Embedded Wireless Stingless Beehive Monitoring And Data Management System

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***Abstract*—In this paper, an embedded wireless stingless bee monitoring system, which investigates the environment's temperature and humidity effect on the bee activity and honey production of Heterotrigona Itama, a stingless bee species, is presented. The variables observed by the system are the weight of the honey container, the temperature inside the hive, humidity inside the hive, temperature of the environment outside of the hive, the humidity of the environment outside of the hive, and bee activity counter. The sensors used are Strain Gauge Load Cell (SGLC) sensor for weighing purposes, DHT22 sensors for temperature and humidity, and infrared transceivers bee counter sensor for bee activity monitoring. All installed sensors were controlled by using a NodeMCU microcontroller. All data were recorded and transferred to a Google Firebase real-time database. The proposed system offers an android application to access the recorded data called EMAS apps. EMAS fetches all the information from the database and represents it on graphs and pages in the user smart devices. This paper analyses the data obtained for 36 hours from a single hive. Results obtained represent a relationship between the temperature collected and bee activity with the honey produced. It was observed that in the morning, the increase of temperature leads to high traffic of bees going out of the hive, which decreases the weight of the hive to 2.7 Kg. Meanwhile, in the evening, the decrease in temperature leads to high traffic of bees going into the hive, which increases the hive weight to 4.5 Kg. For future work, to enhance the system's performance, installation of the embedded system into an array of hives was advised and long-term data observation process was required.**

Keywords—Heterotrigona Itama, embedded system, android application

I. Introduction

Precision Beefarming (PB) is characterised as the apiary management technique, which depends on the observation of bee health state and increasing profitability [1]. The technique collects and analyses a current state of a hive and sends early warnings to beekeepers for immediate response. Temperature and humidity are the most critical variables in beehive monitoring. These variables can be used to evaluate the colony condition [2], colony health level [3], the bees' queen condition, the respiration process in the hive, the level of the fungus growth on the interior walls of the hive [4], and the actual stage of Colony Collapse Disorder (CCD) [5].

There are three levels of data collection category. Firstly, the apiary level, secondly the colony level, and thirdly the individual bee level. The traditional monitoring system which utilizes direct human observation and intervention is too subjective and time consuming [6]. Moreover, the time span for data collection` is limited and irregular, which depends on weather conditions. Hence some important data might be lost during the observation process. Human health and safety are also at risk if overnight observation is required. However, relocating the beehive closer to human residential areas for easy monitoring can incite different kind of problems that originate from the surrounding. This include as attracting black soldier flies, predators to stingless bee as well as the fogging activities performed in these residential areas to control pests and insects [7].

Towards the industrial revolution 4.0, the ubiquity of advanced wireless sensor network and information technologies has been widely explored by researchers for collecting physical items in a system equipped with "Internet of Things (IoT)" [8]. Beehive monitoring which employed modern technologies and techniques had made significant progress in 2007 [9]. The applications utilizes invasive sensors that inevitably made contact with the inner part of the hives or bodies of the bees through the use of a thermocouple for hive temperature monitoring [9] and Radio-Frequency Identification (RFID) tags for bees foraging activity monitoring [10]. Utilizing these techniques, the respective hives need to be opened and exposed to the environment, hence causing discomfort and stress to the bee colony during the data collection, hence not favored in this research. However, in recent years, the non-invasive sensors have been heavily utilized that have the advantages of performing continuous monitoring remotely.

The paramount importance of hive monitoring and data collections is to monitor the development status of the bee colony [11]. the collected data also is able to assist the beekeeper in predicting some unusual events such as swarming/pre-swarming [12], excessive honey spilt due to infestation of invaders [13], death and absence of queen bees [14], health and growth condition of the brood [15], dying or starving of the bee colony due to lack of food, and the low level of foraging activity [16]. Prompt actions from the

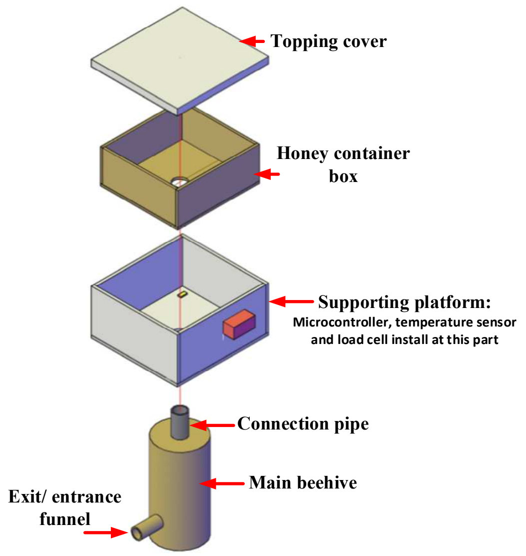


Fig. 1. Hive design for stingless bee monitoring system

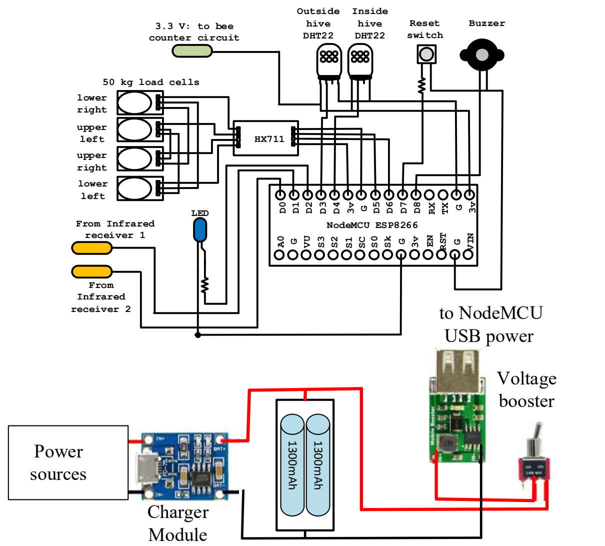


Fig. 2. Wireless stingless bee monitoring system and power module circuit diagram

farmers through precise measurement and detection will lead to the best security, productivity, and longevity of the bee colony. It is also essential to detect foreign biological substance such as bacteria, viruses, and fungus that could lead to the colony collapse disorder [3][4].

II. BEEHIVE DESIGN

The hive for stingless bee colony monitoring system was designed as illustrated in Fig. 1. There are two main parts of the stingless beehive constructions, which are the main hive and the honey box or commonly known as the topping. The bottom part is where the entrance funnel is situated, which is perpendicular to the main hive, as shown in Fig. 1. To perform foraging activities as well as to defend their hive effectively, a unique, funnel-shaped entrance is constructed. On top of the main hive, a connection pipe is installed which is linked to the main hive i.e. to the honey container. Stingless bee colony will crawl into the honey container and keep their honey and bee bread. The electronic wireless stingless bee monitoring system as illustrated in Fig. 2 was installed in the outer part of the honey box called supporting platform. In this project, the whole hardware system was employed on an existing stingless beehive which is in the farm for more than six months. These bees are considered healthy and active.

III. SENSOR DEVELOPMENT

In Fig. 2, a schematic of the circuit fabricated using NodeMCU microcontroller is illustrated. NodeMCU microcontroller built-in with ESP8266 module that offers lower power consumption operate at 3.3 V. The whole designed system was powered by using 2 units of lithium battery with the charger module. There are three significant parts of the sensors, which are the bee counter circuit sensor, honey container weight sensor, and temperature and humidity sensors to measure the temperature and humidity values inside and outside the hive. In addition, one unit of buzzer is installed to alert the beekeepers when drastic change of weight is detected. The drastic changes may be due to the presence of hive thieve, wild animals attack or damage by harsh weather.

A. *Weight and temperature sensor setup*

Four units of Strain Gauge Load Cell (SGLC) are integrated with an HX711 module, installed on each edge of the supporting platform for honey container weight measurement, as illustrated in Fig. 3. The SGLC sensors relate to two precision resistors and designed in a Wheatstone Bridge (WB) formation powered at $V_{in} = 5$ V. A honey container box with a dimension of 30 cm × 33 cm × 5 cm with a 60 mm diameter hole in the center is placed on top of the load cells where there is a pipe to connect the honey box with main hive log at the bottom. The pipe will channel the stingless bees crawling from the bottom main hive into the honey container box for keep the honey. For protection, the honey container box is sealed with plastic wrapped and closed with a wooden cover, followed by the roof at the top. The wooden cover and roof design do not add to the honey container weight measured by SGLC.

B. *Bee counter sensor*

A Heterotrigona Itama bee has a body size between 3.0 mm to 7.5 mm [17]. To estimate the number of the bees going in and out of the hive, two pairs of infrared light transmitters (SFH 4550 infra-red emitter) and receivers (SFH 309 IR Phototransistor) were used in the hardware setup. In Fig. 4(a), the SolidWork design of the funnel installed as an extension to the entrance/ exit of stingless beehive is illustrated while Fig. 4(b) is the actual funnel fabricated with 3-D printer installed at the main hive entrance/ exit. The infrared light transmitter and the receiver pairs were placed in arrays at the middle area of the funnel. For each pair, the infrared light transmitter and receiver were inserted in vertical through holes with the size of 3 mm on the circumference of the extension funnel. The infrared light transverses through the stingless bee path perpendicularly from the transmitter to the receiver (direct incident). The distance between the sensor pairs was set to 10 mm. The schematic diagram of the bee counter system for the first pair of the infra-red sensor is shown in Fig. 5. For the second pair of the infra-red sensor, the circuit as in Fig. 5 is replicated. Refer to Fig. 5, when the infrared light is obstructed by a bee, I_{ce} will be equal to the dark current of SFH 309 phototransistor, which is equivalent to 1 nA. V_{out} will be

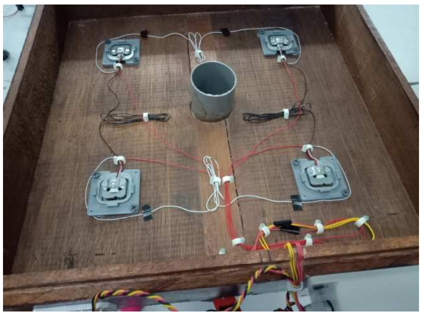


Fig. 3. SGLC sensors installed on top of supporting platform

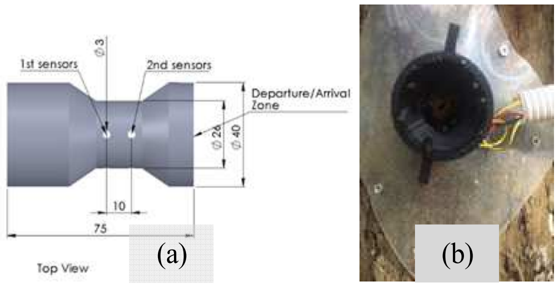


Fig. 4. a) Extension funnel drawn using SolidWorks b) Funnel

near equivalent to NodeMCU operating voltage of 3.3 V which can be calculated from equation (1):

$$I_{CE} = \frac{3.3 - V_{OUT}}{R_2},\ I_{CE} = 1\ \text{nA} \approx 0, \quad \therefore\ V_{OUT} = 3.3\ \text{V} \tag{1}$$

When no bee is detected, the infrared light transverses straight to the SFH 309 phototransistor, and the phototransistor will reach saturation. The values of I_{CE} and V_{CE} are then is equivalent to 120 μA and 0.2 V, respectively. V_{out} is equal to V_{CE}, Hence, the value of R_2 can be determined from equation (2):

$$I_{CE} = \frac{3.3 - V_{CE}}{R_2}\ \therefore\ R_2 = 25.83\ \text{k}\Omega \tag{2}$$

In this project, 24 kΩ resistor was used. V_{out} is sent to the next stage which acts as a non-inverting low pass filter with a dc gain of 2. Dual JFET TL082 operational amplifier is used for the low pass filter. The system is used to detect the

average crawling speed of the stingless bee, which is 1.75 cm/s [18]. If a stingless bee commutes between the first and second pair of the infra-red sensors with a distance of 1 cm, indicates that the maximum time of travel is 0.571 s or 1.75 Hz. As a compromise between the required bandwidth related to the crawling speed of the stingless bee, a low pass filter cut-off frequency, f_c of 20 Hz is chosen for the system. R_3 is set to be equal to 1 kΩ, and R_3=R_4 = R_5. Therefore

$$f_c = \frac{1}{2\pi R_3 C_1}, \therefore C_1 = 7.96\mu\text{F} \tag{3}$$

$$Gain = 1 + \frac{R_5}{R_4} = 2 \tag{4}$$

For C_1, 8.2 μ*F* is chosen. To account for a condition where the stingless bee is resting or not moving on the path of the infra-red light, the output from the previous stage is sent to a passive high pass filter effectively producing a bandpass filter. The time constant of this passive high pass filter is $\tau = R_6C_2 =$ 1 second. As such the corner frequency is $fc = 1/2\pi\tau = 0.159$ Hz. The final output is sent to the *D*1 input of NodeMCU microcontroller. When V_{out} is "HIGH" or equivalent to 3.3 V, the final output will remain at 3.3 V, and the *D*1 digital input will read as "HIGH". When V_{out} is "LOW" or equivalent to 0.2 V, the final output is the product of multiplication with the GAIN of the low pass filter which is equal to 0.4 V. Any input value to the *D*1 digital pin which is below than 0.825 V will be read as "LOW". The bee counter system works by recognizing a departing bee when the first *D*1 digital input is HIGH followed by the second *D*0 input, and then, value "1" is added to the current total count. Meanwhile, an arriving bee is detected when the second *D*0 input is HIGH followed by the first *D*1 input. Finally, the current total count is added with a value of "-1".

C. Dewpoint

To detect a possibility of fungus growing inside the hive, measurement from temperature and humidity sensors are the utmost important. The relationship between temperature and humidity can be interpreted by using dew-point formula as described in equation (5) and (6).

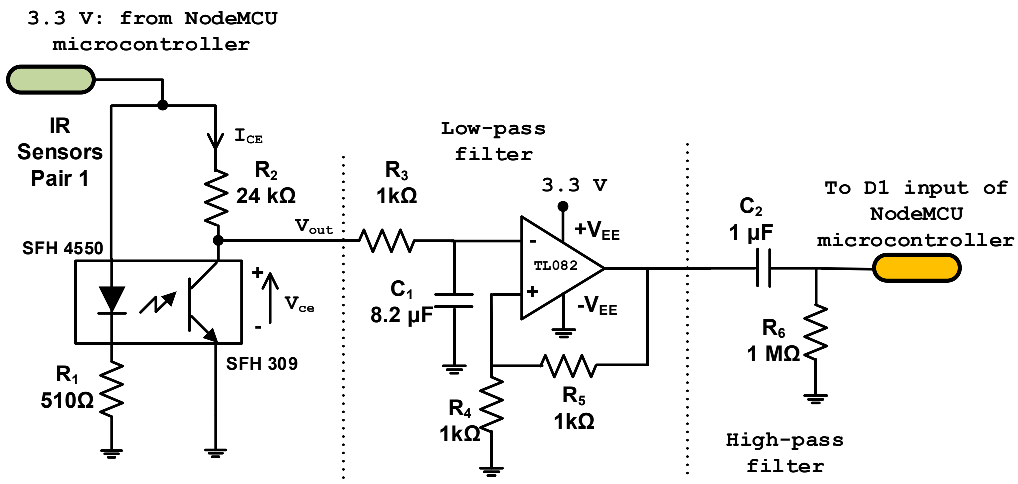


Fig. 5. Schematic diagram of 1 pair of bee counter infrared transceivers

$$T_{dp}(^{0}C) = \frac{237.3 \bullet N}{1 - N} \tag{5}$$

$$N = \frac{\ln\left(\frac{RH}{100}\right) + \frac{17.27 \bullet T_{in}}{237.3 + T_{in}}}{17.27} \tag{6}$$

where:

T_{dp} = *dew-point temperature in* ^{0}C

RH = *relative humidity of internal beehive in %*

T_{in} = *Internal temperature of beehive in* ^{0}C

Dewpoint or dew-point temperature is the temperature at which the air achieves maximum reading of saturation. In order to determine the value of the dew point temperature, the inside hive relative humidity (RH_{in}) and inside hive temperature (T_{in}) needs to be determined. If the inside hive temperature is lower than the dewpoint (T_{dp}), the condensation process occurs. From literature, the range for occurrence of condensation is estimated to be at T_{dp} + 1.5 °C [19], however the value may vary depending on types of surfaces used. The definition described above is valid for water vapors only.

D. Android application

The application of the proposed system is designed based on an Android system which can run on any system with SDK Version 16 onwards. The application is developed to assist stingless bee farmers in documenting information on the important aspects of stingless bee keeping such as hive health, security, and hive produced though android devices. In the invention, all information related to the hive is recorded and transferred to a Google Firebase real-time database. The apps is named Electronic Meliponini Advanced System (EMAS) and can be readily downloaded in google store. EMAS fetches all the information from the database and conveniently represent them on graphs and pages, that are more user-friendly approach to farmers. The opening interface of the developed user apps has the splash page as shown in Fig. 6(a). The splash page provides an overall overview of the brand as well as the developer logo to the user. The login page was created to allow multiple users, and each user can key in their own hive data into the registered account (Fig. 6(b)). The dashboard page is the first page displayed once user has completed the login process. The dashboard page contains the averaged value of total estimated honey production and temperature readings of each registered hives as shown in Fig. 6(c). The apps offer users the option to choose a manual inserted data or IoT inserted data. The IoT data is data that are automatically inserted into the apps through embedded hardware and sensors design as explained in the early section of this paper.

IV. RESULT AND DISCUSSION

In this project, the embedded hardware with IoT system was installed on a single stingless bee (Heterotrigona Itama species) hive. The observed hive was identified as healthy and consists of a strong colony with the hive age of older than 6 months old. The hive is located st a small stingless beehive farm in the resident area of Kolej Dato Onn Jaafar (UTM), Skudai Johor, in the southern region of Malaysia. The location was chosen due to the environment factors where it is surrounded by forests rich with wildflowers and trees containing natural plant resins. The embedded electronic

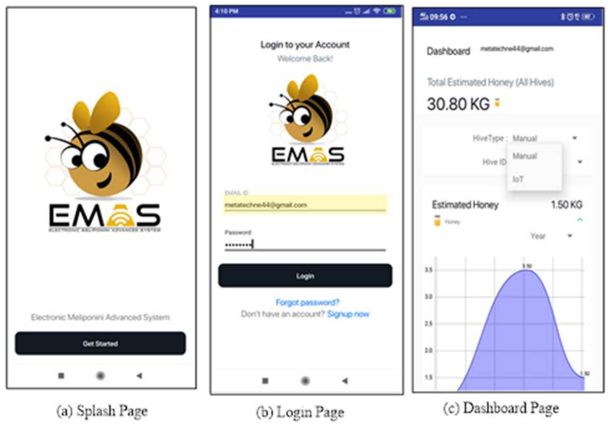


Fig. 6. Pages of the EMAS android App

system installed with IoT pushes the received data to google firebase databased at an interval of 7 seconds. The data to be analyzed were recorded from 7th December 2018 at 4 pm to 9th December 2018 at 5 am, which was approximately 36 hours and a total of 12,200 data was collected. During the experiments, the following variables are monitored from the stingless beehive:

Inside hive temperature and humidity by utilize one unit of a DHT22 sensor.

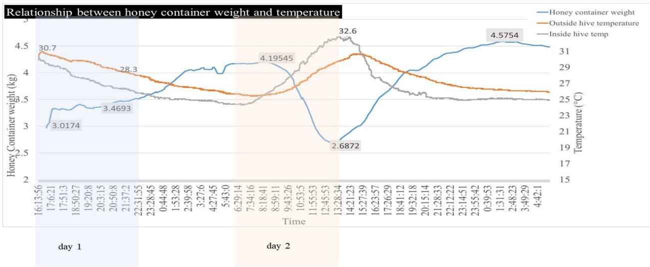
- Outside hive temperature and humidity by utilize one unit of a DHT22 sensor.
- Honey container weight by utilize four unit of SGLC sensor.
- Bee activity count (foraging activity) by utilize two pairs of infrared light transmitters and receivers (transceivers).
- Dew point by utilize the calculation of inside hive temperature and humidity value.

Fig. 7(a) represents the relationship between the honey container weight and temperature (inside and outside hive), while Fig. 7(b) represents the relationship between the honey container weights and bee activity count. The comparison between Fig. 7(a) and 7(b) for the evening session (day 1), whereby the observation period was between 4 pm and 8 pm on 7th December are as follows:

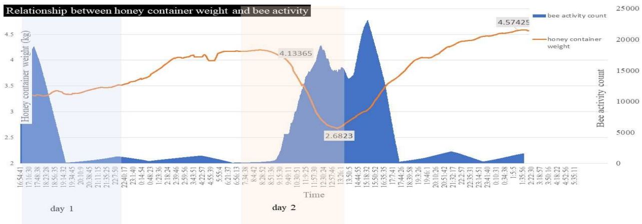
- The weight of the honey container box is slightly increasing from 3 to 3.5 kg.
- The temperature trend was recorded to decrease around 30 °C to 28 °C. (sunset)
- The bee activity at exit/ entrance funnel recorded a high traffic of bees entering the beehive.

The decreasing temperature support with high traffic of bees entering the hive entrance signifies the factors of bee's routine coming back to the hive to perform their night activity inside the hive. The guarding bees were also active during this time interval. Meanwhile, the honey container box weight also shows the increasing trends due to increasing numbers of bees crawling inside the box to build and keep the food inside the honey container box.

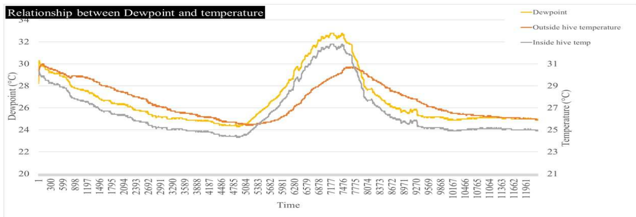
The comparison of Fig. 7 (a) and 7 (b) for morning session (day 2), the observation of the time interval between 6 am to 1 pm (sunrises) on 8th December are as follows:



(a)



(b)



(c)

Fig. 7 Relationship between parameters (a)honey container weight and temperature, (b)honey container weight and bee activity, (c) Dewpoint and temperature

From Fig. 7(a) lowest temperature was estimated at 24 °C around 6 am.

- From 6 am to 1pm, temperature was slightly increasing up to 32 °C, meanwhile the container weight was slightly decreasing to 2.7 kg (observed as minimum for this observation period).
- Fig. 7(b) show high traffic of bees going out of the exit/entrance funnel. (to perform the daily activity)

An estimation and perception of this situation shows that most of the matured stingless bee workers start to perform their daily foraging routine to collect honey, pollen, and resin depending on the current temperature of the surrounding (in this case around 8 am). The minimum value of hive container weighing was at 2.7 kg in this paper (around 1 pm), can be estimated as bees nett produce that left inside the container without the occurrence of majority bees' worker inside the container.

For beehive health factors, Fig. 7(c) shows the temperature trend concerning the Dewpoint and temperature inside the container for the duration of 36 hours of monitoring period. The pattern showed a small difference (less than 1.5 °C) between both variables that can be categorized in the normal condition of air moisture state inside the beehive. From literature, the range for condensation is estimated to occur at Tdp + 1.5 °C [20], however the value may varies depending on types of surfaces being used. The air moisture inside beehive may lead to the growth of fungus in the walls that causes stunted colonization. Besides, stingless bee colony cannot survive in a temperature that is more than 38 °C, hence a regular observation of temperature is adamant.

V. Conclusion and Future Works

In this study, the embedded electronic stingless beehive monitoring system with IoT application through android apps (EMAS) was presented. The temperature, humidity, honey container weight and bee count are the parameters to be observed. Besides, dewpoint value was calculated to monitor the air moisture inside the hive. The results may help farmers to monitor and manage the activity of their farm. In future work, the system should be installed to each hive in the farm and long-term observation of data is required to enhance the system performance.

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