A Review on the Stingless Beehive Conditions and Parameters Monitoring using IoT and Machine Learning

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Abstract. One of the stingless bee types named Heterotrigona Itama are widespread in the tropics and subtropics especially in Malaysia. Due to its excellent nutritional content, stingless bee honey has gained favour in recent years. According to some studies, stingless bee honey has been used to cure eye infections, open wounds, diabetes, hypertension, and a variety of other diseases. Additionally, this stingless bee is non-venomous and smaller in size than common bees. Nevertheless, beekeepers may encounter a number of obstacles that may result in colony failure and under-production. These problems can be attributed to a variety of factors such as surrounding temperature, surrounding humidity and predators. Numerous stingless bee colonies and other bee species lost in 2006 due to Colony Collapse Disorder as a result of this problem. Therefore, this article will review previous research on optimizing stingless beehive conditions via the use of the Internet of Things (IoT) and machine learning to minimise this issue. To begin, a review of existing research on the characteristics of stingless bees, particularly the Heterotrigona Itama species, has been conducted to understand the natural habitat of Heterotrigona Itama. Following that, the articles on colony division was reviewed in order to transition the colony from the conventional hive to the artificial hive which also reviewed its design from the past article to simplify the sensors installation, IoT monitoring system and honey harvesting. Then, the prior article on sensors and IoT deployment was examined to monitor and analysis the data online without disturbing the colony activity inside the beehives. Finally, the article on the application of machine learning with the beehive dataset was reviewed the most precise and accurate machine learning method to predict the existence of bee activity in the hives and the future condition of beehive.

1. Introduction

Stingless bee honey has recently gained popularity in recent years due to its high nutritional value. Heterotrigona Itama is the most common meliponiculture species in Malaysia due to its high demand and abundance [1]. Since a very long time ago, honey produced by stingless bees has been prized for its distinct flavors and used as medicine to treat a variety of ailments. According to researchers, honey has been used to treat eye infection, open wounds, diabetes, and high blood pressure, as well as other diseases [2 – 4]. Stingless bees are non-venomous and smaller than common bees [5]. It is a non-stinging species which can be raised almost anywhere. However, farmers may face a variety of obstacles. There are several causes of colony failure and under-production, such as temperature, humidity, and predators. As a result of this issue, many honeybee colonies and other bee species were lost in 2006 due to Colony Collapse Disorder [6]. Therefore, some researchers particularly in Southeast Asia have recently become interested in stingless bees. Studies on stingless beehive behavior and colony health have been conducted. These studies are vital for stingless bee health on farms in accordance with the current technological progress, especially industrial 4.0 where introduced ubiquitous Internet connectivity, Machine-to-Machine (M2M) connections and improved modelling of collected data by machine
learning algorithms [7, 8]. This will keep stingless bees from leaving their hive and increase honey production.

2. Characteristic of Stingless Bee
A study was conducted on the Morphological, Nest Architecture, and Colony Characteristics of Stingless Bees in Tasik Kenyir Terengganu and Dino-Eye microscope camera is being used to collect images of Heterotrigona Itama’s morphological characteristics for four body parts which are: abdomen, head, leg, and wing as shown in Figure 1 [9].

![Heterotrigona Itama Body Parts](image)

Figure 1. Heterotrigona Itama Body Parts (a) Abdomen (b) Head (c) Leg (d) Wing [9]

A total of twenty Heterotrigona Itama samples were collected from various sites in Penang State in order to examine the variation in morphometric characteristics seen in Heterotrigona Itama and each individual's morphometries were recorded using an Image Analyzer in Olympus Microscope [10]. Numerous bee components have been identified, as listed in Table 1.

| Parts               | USM 2       | USM 5       | Botanical Garden | Balik Pulau 2 |
|---------------------|-------------|-------------|------------------|---------------|
| Body Length         | 4.96 ± 0.37 | 2.54 ± 0.17 | 5.36 ± 0.06      | 5.34 ± 0.05   |
| Width of Head       | 2.34 ± 0.15 | 1.32 ± 0.07 | 2.22 ± 0.07      | 2.23 ± 0.06   |
| Width of Thorax     | 2.00 ± 0.10 | 1.15 ± 0.07 | 2.04 ± 0.06      | 2.04 ± 0.06   |
| Width of Abdomen    | 1.92 ± 0.16 | 1.06 ± 0.06 | 1.96 ± 0.08      | 1.97 ± 0.08   |
| Forewing Length     | 5.63 ± 0.43 | 2.88 ± 0.03 | 5.87 ± 0.26      | 5.87 ± 0.26   |
| Femur Length        | 1.58 ± 0.14 | 0.81 ± 0.07 | 1.51 ± 0.03      | 1.49 ± 0.04   |
| Tibia Length        | 2.19 ± 0.21 | 1.14 ± 0.08 | 2.26 ± 0.06      | 2.26 ± 0.06   |
| Forewing Width      | 2.11 ± 0.20 | 0.93 ± 0.10 | 2.26 ± 0.04      | 2.27 ± 0.04   |
| Width of Femur      | 0.41 ± 0.03 | 0.19 ± 0.01 | 0.39 ± 0.03      | 0.40 ± 0.03   |
| Width of Tibia      | 0.88 ± 0.06 | 0.39 ± 0.03 | 0.84 ± 0.03      | 0.84 ± 0.03   |
2.1. Characteristic of Heterotrigona Itama’s Beehive
A study on two types of stingless bee which are Heterotrigona Itama and Geniotrigona Thoracica was conducted from three distinct hives [9]. Electronic vernier callipers were used to determine the dimensions of both types of pots. The width and length of the entrance tube, honey pot, pollen pot, and brood cells of the Heterotrigona Itama are shown in Table 2.

| Heterotrigona Itama Nest Parameters | Mean ± Standard Deviation (mm) |
|-------------------------------------|--------------------------------|
| Entrance Tube Length                | 114.817 ± 50.378               |
| Entrance Tube Width                 | 15.807 ± 3.566                 |
| Honey/Pollen Pots Length            | 20.364 ± 2.511                 |
| Honey/Pollen Pots Width             | 14.023 ± 0.740                 |
| Brood Cells Length                  | 4.663 ± 0.133                  |
| Brood Cells Width                   | 3.303 ± 0.133                  |

2.2. Survivability of Stingless Bee
Temperature control within the beehive is critical to stingless bee survival. Since stingless bees are very sociable, their cooperative effort to regulate the hive's temperature throughout the year is referred to as passive thermoregulation [11]. A study was conducted utilizing Scaptotrigona Depilis, a stingless bee found in Brazil's humid tropical and subtropical climates, similar to those found in Malaysia. Puppies were incubated in brood cells at five different temperatures: 22, 26, 30, 34, and 38°C. The characteristic of dead pupae is the development of fungal growth, whereas the characteristic of surviving pupae is the emergence of a bee. Figure 2 shows the pupae mortality is maximum at 22°C, followed by 38°C, 26°C, 30°C, and 34°C [12].

![Figure 2](image.png)

**Figure 2.** Scaptotrigona Depilis pupae survival rate after incubation at five different temperatures. The grey sections indicate the survival rate, whereas the black areas indicate the mortality rate [12]

3. Division of The Colony
Splitting colonies is a common procedure in Meliponiculture to prevent a colony swarming, which results in the colony's demise. A gyne, or virgin queen, is a newly emerged queen from a brood cell normally used to split the colony. When a new queen arises, it may be killed by worker bees, replacing the existing queen, or swarm in order to establish a new nest with workers [13].

A study conducted in Karnataka, India, [14] demonstrates the success rate of several ways of colony division. There are six methods used which are parallel division with the presence of gynes in the divided colony, parallel division with the presence of queen cells in the divided colony, brood separation with the presence of gynes in the divided colony, brood separation with the presence of queen cells in the divided colony, brood separation without the presence of gynes or queen cells in the divided colony, and
colony budding method. The study used 50 colonies and lasted four months. Across all successful methods, it took a month to see colonies develop, except for the budding method, which succeeds in four months. The success rate of colony splitting is shown in Table 3.

| Dividing Methods                              | Number of Colonies Divided | Number of Colonies Succeeded | Success Rate (%) |
|-----------------------------------------------|-----------------------------|------------------------------|------------------|
| Parallel Division with The Gynes              | 10                          | 10                           | 100              |
| Parallel Division with The Queen Cells        | 15                          | 13                           | 85.66            |
| Brood Separation with The Gynes               | 7                           | 6                            | 85.71            |
| Brood Separation with The Queen Cells         | 8                           | 6                            | 75               |
| Brood Separation Without the Gynes or Queen Cells | 5                           | 0                            | 0                |
| Budding Method                                | 5                           | 3                            | 60               |
| **Total**                                     | **50**                      | **38**                       | **76**           |

4. Artificial Hive
A study by [15] designed the beehive for monitoring stingless bee colonies as displayed in Figure 3. The stingless beehive structure consists of two major components which are the main hive and the honey box, or commonly referred to as the topping. The bottom section contains the entrance funnel, that is perpendicular to the main hive. To conduct foraging activities and effectively defend their hive, bees construct a unique funnel-shaped entrance. A connection tube is installed on top of the main hive and is connected to the main hive, namely the to the honey container. The stingless bee colony will crawl into the honey container and store its honey and bee bread.

![Figure 3. Design of A Stingless Bee Monitoring Hive [15]](image)

5. Sensors Implementation
Stingless bees are a species of bee that are particularly sensitive to the changes of its surroundings, especially to extreme heat wave. A research indicated that at temperature up to 38 °C might cause mortality of bees especially to the pupae [12]. A study by [5] assessed a new way for managing the hive's temperature. The cooling method employed in this study was a greenroof, a form of roof that incorporates green flora and soil. Two MUSTAFA-hives were exposed to sunlight, one hive was fitted
with a greenroof, while other hive was lacked any kind of cooling and functioned as a control hive. Temperatures inside each beehive were measured twice and compared to the hive that did not have temperature control. According to Table 4, the hive equipped with a greenroof has an amazing cooling performance. When exposed to external circumstances without any shades, the temperatures within the hive fitted with greenroof were much lower than those inside the control hive. The honey cassette and broodcell compartments have seen an average temperature drop of 3.3°C and 6.5°C, respectively.

Table 4. Temperatures at The Minimum, Maximum, and Average Levels in The Honey Cassette and Broodcell [5]

| Temperature (°C) | Honey Compartment | Brood Cell Compartment |
|------------------|--------------------|------------------------|
|                  | Control            | Green Roof             | Control            | Green Roof             |
| Minimum          | 30.1               | 28.3                   | 30.6               | 27.9                   |
| Maximum          | 34.7               | 30.8                   | 39.8               | 31.6                   |
| Average          | 33                 | 29.7                   | 36.7               | 30.2                   |

6. Internet of Things Implementation

The monitoring of stingless bee activities is a means to study the survival determinate and dispersion adaptability of the stingless bees for large-scale honey productions and future crop pollination success [16 – 19]. However, the traditional methods face certain problems such as direct human observation and interaction which can be seen as excessively subjective, intrusive, and time consuming. Therefore, a study in [20] did an Internet-of-Things investigation on the environmental elements affecting meliponiculture. In the honeycomb, also known as the “topping,” a temperature sensor DHT11 has been installed. To prevent propolis from interfering with the sensor's readout, the sensor was wrapped in PTFE tape. Additionally, the study utilized the ThingSpeaks Internet of Things gateway to collect data every 40 seconds and display it live on their website. The maximum temperature of 38°C is achieved in Figure 4 by employing traditional hives consisting of a beehive within a wood and a honey chamber on top. ThingSpeak was chosen in this study because it enables the collection, visualization, and analysis of live data streams over the cloud.

Figure 4. 120-Day Temperature and Relative Humidity [20]

7. Machine Learning Implementation

In [21], researchers examined the preparation and processing of heterogeneous IoT data acquired from beehives, as well as the implementation of appropriate machine learning techniques. By using machine learning to datasets from beehives, it is possible to identify new relationships between hive processes and environmental characteristics such as temperature, humidity, atmospheric pressure, and CO2. After
appropriate data processing, it is necessary to design the right machine learning algorithm [22]. This is a complicated procedure depending on the quantity, quality and type of the gathered data [23]. The research makes use of Microsoft Azure Machine Learning Studio. The page describes the algorithms for Bayes Point Machines [24], Averaged Perceptrons, Boosted Decision Trees [25], and Support Vector Machines (SVM). Following that, the data is compared using four metrics, as specified in Table 5, namely accuracy, precision, recall, and F1 score.

| Table 5. Compared metrics [21] |
|-------------------------------|----------------|----------------|----------------|----------------|
| Bayes Point Machine           | Averaged Perceptron | Boosted Decision Tree | SVM           |
| Accuracy                      | 0.845           | 0.843           | 0.998          | 0.841          |
| Precision                     | 0.395           | 0.392           | 0.991          | 0.355          |
| Recall                        | 0.102           | 0.127           | 0.995          | 0.100          |
| F1 Score                      | 0.162           | 0.192           | 0.993          | 0.156          |

The Two-Class Boosted Decision Tree exceeds the competition in terms of performance measurements. The accuracy value of 0.998 obtained indicates that this model is approximately 99 percent accurate. Precision is 0.991 and sensitivity is 0.995, both of which are acceptable coefficients for this model because they exceed 0.5. The excellent accuracy of the algorithm and the results obtained enable beekeepers to build confidence in IoT devices and systems to acquire information about the present condition of the bee brood. Because of its excellent classification accuracy, this method will be utilized in the present project to forecast the future condition of beehives.

8. Discussion
A complete hardware model of the artificial hive with dimensions of 165mm diameter and 195mm height is created, along with electrical connections for temperature sensors in the room, the artificial hive, and the traditional hive. Additionally, an IoT monitoring system was built and tested, using the Cayence as the IoT platform, the NodeMCU ESP8266 as the controller board, and the DHT22 as the hive's temperature and humidity sensor. Nevertheless, the outcome is insufficient, since the temperature and humidity within hives are still affected by weather, ambient temperature, and ambient humidity. In order to continue with this study, a new hive design will be designed to address and minimize this issue. Following that, weighing sensors will be integrated into this system to estimate the quantity of honey produced in stingless beehives without opening the hive.

9. Conclusion
This article examined strategies for optimizing the stingless beehive condition utilizing Internet of Things (IoT) and machine learning data. Industrial revolution 4.0 could be utilized to do research to discover the optimal honey production parameters. This is because it can display real-time data, allowing Machine Learning to calculate the best conditions for beehives based on the beekeeper's actions. While providing an intelligent stingless beehive that enables successful study and honey collection. It is envisaged that this novel strategy would result in an increase in the number of stingless bee breeders.

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