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Development of Artificial Stingless Bee Hive Monitoring using IoT System on Developing Colony

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ABSTRACT

The trend of stingless bees' farm in Malaysia has increased recently as it has been proven that its honey gives various benefits to human beings. This trend requires beekeepers to do more frequent inspections of beehives. However, the current practice of opening the cover to inspect the colony and honey will disrupt colony activity. According to a recent study, these stingless bees can only survive between 22 and 38 degrees Celsius, and harsh weather conditions might lead to the collapse of bee colonies. In order to ensure a consistent honey production, the IoT monitoring system will be implemented on an artificial stingless beehive. The system is equipped with an embedded system that utilizes a NodeMCU ESP8266, temperature and humidity sensors, and load cell sensors. Next, honey compartment weight, temperature and humidity inside stingless beehive, and temperature and humidity outside stingless beehive will be uploaded to the Internet of Things (IoT) platforms, namely Thingspeak and Cayenne. The data is sent to Thingspeak via the REST API while to Cayenne by the MQTT API. All data from the artificial stingless bee hive indicating the occurrence of colony rising and has been uploaded to the IoT platform. By analysing the data that were recorded for 13 days, all of the input data such as the weight of the honey compartment, the temperature in the hive, and the humidity in the hive, display its respective characteristics. For the honey compart weight, it has been found that the stingless bee colony is rising as a result of the increasing honey and colony in the compartment weight. Regarding the hive temperature, it has been determined that the temperature inside the hive is stable around 26°C to 38°C in normal weather conditions. Whereas for humidity inside the hive, it is remained between 76.5% and 85.6% due to the moisture from the honey inside the compartment. Lastly, these results indicate that the colony living in the artificial hive of stingless bees is healthy and growing.

1. Introduction

One of the areas of agriculture that is seeing an increase in interest among bee farmers in Malaysia is the raising of stingless bees. Not only is it easy to prepare, but stingless bees can give

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beekeepers a large profit, particularly from the honey they produce. In addition to being a non-venomous species of bees, stingless bees are social insects that live in colonies and lacked the ability to produce sting. Normal honeybees defend themselves from potential threats by stinging, but stingless bees defend themselves from potential threats by biting if they are disturbed [1].

In a single hive, colonies of stingless bees or Trigona bees can number in the thousands. The tiers of a bee colony consist of the queen, male bees, worker bees, and young bees [2]. The stingless bee is a type of bee that produces honey, bee pollen, and propolis, all of which have several health advantages and economical worth. In addition, cultivation of stingless bees is a simple endeavour that does not require a substantial investment. The low cost of stingless bee cultivation is due to the fact that it simply requires a fresh hive, colony preparation, and the availability of feed [3].

Due to the inconsistent amount of honey, it is vital for the farmer to determine if the honey pot is full or not. The significance of inspecting the honey pot is to ensure that the honey has undergone evaporation within the hive to reduce the quantity of moisture by waiting a month prior to harvesting [4,5]. However, inspection of the traditional hive frequently will disrupt the colony. In addition, the internal temperature of the stingless bee hive must be monitored to prevent the bees and pupae from dying if their temperatures surpass 38 degrees Celsius [6]. If this continues, colony bees will perish, and Colony Collapse Disorder will result [7-9].

As a consequence of this, research using an IoT system for monitoring stingless bee hive parameters such as temperature, humidity, and weight needs are performed. This is necessary since the health of the bee colony is more assured with this method, despite the involvement of the beekeeper during the development of the colony, to ensure sufficient amount of honey is produced.

Accordingly, a number of studies concerning stingless beehives and the Internet of Things have been conducted. Yunus *et al.,* [10] investigated an IoT-based system towards environmental elements influencing meliponiculture. Anuar *et al.,* [11,12] used DHT22 to monitor the temperature inside and outside of a traditional beehive with a log and a topping in order to create a remote monitoring system for beehive safety and honey production. A study by Harun *et al.,* [13] focused on monitoring many environmental factors in real time. Basrawi *et al.,* [14] and Ramli *et al.,* [15] analysed the thermal performance of a vented honey cassette for stingless bees in order to compare the temperature of the honey compartment when ventilation holes are present compared to when they are not.

For the purpose of this project, an Internet of Things system will be built on an artificial hive that has been purposefully designed to facilitate the installation of electronic sensor items such as load cells and DHT22. Some recent publications use stingless bee IoT monitoring by using microcontroller, DHTs for temperature and humidity measurement, and load cell to measure weight [16-19]. However, these authors are not creating a new hive to measure parameters more conveniently, particularly the weight of honey. The data that has been recorded will subsequently be uploaded to Internet of Things platforms such as Thingspeak and Cayenne. This will make it possible for the beekeeper to monitor data relating to the hive using a computer or smartphone connected to one of these platforms.

2. Hardware and Software Development

2.1 Design of Artificial Stingless Bee Hive

An artificial hive with 2 separate sections: the brood compartment (bottom) and the honey compartment (top) as in Figure 1. In combination with the honey compartment, the ABS Box and the load cell are positioned above and below the honey compartment, respectively. Naturally, stingless bees will always put honey on top and brood on the bottom. So, when the hive is full, the compartment will be added below the load cell (Brood Compartment) because the only compartment to be measured is Honey Compartment. As a result of the addition of the compartment, the honey compartment, load cell plate, and ABS Box must be raised by one level to ensure that the honey compartment is always on top. By placing the ABS Box on top, the wiring and connections are not required to be redone. Furthermore, this artificial hive has an air jacket mechanism of PVC layers of different diameter. In addition, the design is user-friendly since it allows the beekeeper to select, position, or replace any compartment based on personal preference. This design combines Polyvinyl Chloride (PVC) and Polyethylene Terephthalate Glycol (PET-G) as its materials.

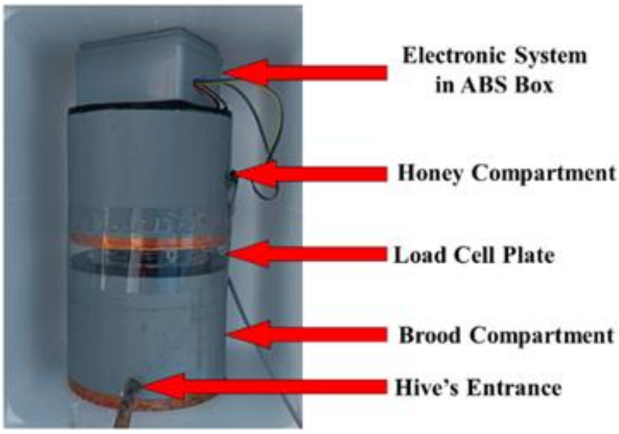
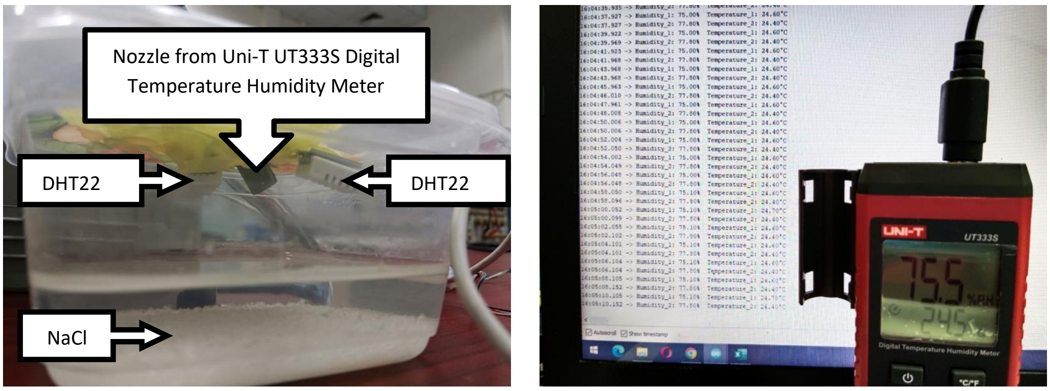


Fig. 1. Artificial stingless bee hive

2.2 Sensors Validation

The sensors utilised in this project are a DHT22 for ambient temperature and humidity and a load cell with a HX711 amplifier for measuring the honey weight compartment. Each sensor included in this research must first undergo a validation procedure. Figure 2(a) depicts the placement of the DHT22 sensors and "Uni-T UT333S Digital Temperature Humidity Meter" in a container filled with Sodium Chloride (NaCl) that lead to 75 ± 2% Relative Humidity (RH) [20]. The readings of the DHT22 sensor will be compared via the Serial Monitor of the Arduino IDE to the data recorded by this Digital Temperature and Humidity Meter as in Figure 2(b). As for the Load Cell, the Steel Round Gage Block's weight is placed on the Load Cell Plate and compared to the readings produced by the Load Cell via the Arduino IDE's Serial Monitor, as shown in Figure 3.



(a) (b)

Fig. 2. DHT22 validation (a) DHT22 and Uni-T UT333S Digital Temperature Humidity Meter in a NaCl-filled container (b) comparison measurement for DHT22 and Uni T UT333S Digital Temperature Humidity

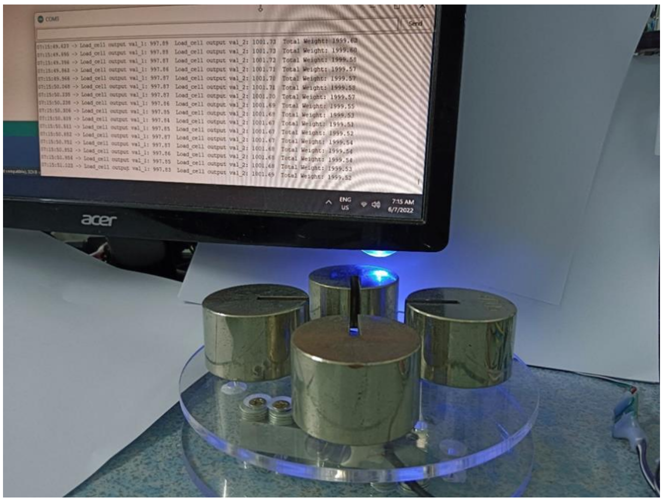


Fig. 3. Compare the readings from the load cell and the steel round gage block placed to the load cell plate

Considered weights are 0.5kg, 1kg, 1.5kg, and 2kg. In addition, the data validation method utilised in this project consists of a variety of formulas, including range different Eq. (1), average difference Eq. (2), percentage error Eq. (3), and standard deviation Eq. (4).

$$Difference, \Delta = Reference\ Value, \upsilon_{Rf} - Reading\ Value\ \upsilon_{Rd} \tag{1}$$

$$Average, \bar{X} = \frac{\sum Sample\ value, X}{No. of\ Sample, n} \tag{2}$$

$$Percentage\ Error, \delta = \left|\frac{\upsilon_{Rf} - \upsilon_{Rd}}{\upsilon_{Rf}}\right| . 100\% \tag{3}$$

$$Standard\ Deviation, S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{Sample, n-1}} \tag{4}$$

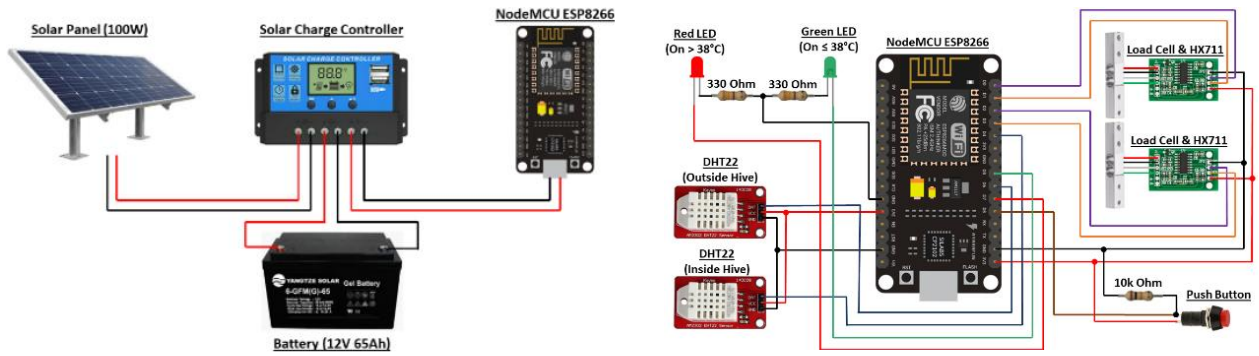
2.3 Electronic Implementation

Attributed to the reason that this is an outdoor project, the solar system is essential for guaranteeing that the electrical devices are always operating properly. A schematic diagram of solar system for the project in Figure 4(a) depicts the connection between the components including Solar Panel 100W, Solar Charge Controller, Battery 12V 65AH, and Nodemcu ESP8266 as for load. The battery can last between 67 days and 135 days approximately.

Figure 4(b) illustrates the schematic diagram for this project, which utilizes the NodeMCU ESP8266 microcontroller. This microcontroller implements the Wi-Fi protocol for data transfer and offers a variety of capabilities, including 13 GPIO Pins, 10 PWM Channels, I2C, SPI, ADC, UART. It can be obtained at an affordable price and is quite simple to use, as it programmable with Arduino IDE.

Additionally, two DHT22 sensors are utilized to measure the temperature and humidity inside and outside of the hive. Because humidity data can also be used to anticipate the amount of honey in the honey compartment, the first sensor will be installed inside the honey compartment. The purpose of the sensor outside the hive is to compare the surrounding temperature and humidity to the sensor inside the hive.

Next, two sets of load cell (1kg) and HX711 amplifiers are used to measure the honey compartment's mass. The sensor will be positioned on one of the two plates under the Honey Compartment and above the Brood Compartment. The reason of using 2 sets of load cell is the accumulation of weight in the colony does not always occur in the same location. Consequently, the more sensors that are utilized, the more accurate the averaged reading will be. However, the optimal number of sensors for this experiment is two, as the load cell plate can only fit two load cells only. Green LED will turn on if the beehive in normal temperature conditions, which are less than or equal to 38 degrees Celsius, while red LED will switch on when the beehive in extremely high temperatures, which are greater than 38 degrees Celsius. Last but not least, a push button has been used to reset tare value of load cell measurement. The switch can be accessed but is concealed by a cap. Therefore, the beekeeper must open the cap in order to press the trigger. Also, only 0.02A to 0.04A of current is being used by the entire system. The price list of the components used in the system is listed in the Table 1.



(a) (b)

Fig. 4. Electronic system (a) Schematic diagram for solar system, (b) Schematic diagram for embedded system

Table 1
Components price list

Components	Unit	Price (RM)	Amount (RM)
NodeMCU ESP8266	1	14.90	14.90
DHT22	2	15.50	31.00
Load Cell	2	7.90	15.80
HX711	2	4.90	9.80
LED	2	0.20	0.40
Push Button	1	1.90	1.90
330 Ohm Resistor	2	0.05	0.05
10k Ohm Resistor	1	0.05	0.05
Total Price (RM)	-	-	73.90

2.4 Internet of Things Implementation

The Internet of Things (IoT) is an ongoing phenomenon in which a large number of embedded devices are linked to the Internet. These linked devices communicate with people and other devices and can often send sensor data into the cloud storage and cloud computing resources, in which the data is processed and analysed to create insightful conclusions. As the Internet of Things platform for the project, Figure 5 illustrate the link between Artificial Stingless Bee Hive, Cayenne Dashboard and ThingSpeak that were chosen to monitor the data remotely. Both Cayenne and Thingspeak code can be found in the Arduino IDE library for programming.

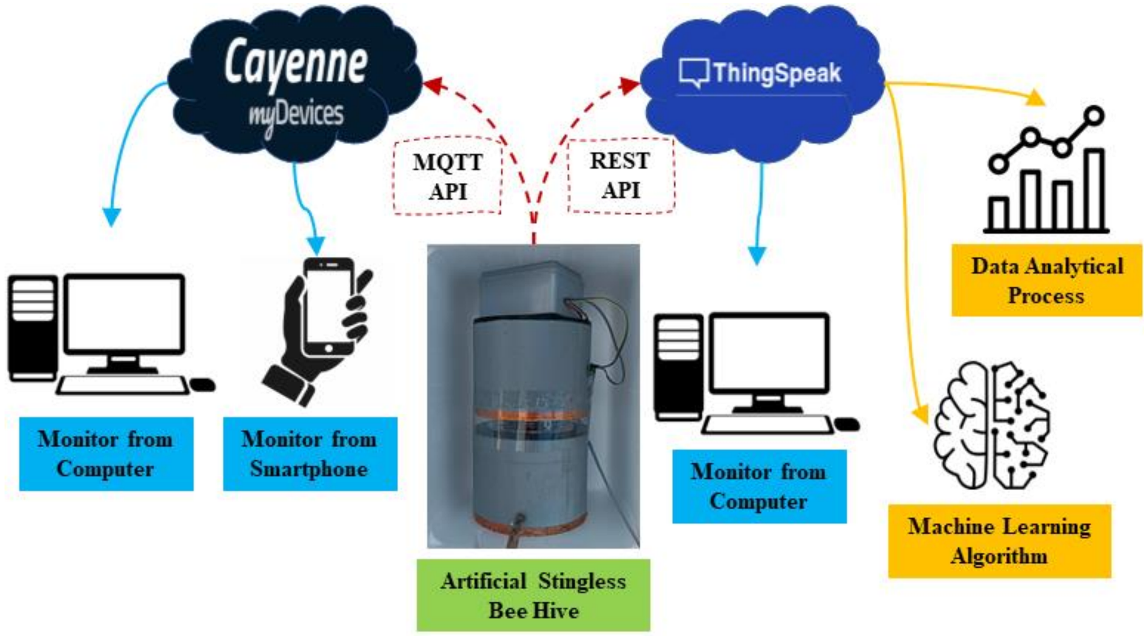


Fig. 5. Internet of Things system

2.4.1 Cayenne myDevices IoT platform

The Cayenne myDevices is the primary interface for configuring, personalising, monitoring, managing, and controlling all connected devices. Cayenne employs widgets in order to see devices, as well as their data, status, and activities. Cayenne automatically associates one or more widgets with each newly introduced device, sensor, or actuator based on the capabilities of the underlying hardware.

Cayenne myDevices leverages the MQTT API to connect the user's devices to the Cayenne Cloud. MQTT API is an ideal choice for use in monitoring systems due to the fact that it can send data swiftly while consuming very little power. This API is suitable to be used on this platform since beekeepers use it to monitor the condition of artificial hive variables. In addition, the Beekeeper gets access to the data via PC and mobile device.

2.4.2 Thingspeak IoT platform

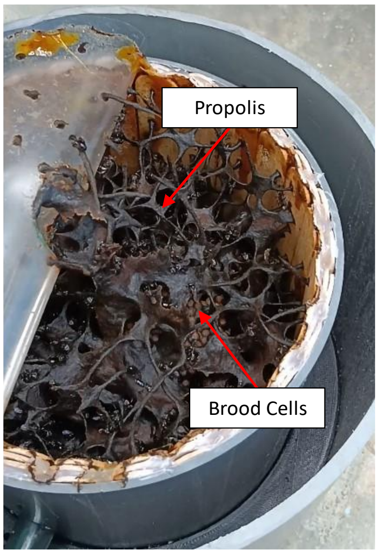
ThingSpeak is a cloud based IoT analytics platform that permits users to collect, display, and analyse real-time data streams. ThingSpeak provides representations of data uploaded by connected devices in real time. ThingSpeak is commonly used for IoT system prototypes and proofs of concept requiring analytics.

This ThingsSpeak platform is capable of utilising both the MQTT API and the REST API. In contrast, just the REST API is being used to get any trend analysis, such as data within a specific time range. This is consistent with the research, as the acquired data will be used to investigate and create Machine Learning algorithms to determine the ideal time for honey harvesting. With the gathered data, it is possible to conduct further analyses and create machine learning algorithms to determine the ideal time to harvest honey.

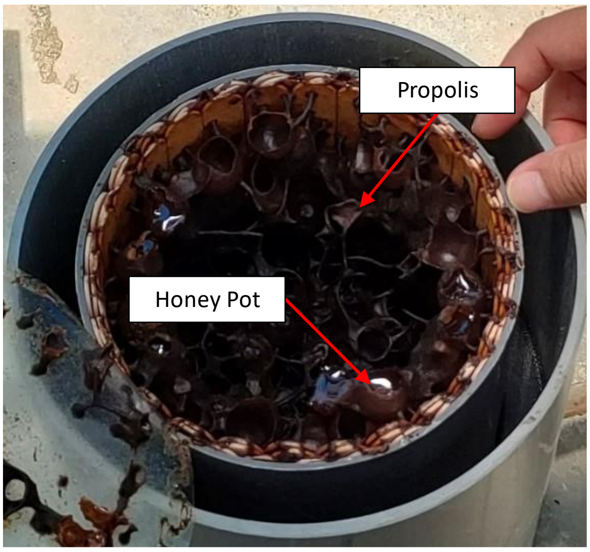
3. Results and Discussion

3.1 Artificial Stingless Bee Hive

Additionally, the artificial hive employed in this experiment is a hive containing a colony of stingless bees (Heterotrigona Itama). Figure 6(a) displays the inside of brood compartment which is placed below the honey compartment and load cell plate while Figure 6(b) depicts the inside of the honey compartment at the top of the load cell plate. Both pictures indicate that stingless bees have constructed propolis, brood cells in the brood compartment and honey pot in the honey compartment. Generally, stingless bees will develop their brood cells at the bottom and the honey pot at the top, which is very beneficial for stingless beekeepers who only need to access the honey compartment to harvest honey. All these colony construction shows that a colony of stingless bees in this hive is developing in a healthy manner.



(a)



(b)

Fig. 6. Colony development (a) Colony inside brood compartment (b) Colony inside honey compartment

3.2 Results for Data Validation

The experiment was conducted in the Faculty of Electrical Engineering & Technology's Robotic Lab at Universiti Malaysia Perlis (UniMAP) in Perlis, Malaysia. Data as shown in Table 2 and Table 3 were gathered by 2 DHT22 and a Uni T UT333S Digital Temperature Humidity as reference for 20 samples every 5 minutes in a NaCl-filled container in an air-conditioning room.

Table 2 reveals that the standard deviations for sensor 1 and sensor 2 are 0.095 and 0.019, respectively, indicating that the sensor readings are not scattered. Meanwhile, the average percentage difference lies between 1.113% and 2.944%. The highest difference between sensor 1 and sensor 2 in comparison to the reference is 0.9 and 2.32, which satisfies the requirements stated by Liu [21], Max ±5% RH for accuracy.

Table 2
Data validation for relative humidity

Reference Relative Humidity, (%)	Relative Humidity Reading Sensor 1 (%)	Relative Humidity Reading Sensor 2 (%)	Difference Sensor 1, Δ_1 (%)	Difference Sensor 2, Δ_2 (%)	Percentage Error Sensor 1, δ_1 (%)	Percentage Error Sensor 2, δ_2 (%)
75.80	75.00	78.10	0.80	-2.30	1.055	0.185
75.80	75.00	78.10	0.80	-2.30	1.055	0.237
75.80	75.00	78.12	0.80	-2.32	1.055	0.237
75.80	75.00	78.12	0.80	-2.32	1.055	0.237
75.88	75.08	78.20	0.80	-2.32	1.054	0.185
75.90	75.10	78.18	0.80	-2.28	1.054	0.264
75.90	75.10	78.16	0.80	-2.26	1.054	0.237
75.90	75.10	78.20	0.80	-2.30	1.054	0.264
75.90	75.10	78.18	0.80	-2.28	1.054	0.264
75.92	75.12	78.20	0.80	-2.28	1.054	0.263
76.00	75.16	78.20	0.84	-2.20	1.105	0.263
76.00	75.20	78.20	0.80	-2.20	1.053	0.263
76.14	75.28	78.20	0.86	-2.06	1.129	0.263
76.10	75.20	78.20	0.90	-2.10	1.183	0.263
76.00	75.12	78.20	0.88	-2.20	1.158	0.263
76.00	75.10	78.16	0.90	-2.16	1.184	0.263
75.90	75.06	78.12	0.84	-2.22	1.107	0.264
75.90	75.00	78.10	0.90	-2.20	1.186	0.264
75.90	74.92	78.10	0.98	-2.20	1.291	0.264
75.90	74.90	78.10	1.00	-2.20	1.318	0.264
Average, $\bar{X}$	75.077	78.157	0.845	-2.235	1.113	2.944
Standard Deviation, S	0.095	0.019	-	-	-	-

As for the temperature, Table 3 shows the measurements for sensor 1 and sensor 2 indicate that the average temperature is perceptibly 0.779 and 0.029, while the maximum difference compared to the reference is 0.2 and 0.04, which also satisfies the Liu [21] specification of greater than ±0.5 degrees Celsius for temperature precision. The fact that the standard deviations of the sensor measurements were as low as 0.019 and 0.013 shows that they are precise.

Table 3
Data validation for temperature

Reference Temperature, (°C)	Temperature Reading Sensor 1 (°C)	Temperature Reading Sensor 2 (°C)	Difference Sensor 1, Δ_1 (°C)	Difference Sensor 2, Δ_2 (°C)	Percentage Error Sensor 1, δ_1 (%)	Percentage Error Sensor 2, δ_2 (%)
24.4	24.54	24.40	-0.14	0	0.574	0
24.4	24.58	24.38	-0.18	0.02	0.738	0.082
24.4	24.58	24.36	-0.18	0.04	0.738	0.164
24.4	24.58	24.36	-0.18	0.04	0.738	0.164
24.4	24.54	24.40	-0.14	0	0.574	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.58	24.40	-0.18	0	0.738	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.38	-0.20	0.02	0.820	0.082
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.6	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.38	-0.20	0.02	0.820	0.082
24.4	24.60	24.40	-0.20	0	0.820	0
24.4	24.60	24.40	-0.20	0	0.820	0
Average, $\bar{X}$	24.59	24.393	-0.19	0.007	0.779	0.029
Standard Deviation, S	0.019	0.013	-	-	-	-

While for load cell validation, the data collected between the standard weight of the 0.5kilogram, 1 kilogram, 1.5 kilograms, and 2 kilograms total weight of round gauge blocks are compared to the mass of the load cell sensor utilizing a HX711, as indicated in Table 4. The average difference is between 0.606% and 3.949%, or between 0.3% and 0.5%. With a value as low as 0.5%, it is evident that the employed load cell is quite precise. In addition, the dispersion of this sensor reading is small, since the standard deviation ranges from 0.30 to 0.83 for this sensor.

Table 4
Data validation for load cell (weight)

Reference Weight, υ_{Rf} (g)	Load Cell Readings, υ_{Rd} (g)					Average of Difference, $\bar{X}_\Delta$ (g)	Average Percentage Error, $\bar{X}_\delta$ (%)	Standard Deviation, S
500	497.171	497.151	497.025	497.015	496.993	2.929	0.586	0.083
1000	996.031	996.046	996.101	996.016	996.061	3.949	0.395	0.033
1500	1497.309	1497.289	1497.253	1497.233	1497.260	2.731	0.182	0.030
2000	1999.410	1999.459	1999.382	1999.407	1999.312	0.606	0.030	0.054

3.3 Results for Internet of Things

The study was carried out on the backyard of the Robotic Lab in the Faculty of Electrical Engineering & Technology at Universiti Malaysia Perlis (UniMAP) in Perlis, Malaysia. All widgets that have been utilised in both Cayenne myDevices and ThingSpeak are displayed in Figure 7 and Figure 8. Based on both figures, the widget represents honey compartment weight, inner temperature, inner humidity, outer temperature, and outer humidity, from upper left to lower right.

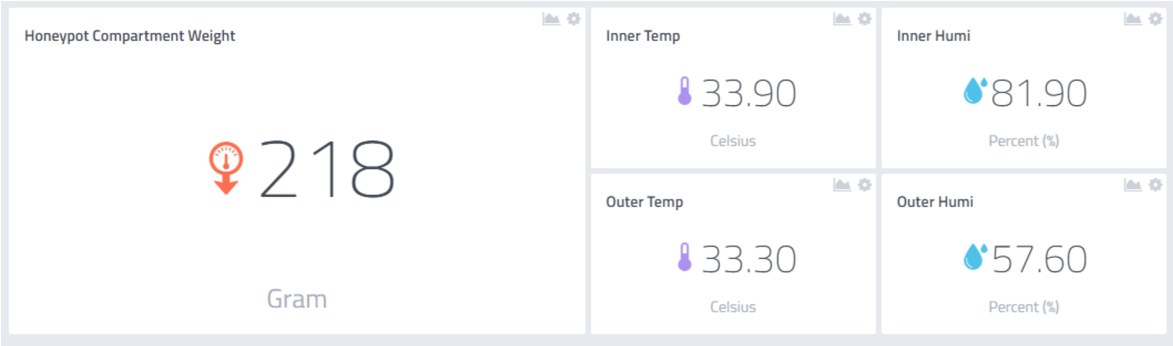


Fig. 7. Widgets from Cayenne myDevices IoT platform

Fig. 8. Widgets from Thingspeak IoT platform

To investigate the capability or performance of the artificial hive, the relative humidity and temperature of the surrounding environment and artificial hive are compared. Figure 9 and Figure 10 represent the temperature and relative humidity of the artificial hive's surroundings and inside over a 13-day period, from April 19 to May 1, 2022. All temperature readings for this research are collected outdoors.

Figure 9 demonstrates that from midnight to dawn, between 12 a.m. and 10 a.m., both outside and inside artificial hives record their lowest temperatures. Technically, this is the lowest temperature observed within the artificial hive on a daily basis. At this temperature, stingless bees disperse to find pollen, water, or resin, and passive thermoregulation occurs indirectly.

Moreover, given both lines are near together on the graph, it is likely that the graph temperature for artificial is influenced by the surrounding temperature. However, the temperature inside the artificial hive is always slightly higher than the surrounding temperature, which could be caused by stingless bees living in the hive producing heat from inside. The temperature in normal weather conditions within the artificial hive is consistent between 26°C and 38°C. However, the highest temperature record is 39 degrees Celsius, set on April 21, 2022, due to the extremely hot weather on that day.

Due to relative humidity readings between 76.5% and 85.6%, Figure 10 demonstrates that the relative humidity inside the artificial hive remains consistent for 13 days compare to the relative humidity outside which are fluctuates. This is reasonable due to the fact that the DHT22 sensor measures the moisture level of the honey in the hive which will always be moist so long as honey is in the hive.

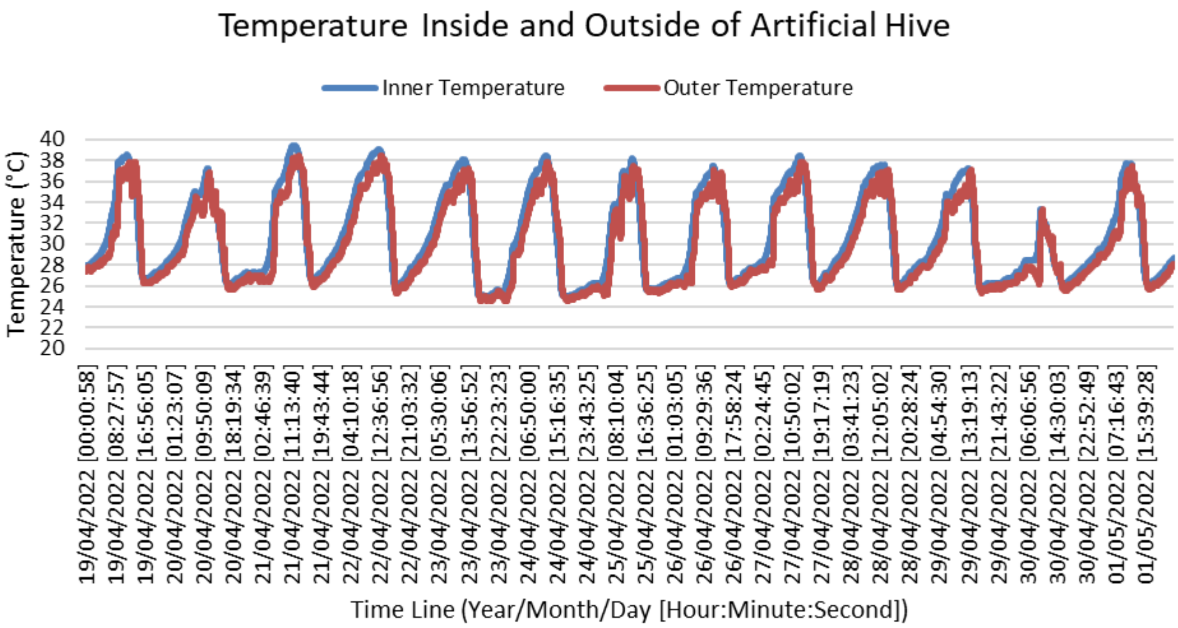


Fig. 9. Graph for temperature inside and outside of artificial hive

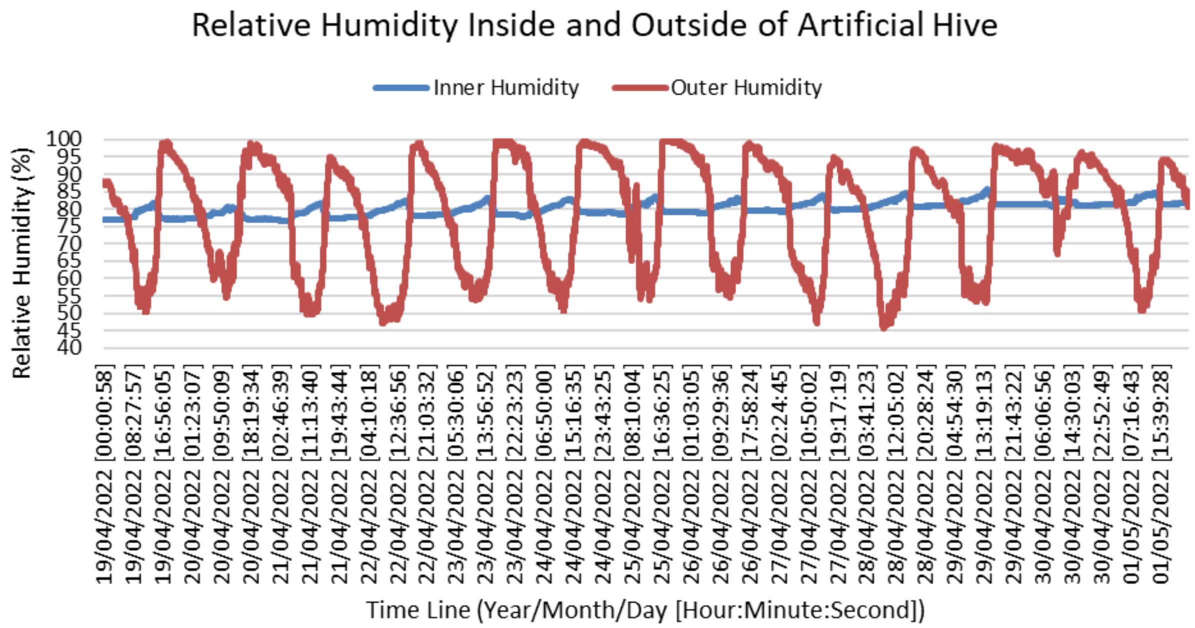


Fig. 10. Graph for relative humidity inside and outside of artificial hive

Lastly, Figure 11 depicts the total weight of the honey compartment from April 19, 2020, to May 1, 2020. Based on this diagram, the line in the graph indicates that the honey compartment's weight begins to decline from morning to midday and then begins to increase from evening to late night. This is as a result that worker bees seek sustenance during the day and return to the hive at night.

Since the gathered data fluctuates by 1 cycle every day, the data have been averaged by day in order to monitor the weight change clearly, and the results are shown in Figure 12. The weight of the honey compartment steadily increases from day to day as a result of the data acquired on growing colony.

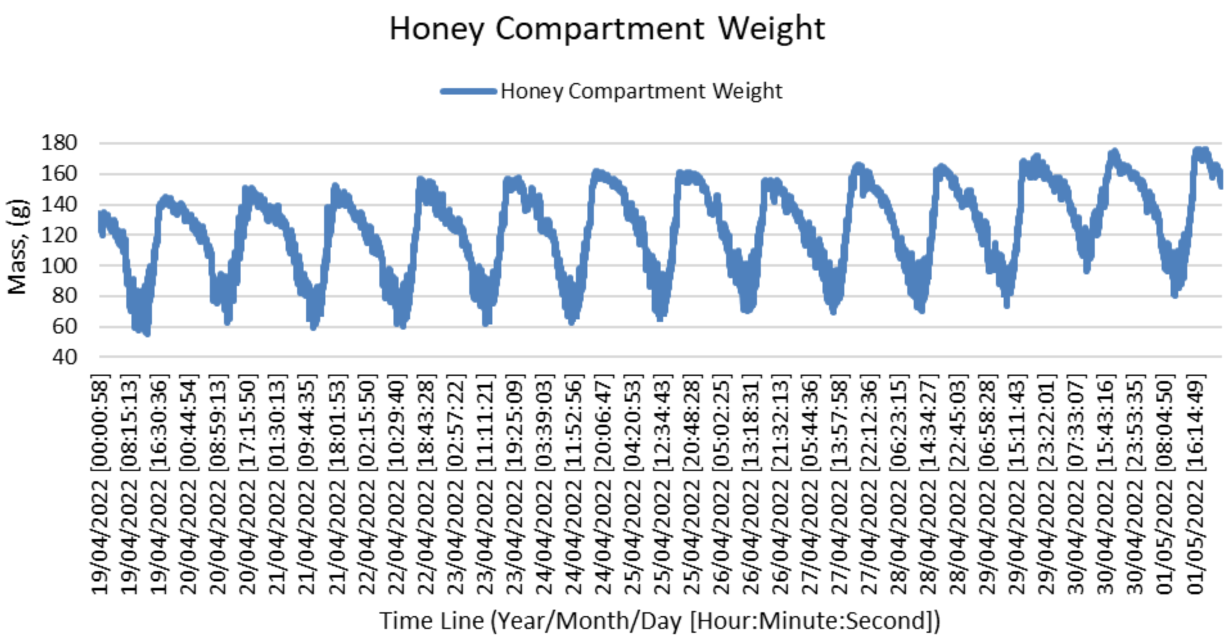


Fig. 11. Graph for honey compartment weight

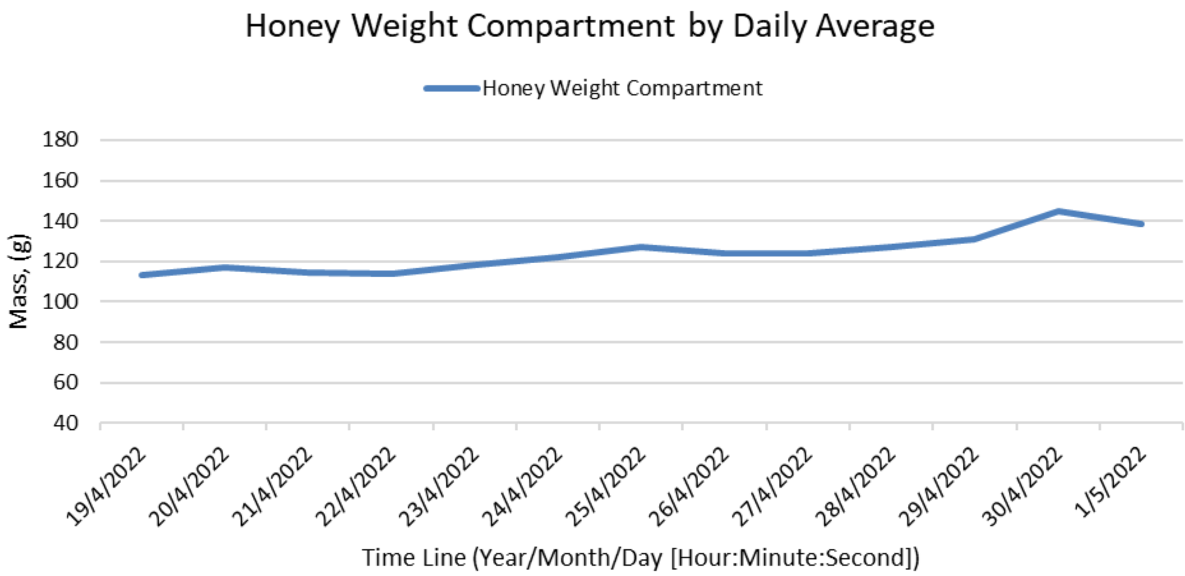


Fig. 12. Graph for honey compartment weight averaged by daily

4. Conclusion and Future Recommendation

To guarantee that all sensors included in this project follow the standard, they have all been validated, and the results meet the datasheet's accuracy and precision requirements. By using Cayenne myDevice and ThingSpeak, the project has successfully integrated the artificial hive with the Internet of Things monitoring system. Long-term data monitoring of the honey weight compartment will aid the stingless beekeepers in estimating future honey production. Long-term observation and analysis of temperature and humidity data are necessary to anticipate the patterns of beehive condition using big data analysis and machine learning algorithms for future recommendations. In this phase, the analysis process has proven that the colony inside the artificial hive is healthy and developing. However, the highest reading for temperature is 39.4 degrees Celsius which has reached a mortality rate for bee pupae which is 38 degrees Celsius. This is very dangerous and may result in Colony Collapse Disorder (CCD) if no improvements are made. Therefore, artificial hives of the future will require heat-resistant materials such as aluminum and polystyrene and Transferable heat hive to remove heat from the interior to the exterior.

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