybee the predominant and highly active pollinator species across the world (Fitzgerald, Murphy, Wright, Whelan, & Popovici 2015). Among these pollinators are stingless honeybees, which also serve for commercial honey production, albeit at a lower scale. Research suggests that the honey produced by these bees could potentially aid wound healing by promoting processes like angiogenesis and oxygen circulation (Jalil, Kasmuri, & Hadi, 2017). Honey is most frequently used as a sweetener. Honey is also renowned for its healing properties (Chan-Rodríguez *et al.*, 2012). Additionally, stingless bee honey has demonstrated promise in the realm of medicine due to its phenolic content that enhances antioxidant levels and may help mitigate diseases related to oxidative stress (Yaacob, Rajab, Shahar, & Sharif, 2017). Stingless bee honey showcases unique physicochemical properties that distinguish its composition from honey produced by other species (Özbalci, Boyaci, Topcu, Kadılar, & Tamer 2013). These stingless honeybees are significant not only for their contribution to pollination and honey production but also for their suitability in urban environments due to their non-aggressive behavior and lack of stinging capability in comparison to common honey bees (Honeybees Vs Stingless Bees-The Real Difference, 2020).

In the Philippines, various species of stingless bees play an essential role as pollinators for agriculture in certain regions, often nesting in old bamboo and wooden structures. These bees inadvertently pollinate flowers while collecting pollen for nourishment and produce small amounts of honey. They have a wide foraging range but prefer high-quality pollen sources nearby, visiting numerous flowering plants and potentially contributing to the pollination of around 60 crop species. Despite their importance, their small size often leads to their neglect and confusion with other insects, contributing to declining populations due to habitat loss and pesticide use (Roubik, 2014). Research shows that the population of bees is declining at an alarming rate due to various natural and human-induced factors (Fitzgerald *et al.*, 2015). Researches also show that the understanding of humans of various stingless bee biology and ecological topics continues to lag behind the understanding of honeybees and bumblebees (Biesmeijer, Hartfelder, & Imperatriz-Fonseca, 2006). One research aims to solve this problem and come up with an idea of utilizing useful sensors to monitor the beehive (internal and ambient temperature, humidity, and weight of the hives). These sensors enable beekeepers to effectively evaluate and respond to the bees' needs based on changes in parameters (Zabasta, Zhiravetska, Kunicina, & Kondratjevs 2019). Most of these researchers have utilized a weighing scale to measure and document the hive's weight as part of their approach (Johannsen, Senger, & Kluss, 2020). The researchers aim to follow the same goal but with the use of IoT to monitor the beehive of Stingless honeybees. This study has the potential to support the preservation of bee populations while minimizing stress on the bees, all while enabling remote monitoring of hive conditions. There is a pressing need to comprehensively assess environmental factors affecting stingless bee colonies. By focusing on critical parameters such as temperature, humidity, and light intensity, the study shed light on the influence of the monitoring system on hive health and honey production (Harun *et al.*, 2015).

Beekeepers employ various hive management strategies, including inspection, to check hive occupancy, protect it against enemies, and facilitate honey harvesting (Kwapong *et al.*, 2010). Beekeepers from the Hadiya zone in Southern Ethiopia believe that inspecting hives during the rainy season could lead to disease (Jalil *et al.*, 2017). While external inspections are conducted year-round, caution is advised regarding the timing and frequency of internal inspections. Hive visits serve diverse purposes such as confirming occupation, observing bee activity, and ensuring hive cleanliness (Kiros & Tsegay, 2017; Alebachew, 2018). Yet, internal inspections are less common except for honey assessment (Tesfa & Kebede, 2013). Beekeeping practices and harvesting frequency are influenced by agro-ecology, with higher-frequency harvesting in highland areas due to better forage availability and climate. A study showed that stingless bee activity was intense on warmer days, particularly when the temperature exceeded 30°C. Humidity had minimal impact on flight activities. The study demonstrated the potential of IoT applications in monitoring stingless bee conditions and understanding climate effects on their activities (Yunus, 2017). Also, a study presents an IoT-based strategy that focuses on individual monitoring of bee colonies to enhance resource efficiency and maximize productivity (Ochoa, Gutierrez, & Rodriguez, 2019).

The technology known as "Wireless Sensor Networks" (WSN) is a result of recent developments in embedded sensing, downsizing, wireless communications, low-power operation, and energy harvesting. The Internet of Things (IoT), a new idea, is not complete without WSN. In several fields, such as healthcare (Kulkarni & Ozturk, 2011), smart homes (Edwards-Murphy *et al.*, 2013), and security (Magno, Tombari, Brunelli, Di Stefano, & Benini, 2009), WSN are quickly becoming a necessary component of daily life. A study by Fitzgerald *et al.* (2015), used NodeMCU ESP8266 as a Controller. NodeMCU is an open-source firmware and development kit renowned for its advantages in prototyping IoT (Internet of Things) products with minimal Lua script lines. This versatile controller offers several benefits, including its cost-effectiveness, integrated support for WiFi networks, compact board size, and low energy consumption. They are now a focus of both academic and industrial study, and there are numerous ready-made solutions. Researchers aimed to develop an autonomous smart sprinkler system that responds to real-time soil moisture levels and incorporates Internet of Things (IoT) technology. This system allows users to remotely control watering, offering advantages such as conserving water and preventing overwatering, especially useful in situations like impending thunderstorms. Their research showcases the potential of cost-effective IoT-enabled smart sprinklers as a replacement for traditional sprinkler systems (Chowdhury & Raghukiran, 2017).

The field of agro-industry and the environment are well-suited for implementing Internet of Things (IoT) solutions. This is because they encompass expansive regions requiring constant surveillance and management. Concurrently, IoT introduces fresh possibilities that extend beyond basic operational automation. Utilizing the gathered data to fuel machine learning algorithms for predictive purposes simplifies the process of strategic decision-making and planning for proprietors, supervisors, and policymakers (Talavera *et al.*, 2017).

The current beekeeping method at the International Islamic University Malaysia (IIUM) relies on manual inspections, which can stress stingless bee colonies and potentially lead to colony collapse disorder (CCD). To address this issue, a prototype of an intelligent apiary system using IoT technology is introduced, allowing real-time monitoring of stingless bee health through parameters like weight, temperature, and humidity. The system integrates with a mobile app and employs various sensors, including an HX711 load cell and an FSR402 force sensor, to provide valuable insights and issue alerts for emergencies (Rosli, Malik, & Ahmad, 2022). In another implementation of IoT based monitoring system, an artificial hive was created and a NodeMCU ESP8266 was implemented, along with temperature and humidity sensors, and load cell sensors. The setup monitors various parameters such as the weight of the honey compartment and temperature and humidity inside and outside the stingless beehive. The data collected from these sensors is uploaded to IoT platforms, allowing users to conveniently monitor it via their computers or mobile phones. However, the IoT monitoring system recorded a high-temperature reading of 39.4 degrees Celsius, highlighting the urgency for developing future hives integrated with heat-resistant materials and advanced heat management systems to mitigate the risk of Colony Collapse Disorder (Ali *et al.,* 2023). Numerous IoT-based monitoring systems monitor mainly the temperature, humidity, and weight using different kinds of sensors and methods. Some systems have additional features such as a smoke-gas sensor (Yusof, Billah, Kadir, Ali, & Ahmad, 2019), and GPS for monitoring a large number of colonies (Man, Bakar, & Razak, 2019).

The authors aim to follow existing studies by creating an IoT-based monitoring system that would monitor surrounding temperature, surrounding humidity, and weight at high accuracies for reliability. Additionally, the researchers aim to improve current studies by adding a water-cooling system in an effort to control the surrounding parameters and maintain it at a desired level. The system is designed to minimize human interaction to further explore the impact of the monitoring system compared to colonies without the monitoring system.

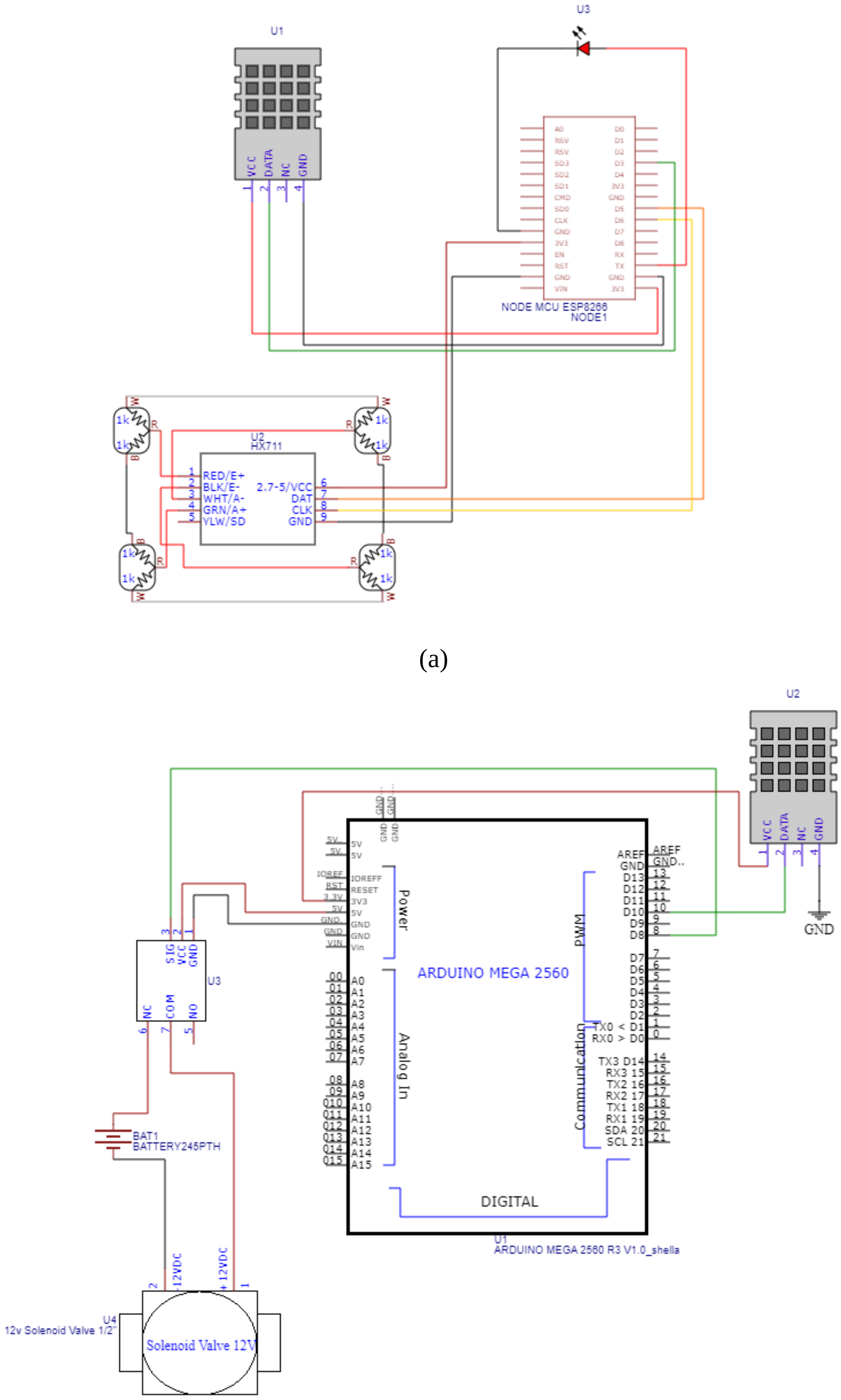
Materials and Methods

Design and construction of the monitoring system circuit

The Internet of Things monitoring system for the stingless bee colony was composed of two circuits and both were designed using the EasyEDA software application. The first circuit was responsible for the online system. In this circuit, the microcontroller unit used was the ESP8266. The sensors and components that were integrated were the DHT22 temperature and humidity sensor, load cells which were connected in a Wheatstone bridge circuit and then to the HX711 amplifier module, and the light emitting diode (LED) light indicator for weight. Figure 1a shows the actual schematic diagram of the IoT system including the specific pin mode mentioned. The second circuit that was developed is responsible for the water valve control system. The water valve control system works by opening the valve of a water mister to increase the surrounding humidity or decrease the surrounding temperature when it detects that the surrounding temperature and/or humidity is not at the desired level. Once the sensors detect that the parameters are back to the desired level, it closes the valve. Although the control valve is located beside the stingless bee hive, the water mister is installed on the roof of the shed of the beehive to prevent direct contact of the water with the bees. The water-cooling system is designed to be very passive so as not to disturb the stingless bees. The MCU used in this circuit was the Arduino Mega 2560 R3. The components that were integrated were the DHT22 temperature and humidity sensor, the 12V solenoid water valve, and the 5V relay. The power supply needed for the Arduino Mega and ESP8266 to operate was also taken from the 12V battery via a 12V to 5V converter. Figure 1b shows the actual schematic diagram of the circuit for the water valve control system.

Development of the program for the IoT system

The IoT monitoring system was composed of two programs. The first program was made using Arduino IoT Cloud for the online part of the system responsible for updating the real-time parameters via the user dashboard. The second program is for the water valve control system, an offline part of the monitoring system, made using an Arduino Integrated Development Environment (IDE) sketch editor. To create the program, it was essential to initially declare the variables for temperature, humidity, and weight. This step ensured that the system could recognize and process their inputs. Libraries were also included in the sketch such as the ESP8266, DHT22, and the HX711. The input data underwent calibrations before being displayed on the user dashboard. The calibration factor was achieved through trial and error basis, by measuring the parameter with a trusted measuring device such as a weighing scale or temperature humidity meter, and comparing it to the result of the system. The calibration factor was adjusted until the system and the measuring instrument displayed the same readings. The sketch was set to a specific threshold weight of 2500 grams that will trigger the light-emitting diode (LED) indicator to light up as a signal that the colony is ready for harvest. This feature will be visible on the physical chassis via LED and on the user's dashboard by the color status in which red means not ready and green means ready for harvest. Lastly, the data was expected to show the actual reading on the end user using a dashboard via widget gauge for the temperature, humidity, weight, and color status of the LED.



(a)

(b)

Fig. 1. Circuit diagram of the system (a) online part of the system, and (b) water valve control system

For the second program, the sketch was edited with a specific threshold temperature and humidity that will trigger the water valve to work during the hot season that reaches high temperatures of 35 degrees Celsius and higher and humidity levels at or below 50 percent.

Figure 2 illustrates the flowchart of the IoT system program from the start, which was to read the temperature, humidity, and weight values as an input. For the first condition which was the temperature, as it reaches 35 degrees Celsius and above or as the humidity reading is less than or equal to 50 percent, the solenoid valve would open, otherwise it would remain closed. The next condition was the weight, as the weight reaches the predetermined weight of the hive which in this case was 2500 grams and above, the LED will light up, otherwise it would remain off.

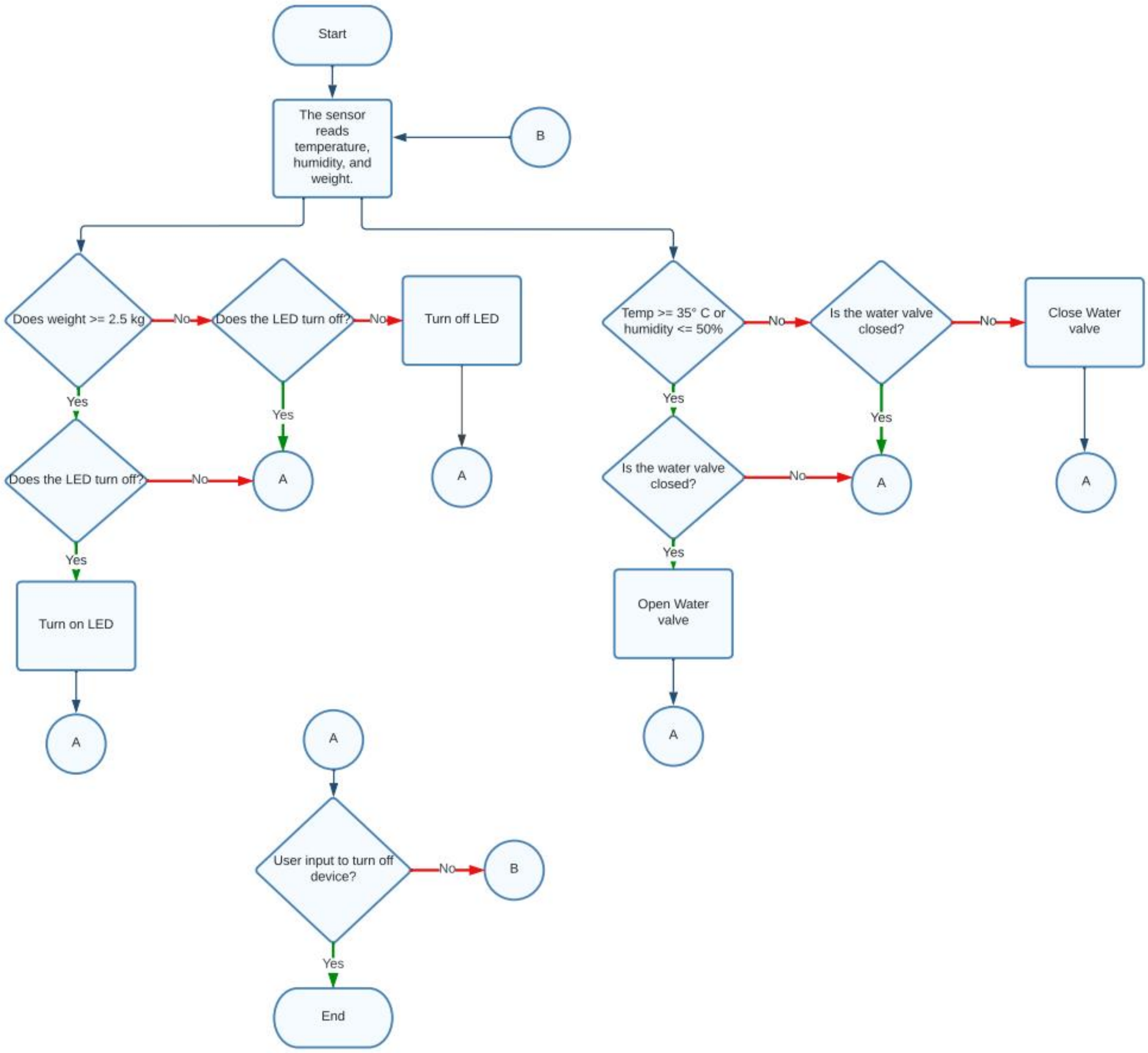


Fig. 2. Flowchart of the IoT system program

Development of the system user's dashboard

The user dashboard for the IoT System was created using the Arduino IoT cloud. The Arduino cloud service also has a user dashboard that could be modified by adding widgets that are suitable for each variable. This was made possible by assigning appropriate data types to the properties such as float for the temperature and humidity readings, integer for weight, and Boolean for the light emitting diode (LED). After assigning these variables, it can be represented by adding suitable widgets such as gauge for temperature, humidity, and weight readings, and color status for the LED. A sticky note was also added to the dashboard with a short description of the critical temperature, and how the light indicator works to inform the beekeeper of the harvest status. The user dashboard editor is web-based and can be arranged easily on Arduino Create Agent. The mobile view is also available and can be positioned just like the desktop view.

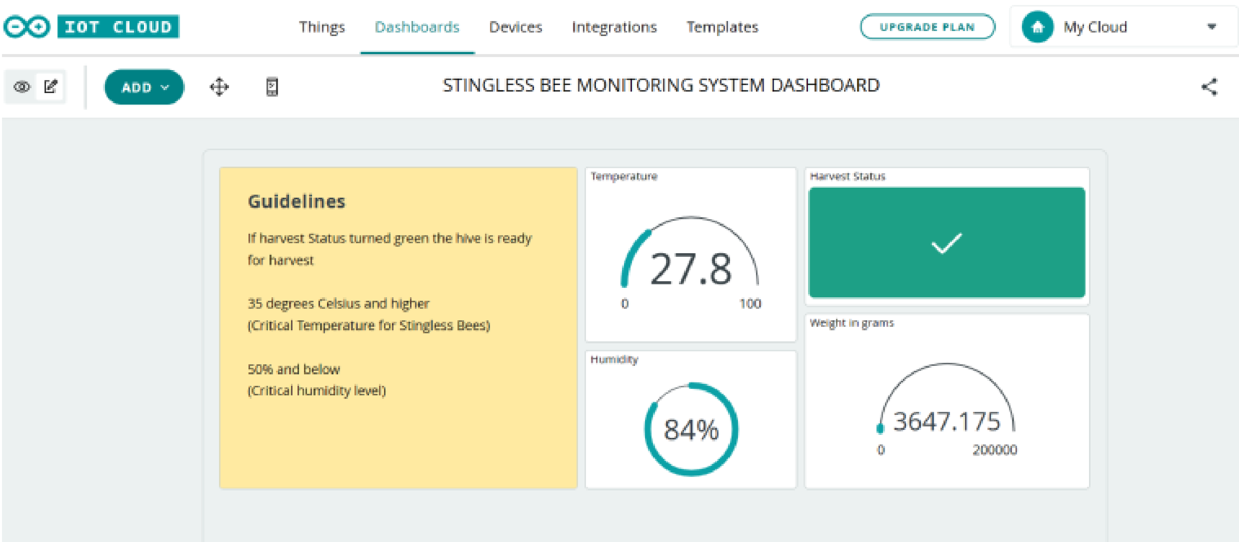


Fig. 3. Desktop view of the user dashboard

Design and construction of the chassis

The IoT system device includes a protective chassis made of 3mm plywood measuring 14.5 x 19.88 x 16 cm to safeguard its components, sensors, and microcontroller unit from potential damage by the bees. The chassis containing the system is placed beside the stingless bee hive, and it features a hinge on the top cover for easy access, holes for sensor connectors and wiring, and an additional hole for a rocker switch. Additionally, a weighing platform constructed from 5.2mm plywood, measuring 21 x 26 cm, was created with load cells installed underneath on a Wheatstone bridge circuit. The weighing platform is placed under the hive for continuous measurement of the weight. Both the chassis and weighing platform were painted with yellow wood paint after construction.

Fig. 4. Actual device installed on a beehive

Evaluating the system

Accuracy of the system parameters reading

To test the monitoring system's accuracy with its reading capabilities for the temperature, humidity, weight, and water valve control system, the device was used to take 100 sample data for each parameter and then calculated for accuracy in comparison to the readings of 100 sample data of the actual measuring instrument in the same environment the sensors were being tested. The actual measuring instrument used to calibrate and determine the accuracy of the temperature and humidity is the UT333 Mini Temperature Humidity Meter of Uni-Trend. The weights used for the calibration and accuracy test of the weight parameter are iPhone 6 (130g), 500g of rice, and 1000g of rice. The formula used for obtaining the accuracy is mean absolute percentage error.

The Mean Absolute Percentage Error (MAPE) shown in Equation 1 was particularly useful in assessing the performance of such models for obtaining data that have varying scales or magnitudes. To determine the degree of prediction inaccuracy in relation to the actual results, MAPE calculates the average percentage difference between the predicted values and the actual values. This is advantageous because quantifying errors as a percentage makes it easier to analyze accuracy more understandably.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right| x\ 100\% = 1.26\% \quad (1)$$

Where:

- **n** represents the total number of data points
- A_i is the actual value of the observation
- F_i is the forecasted/predicted value for observation
- $|\cdot|$ denotes the absolute value

To test the water valve control system's accuracy for working performance, the device was taken out of the shed for the authors to blow hot air at the sensors and simulate 50 samples of 35 degrees and above. The authors also conducted further analysis by evaluating the response of the water valve control system with an additional 50 temperature samples at or below 34 degrees Celsius. A confusion matrix was utilized to calculate the accuracy of the system when it comes to the water valve control system. A confusion matrix is a tabular representation used to assess the performance of a classification model. It helps in understanding the accuracy. The matrix displays the actual and predicted classifications of a dataset, providing insights into the true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN). The confusion matrix table displays a summary of the classifiers' actual versus projected results.

A confusion matrix resides in its capacity to offer a thorough and in-depth evaluation of a classification model's performance. When evaluating the correctness of models in situations involving numerous classes or categories, a confusion matrix is very helpful.

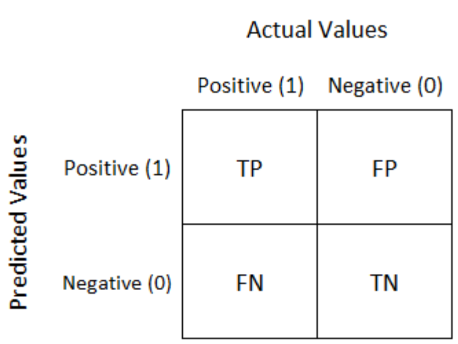


Fig. 5. Confusion matrix

Accuracy is calculated by taking the total of all entries in the confusion matrix as the denominator and using the sum of the true positive and true negative values as the numerator. Equation 2 shows the formula used to obtain the accuracy of the water valve control system reaction to changes in temperature and humidity.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (2)$$

Hive health comparison

A pair of typical beehives was chosen for the comparison. One of these beehives had a monitoring system installed, but the other one was left without any such modernization. This data-gathering technique, which was based on a week-specific indicator of honey harvest readiness, made it easier to focus on the effect of the monitoring system on the hive's internal environment. Every afternoon, the researchers manually weighed the unmonitored hive using a weighing scale while also gathering the weight of the monitored hive through the system. The unmonitored beehive was manually cooled as part of the manual monitoring process by transporting it to a cooler location during peak noon temperature. The monitored hive's use of modern sensors allowed for the collection of a substantial dataset and a thorough analysis of how the monitoring system affected and possibly improved the conditions favorable to productive honeybee activity. As a result, this analytical approach enabled a nuanced investigation of the advantages of integrating monitoring systems into beehives and their potential contribution to improving hive production and health.

Figure 6 shows the manual weight data collection for the IoT-based and non-IoT-based monitoring of beehives. It also shows the bee shed housing the beehive used for non-IoT-based monitoring.

(a) (b)

Fig. 6. Beehive weight data gathering (a) w/o IoT system, and (b) w/ IoT system

To calculate the percentage difference between the health of the monitored beehive to the other without the monitoring system, the percent increase of the monitored hive was subtracted from the percent increase of the unmonitored hive using the formula shown in Equation 3. On the other hand, the percent increase formula used for obtaining the percent increase in both hives is presented in Equation 4.

$$PercentIncreaseofMonitoredHive - PercentIncreaseofNormalHive = PercentageDifference \quad (3)$$

$$PercentIncrease = \frac{FinalValue - InitialValue}{InitialValue} x\ 100\% \quad (4)$$

Results and Discussion

System Evaluation

Parameter Accuracies

For the accuracy percentage results, which were obtained using mean absolute percentage error for the parameter readings, the temperature's accuracywas 1.26 percent. This means that the temperature accuracy was 98.74 percent in comparison to the reading of the actual temperature measured by a temperature humidity meter in the same environment. This accuracy percentage result tells that the system obtained its objective of providing an acceptable temperature reading to be used by the beekeeper for remote monitoring as shown in Figure 7.

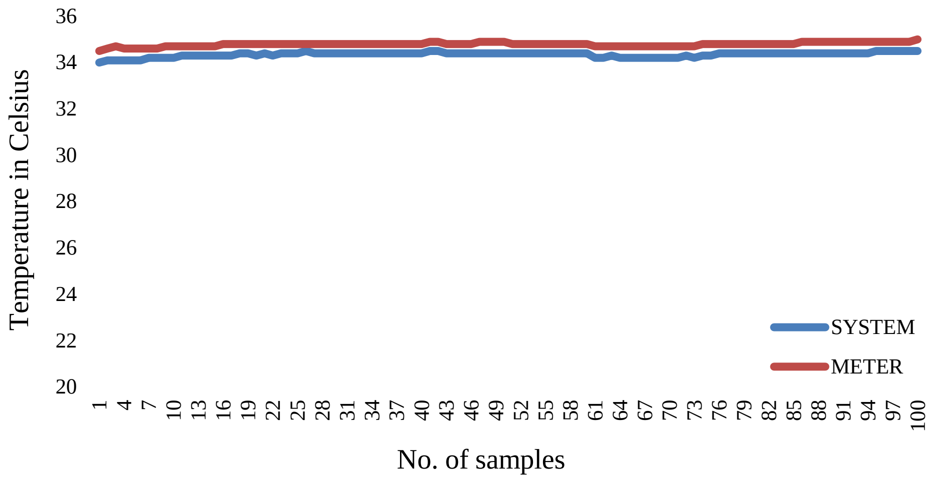


Fig. 7. Temperature reading comparison of the system

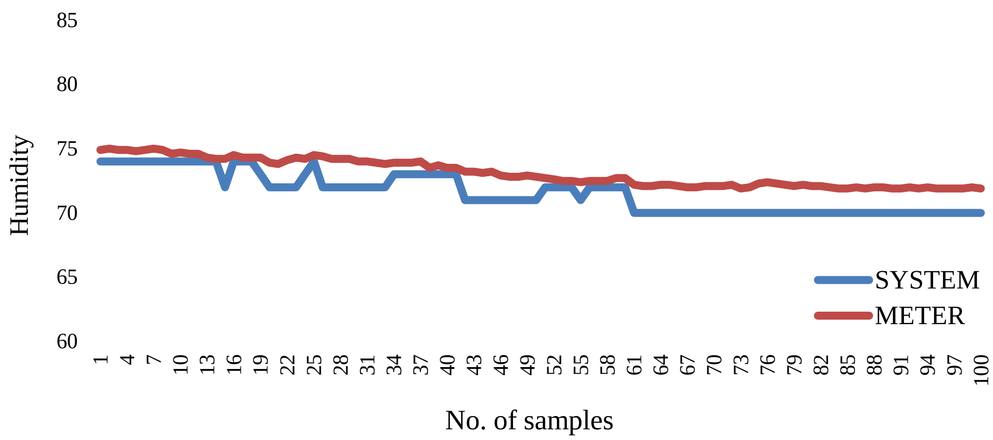


Fig. 8. Humidity reading comparison of the system

The second parameter was the surrounding humidity, which has a mean absolute percentage of 2.11 percent and an accuracy of 97.89 percent (Figure 8). This accuracy result concludes that the humidity reading could also be reliable data that could be helpful for the beekeepers in monitoring the health and optimal humidity of the stingless bee's colony.

The weight parameter was tested using the weighing platform of the monitoring system to weigh three known weights: 130g, 500g, and 1000g. These weights were used to make sure that the monitoring system could weigh light, medium, and heavy objects. The test resulted in 95.92 percent accuracy with a mean absolute percentage error of 4.08 percent. This accuracy result concludes that the weighing platform could accurately provide the weight parameter that the beekeepers could use as they remotely monitor the bee colony. This weight parameter could tell several facts about the health of the colony. As the weight increases day by day, the beekeeper canconclude that the hive is in good condition which means that the stingless bees were continuously growing and collecting honey and pollen.

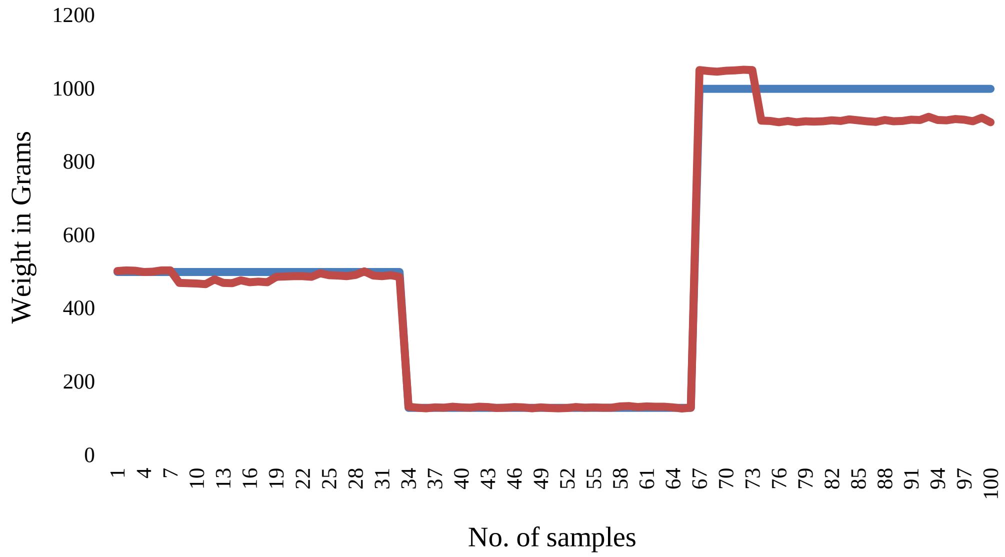


Fig. 9. Weight reading comparison of the system

The water valve control system had 93.46 percent accuracy using the confusion matrix. The true positive (TP) was 43, the true negative (TN) was 50, the false positive (FP) was 0, and the false negative (FN) was 7. The water valve accurately reacted to the 43 true positives by turning on 50 times as the temperature reached 35 degrees and above. There was no recorded false positive from the water valve testing and evaluation. During the testing, the authors found that the false negative results were caused by the direct blowing of hot air in the sensors which caused the DHT222 to fail a few times.

The accuracy percentages were acceptable and efficient in comparison to manually checking the temperature, humidity, and weight of the hive which causes disturbances to the bees affecting their behavior that leads to several issues specifically the colony collapse disorder. Also, the cooling system was more efficient than the traditional way, which was manually lifting the beehive and moving it to another area with optimal or lower temperature.

Table 1 shows the system accuracy for parameters reading in temperature, humidity, weight, and water valve control system. The results indicate that the objectives were successfully met, achieving high accuracy percentages that the system can offer to beekeepers for effective monitoring.

Table 1- Summary of accuracy results of the system

Parameter	System accuracy (%)
Surrounding temperature	98.74
Surrounding humidity	97.89
Colony’s weight	95.92
Water valve control	93.46

Table 2 presents a concise summary of the manually tallied measurements for true positives, true negatives, false positives, and false negatives, reflecting the performance of the water valve in response to temperature variations. TP corresponds to the value of temperature 35 degrees Celsius and above, TN corresponds to the value of temperature 34 degrees and below, FN for the false negative, and FP for the false positive. It shows that the water control system functioned well and was able to achieve its objective which was to maintain the hive's temperature within optimal and safe limits.

Table 2- Performance of valve control TP, TN, FP, and FN of the system

	System Valve Off	**System Valve On**
Actual Off	TN = 50	FP = 0
Actual On	FN = 7	TP = 43

Hive Health Comparison

The monitored hive consistently exhibited more stable internal conditions, with narrower fluctuations in temperature and humidity compared to the normal hive. Additionally, the Monitored Hive provided real-time data on the colony's weight changes, allowing for early detection of potential issues such as swarming or food shortages.

The monitored hive produced a 3.414 percent higher weight gain compared to the normal hive. This difference in weight gain can be attributed to the Monitored Hive's ability to maintain optimal hive conditions, thereby promoting better foraging efficiency and colony health. Also, there was no need for unnecessary inspections thus promoting continued production and less stress for the stingless bees. The weight values provided by the system were a useful reflection of the beehive's health, which was fundamental in beekeeping. The weight provided by the system reflects whether the bee had continuous production by accumulating an expected daily weight. On the other hand, decreasing weight could alarm the beekeeper and he/she could immediately respond to investigate and solve the problem effectively. Manual checking of the beehive's internal condition leads to stress in the stingless bees' behavior and could cause colony collapse and other problems such as fermentation of honey, pest invasion, and low honey production.

Table 3 shows the daily weight data comparison of the bee colony with the IoT monitoring system in comparison to the beehive without the system. The total weight gain for the whole week is also included in the last row.

Table 3- Daily weight comparison of the beehives

Date	**Beehive With IoT System Weight In (g)**	**Beehive W/O IoT System Weight In (g)**
August 16, 2023	3433.882	3417.691
August 17, 2023	3699.107	3644.327
August 18, 2023	3913.446	3838.196
August 19, 2023	4157.259	3961.348
August 22, 2023	4381.764	4141.234
August 23, 2023	4509.876	4371.928
Total weight gained	1075.94	954.237

The results of this study highlight the benefits of integrating monitoring systems into beekeeping practices. The Monitored Hive's ability to maintain stable internal conditions contributed to its higher weight gain. By offering real-time insights, monitoring systems empower beekeepers to intervene promptly in response to changes in hive dynamics, potentially preventing issues that could otherwise negatively impact hive health and productivity.

Cost Computation

Table 4 presents a detailed breakdown of the cost computation for the IoT System. It includes quantity, description, unit cost, and the total cost per material. The overall cost amounted to P10, 004 (Philippine Peso).

Table 4- Cost computation of the IoT system

Quantity	Description	Unit cost (PHP)	Total cost (PHP)
1	ESP8266MOD	300.00	300.00
1	NodeMCU Arduino Mega 2560 R3	500.00	500.00
5	Arduino IoT Cloud Subscription Plan	400.00	2000.00
1	HX711 Load Cell	250.00	250.00
2	DHT22	250.00	500.00
1	Tem and Hum 12V Battery	700.00	700.00
1	Rocker Switch	9.00	9.00
1	5V relay	50.00	50.00
1	12V Solenoid Valve	300.00	300.00
1	LED	5.00	5.00
4	Female hose connectors	70.00	280.00
3	Male connectors	70.00	210.00
2	Water hose (10m)	300.00	600.00
1	12V to 5V DC adapter	300.00	300.00
1	Paint/brush	300.00	300.00
1	Wooden Chassis	500.00	500.00
	Miscellaneous	3 200.00	3 200.00
Total			10 004.00

Conclusion

The study was able to accomplish high-accuracy readings which were acceptable and can be used by the beekeepers. Using the mean absolute percentage error subtracted from 100 for each parameter, accuracy values of 98.74 percent for the surrounding temperature, 97.89 percent for the surrounding humidity, 95.92 percent for the weight scale, and 93 percent for the water valve control system were obtained. These accuracy percentage results mean that the system was reliable in providing valuable information to the beekeeper through the sensors that were integrated. The weight difference was also higher at 3.414 percent in the hive with the IoT system in comparison to the weight of the stingless bee colony without the IoT system. The automatic water valve control also helped in optimizing the temperature and humidity, specifically during the hot season. The total cost of the IoT monitoring system amounted to P10,004 (Philippine Peso). While this was only used on one beehive colony, further expansion of the monitoring system will be more cost-effective, as some components have the capabilities for expansion.

In conclusion, the IoT monitoring system for stingless bee colonies was a success. It demonstrated the capability to deliver satisfactory parameter accuracy while contributing to the overall health of the hive. Utilizing the monitoring system for the remote oversight of stingless bee colonies is a highly effective strategy for preventing potential issues. This approach empowers beekeepers to take prompt action in response to any changes in the colony's environment. Using the IoT monitoring system could also prevent colony collapse disorder by decreasing stress on the bees caused by human intervention and could help in optimizing the temperature as it reaches the critical level to prevent deaths of the stingless bees' larvae.

The authors recommend that in future studies, the use of more compatible Arduino IoT Cloud boards would be better to fully maximize the programming and avoid errors and incompatibilities. It is advisable to use boards that support over-the-air code updates to reduce the necessity of disturbing the stingless bees whenever issues arise. The authors suggest adding a messaging feature to alert beekeepers about their colony's health, eliminating the need to frequently open the app. The implementation of a camera on the monitoring system is also recommended to provide more data to the end user and track the health of the colony. The authors recommend an alternative source of power supply due to the fact the available source of power is limited, especially in secluded and remotely located areas. Lastly, the authors also recommend longer periods of actual testing to further understand the reliability and effectiveness of the system. This would also help in identifying if the monitoring system, although non-moving, affects the colonies itself. Longer periods of observation would also provide a way for an in-depth economic analysis of the system.

Declaration of competing interests

The authors declare that they have no conflict of interest.

Authors Contribution

R. J. Arendela: The author constructed the circuit for IOT Stingless Bee monitoring system. He also tested and evaluated the developed system.

R. A. Ebora: The author constructed the circuit for IOT Stingless Bee monitoring system. He also tested and evaluated the developed system.

E. R. Arboleda: The author contributed the following: conceptualization of the research idea, supervision in the conduct of the study, provided technical advice as well as devised the methodology for this study.

J. L. M. Ramos: The author performed the writing, review and editing of the manuscript in a publishable format. He also contributed in data acquisition, data pre and post processing, statistical analysis, numerical/computer simulation, validation and visualization

M. Bono: Provided technical advice in the behavior of the sting less bees and how the process of taking care of them can be automated.

D. Dimero: Provided technical advice in the behavior of the sting less bees and how the process of taking care of them can be automated.

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مقاله پژوهشی
جلد ۱۵، شماره ۱، بهار ۱٤٠٤، ص ٦٣-٤٧

سیستم نظارت بر کلونی زنبورهای بدون نیش با کمک اینترنت اشیا

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تاریخ دریافت: ۱۴۰۲/۱۰/۱۷
تاریخ پذیرش: ۱۴۰۳/۰۱/۱۸

چکیده

هدف از توسعه سیستم نظارت بر کلونی‌های زنبورهای بدون نیش با اینترنت اشیا، ارائه اطلاعات در لحظه درباره دما، رطوبت و وزن کندو برای مقابله با اختلال فروپاشی کلونی (CCD) ناشی از مداخله انسان در زنبورداری است. همچنین بهبود روش‌های فعلی نظارت بر زنبورها و نظارت موثرتر و کارآمدتر از دیگر اهداف این سیستم هستند. سیستم نظارتی همچنین دارای یک سیستم خنک‌کننده آب برای حفظ دمای مطلوب زنبورهای بدون نیش (*Tetragonula Biroi*) است. این سیستم همچنین دارای داشبورد کاربر برای نظارت از راه دور بوده و هنگام فرارسیدن زمان برداشت به زنبوردار اطلاع می‌دهد. این دستگاه بر روی میکروکنترلر ESP8266MOD ساخته شده و از Arduino Mega 2560 R3 برای سیستم کنترل دریچه آب استفاده شده است. داده‌های دما و رطوبت با سنسور DHT22 و وزن کندو با لودسل‌های متصل به آمپلیفایر HX711 جمع‌آوری شدند. برای تست سیستم، داده‌های به‌دست‌آمده از سیستم با اندازه‌گیری دستی به مدت دو ماه و با استفاده از MAPE مقایسه شدند و در نتیجه، دقت سیستم به‌ترتیب ۹۸/۷۴ و ۹۷/۸۹ درصد برای دما و رطوبت محیط اندازه‌گیری شد. همچنین دقت ۹۵/۹۲ درصد برای وزن کندو و ۹۳ درصد برای سیستم کنترل شیر آب به‌دست آمد. کندوهای مجهز به سیستم نظارت اینترنت اشیا ۳/۴۱۴ درصد وزن بیشتری نسبت به کندوهای عادی به‌دست آوردند که نشان‌دهنده‌ی موفقیت پژوهش در دستیابی به اهداف خود می‌باشد.

واژه‌های کلیدی: پارامترهای محیطی، پایش از راه دور، سیستم نظارت اینترنت اشیا، کلونی زنبورهای بدون نیش، وزن کندو

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https://doi.org/10.22067/jam.2024.86261.1222