A Lora-based Testbed Development for Stingless Bee Monitoring System

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Abstract **– In recent years, stingless bee honey has gained popularity due to its health benefits and commercial potential. There is a worrying tendency of bee colonies leaving its hives suddenly, and a specific research has been done to monitor the insect's habits. This project proposed a testbed for a stingless beehive monitoring system capable of capturing sensory data that provides an accurate indication of the bee's health and activity. This project utilises a raspberry pi gateway as a LoRa packet forwarder and four Arduino end nodes to collect sensor data from stingless beehives. The outcome showed that all planned functionalities had been accomplished, and these characteristics are expected to provide sufficient information to the beekeeper to take appropriate action to avert colony collapse. Future studies will focus on the modelling and correlation of measured environmental data in order to forecast bee colony loss.**

Keywords **– Arduino, Beehive, Raspberry Pi, Nod-red, Internet of Things, LoraWAN.**

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1. Introduction

Honey produced by stingless bees has a great economic value, and the commercial stingless beekeeping industry has grown exponentially in recent years. Consumer demand is boosting popularity, which benefits local manufacturing and supply chain expansion [1], [2]. The number of farmers working with stingless bees has risen dramatically during the last five years. Over 1000 farmers who have registered their farming activities throughout the country attest to the growing trend. Malaysia imported honey-related items worth around RM50 million in 2003, a figure that climbed in subsequent years [3].

Although there are over 30 species of stingless bees globally, the Trigona Itama and Trigona Thoracica are the two most widely employed in Malaysia's stingless bee farming sector [4]. Numerous critical factors can influence the amount of honey harvested from the hives. The most prevalent consequences of a reduced honey amount extracted are colony loss and an unproductive hive. Both concerns are exacerbated by the poor quality of the stingless bee habitat around the farm. If the bees are positioned near their food source, a healthy stingless bee colony can be obtained. Reduced food supply might result in starvation of the bee colony. As a result of the fight for food, bees exhibit abrasive behaviour. Due to this, the stingless bee will relocate from its current site to one that is closer to the food supply. A stingless bee colony is considered healthy when honey propolis covers more than 50% of the surface area of the stingless bee hive [5]. Apart from food supplies, the air quality, temperature, and humidity level of the hive may all affect the quality of the stingless bee habitat. These conditions might result in the rapid extinction of the stingless bee colony, which has been a source of concern in recent years, and this emphasized the crucial necessity of comprehensive hive monitoring.

Several attempts have been made to address a better stingless beehive monitoring method by using the Internet of Things (IoT) and embedded system technologies can be seen documented in [6], [7]. Multiple sensors were deployed and fastened inside the stingless beehives in order to collect as many readings as possible, including temperature sensors, presence of gases such as carbon dioxide, carbon monoxide, and smoke. The degree of bee activity and its association with environmental variables such as temperature, pressure, and sun irradiance were examined and modelled in [8] using Recurrent Neural Network (RNN). The results suggested that temperature and sun irradiance level had a significant effect on the quantity of bee activity measured. Internal hive temperature and other environmental characteristics such as dew point and rainfall were also employed in another study in [9] to forecast a bee colony's health state using a supervised machine learning technique. Apart from monitoring beehives, IoT technologies are also being used in wide range of industries, including health monitoring [10], [11], agriculture [12], [13], environmental monitoring [14], and remote monitoring of embedded systems [15], [16].

Wireless network reliability is a critical component of IoT devices, particularly when deployed outside. Due to its energy efficiency [17], high reliability and effectiveness [18], LoRa technology has been cited as a preferable data transmission method in a variety of publications. Numerous researchers have employed the LoRa protocol for precision agriculture applications, including monitoring beehives [19], [20]. It is based on the LoRa protocol and makes use of the Chirp Spread Spectrum (CSS) modulation method. Users may simply modify the deployment of a LoRa-based sensor network using readily available component kits, and it does not require complicated infrastructure. Additionally, an autonomous LoRaWAN network may be constructed by using the existing global opensource community on The Things Network (TTN), which aids in packet transmission and gateway deployment. Additionally, several works of literature have evaluated SigFox as a wireless data transfer option [21], [22]. Their effort focused on constructing a beehive weight measurement device that communicated with consumers over the IoT SigFox communication network. According to their results, weight changes can be detected owing to a variety of factors, including rainfall, beekeepers harvesting and monitoring activity, bees exiting and entering the active period, and many more. Additionally, various papers have been published that demonstrate the use of 5G narrowband IoT (NB-IoT) for remote monitoring applications such as air quality [23], water quality [24], and agricultural [25], [26]. NB-IoT is capable of transmitting data at a maximum rate of 200kbit/s and sending an infinite number of messages each day. It is a modulation method based on Quadrature Phase Shift Keying (QPSK) with additional encryption capabilities. Unlike LoRaWAN, however, the position of Sigfox and NB-IoT gateways is controlled by the infrastructure provider, and users are not permitted to deploy their own gateways. The deployment area's coverage often varies according to the national operator's rollout strategy.

While some research has been carried out on the development of beehives monitoring system, there is still limited number of works focusing on stingless beehives. Thus, this paper proposes the design and implementation of a stingless bee monitoring system using LoRaWAN technology and is organized as follows: The materials and methods are presented in Section 2, where the component and experimental setup are described. The results and discussion are reported in Section 3, and the conclusion is given in Section 4.

2. Methodology

The configuration for the stingless bee monitoring system described in this study is depicted in Figure 1. It is composed of LoRaWAN end-nodes and a gateway placed in a star topology. The end nodes communicate with the gateway by sending payloads, including sensory data. The gateway will constantly be on the lookout for incoming data packets and will require an Internet connection to forward them to the "The Things Network" (TTN) server. A node-red application was used to retrieve the data stream from the TTN server and push it to Hostinger, a web-hosting provider. A MySQL database was used to store the data stream, which was then connected with a web-based application that serves as the user interface.

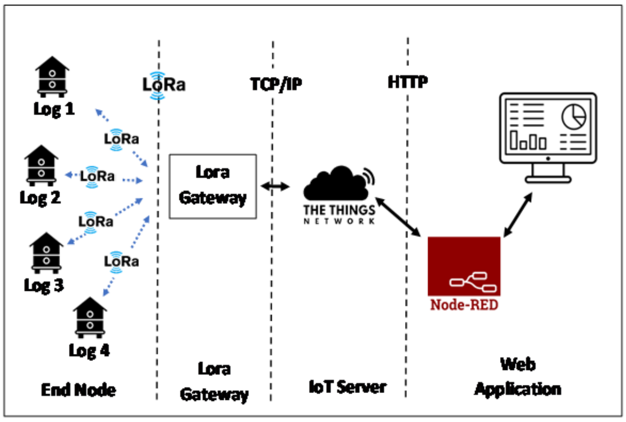
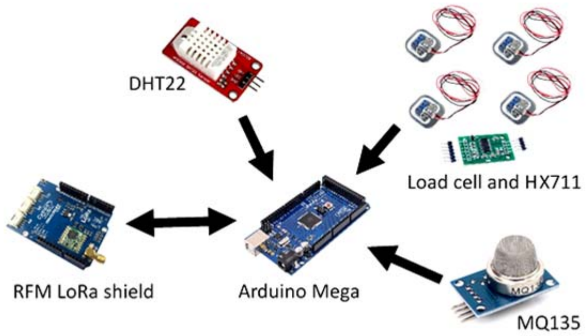


Figure 1. Overview of the proposed stingless bee monitoring system based on LoraWAN

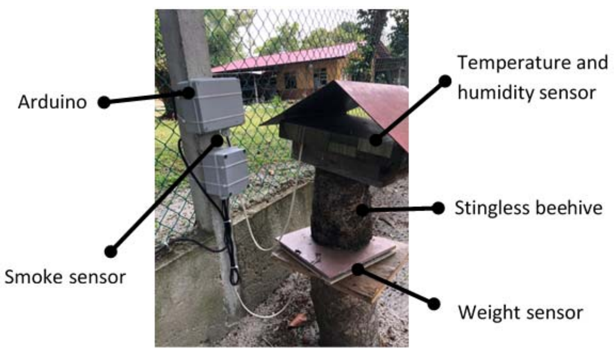
2.1. Lora End Node

Figure 2(a) and Table 1 detail the end node configuration and specifications employed in this project. RFM Using the LoRa modulation technology, a LoRa shield equipped with an RFM95W LoRa module was utilized to transmit data from each end node. Along with its long-range spread spectrum communication and low-power properties, it enables low-data-rate transmission with good interference rejection [27]. Meanwhile, the Arduino microcontroller served as the central processing unit for the end node, processing data from all sensors linked to the stingless beehive. The weight of the bee log was monitored over time using a load cell capable of measuring up to 10 kg. This was to estimate the honey output of the beehives over time using the weight measurements. Additionally, each end node was equipped with a smoke sensor based on the MQ135 standard to monitor the ambient air quality.

Meanwhile, the DHT22 sensor was used to determine the temperature and humidity levels inside each hive. These components were mounted to the beehives in the manner illustrated in Figure 2(b). The values from the weight, smoke, humidity and temperature sensors were combined into a single packet stream using the Cayenne Low Power Payload (LPP) format. Every 60 seconds, these packet streams were forwarded to the LoRa Gateway for additional processing.



(a)



(b)

Figure 2. (a) Component's integration for end nodes. (b) The Arduino board and sensor placement at the stingless beehive

Table 1. End Node component specifications

Component	Part Number	Specifications
Arduino Mega	ATmega2560	54 Digital I/O, 16 analogue I/O, 256KB flash memory
RFM 95 Lora shield	Cytron-LoRa RFM shield	915 MHz frequency band
Gas sensor	MQ135	Detect/Measure NH3, NOx, alcohol, Benzene, smoke, CO2
Load Cell	Load cell with HX711 amplifier	Load capacity 40-50KG
Temperature sensor	DHT22	-40 - 80 degrees C temperature range
Humidity sensor	DHT22	Humidity from 0-100% RH

The Lora payload structure utilized in this project is depicted in Figure 3. It is based on the Cayenne LPP format, which consists of a single-byte data channel, a single-byte data type, and an M-byte data value. The packet length can be configured up to the number of data channels N. Due to the fact that each end node included four sensor sets, four channels were utilized in conjunction with data types 67, 68, and 02 to represent temperature, humidity, and analogue input, respectively, in the Cayenne LPP format. As a result, the payload size for this investigation was set to a 15-byte array, as shown in Table 2.

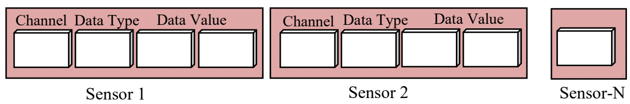


Figure 3. LoRa payload structure based on Cayenne LPP

Table 2. Payload packet content arrangement setting according to Cayenne LPP

Channel	Data ID	Data Type	Data Size (Byte)
0	67	Temperature	4
1	68	Humidity	3
2	02	Analog input (weight)	4
3	02	Analog Input (smoke)	4

2.2. Lora Gateway

The Lora gateway is comprised of a Raspberry Pi 4 and a RAK Lora Gateway HAT, which utilizes the RAK833 mPCIe with Semtech SX1301 Lora technology. This project utilized a normal IP connection to link the gateway to a central network server known as "The Things Network" (TTN). The TTN network is a free and open-source worldwide network devoted to the internet of things applications. It made use of LoRaWAN technology, which is optimized for long-range data transmission while consuming little power and bandwidth. All end nodes will transmit data packets to the gateway, which will deliver them to the TTN network. It can simultaneously receive packets from hundreds of nodes with little interference.

2.3. Node-Red Integration

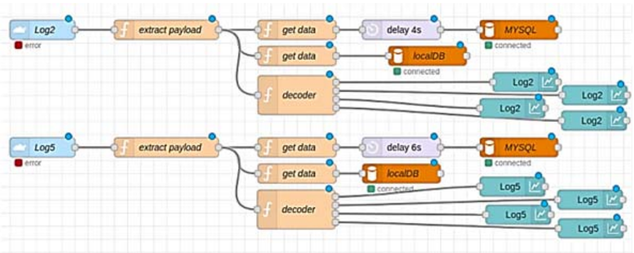


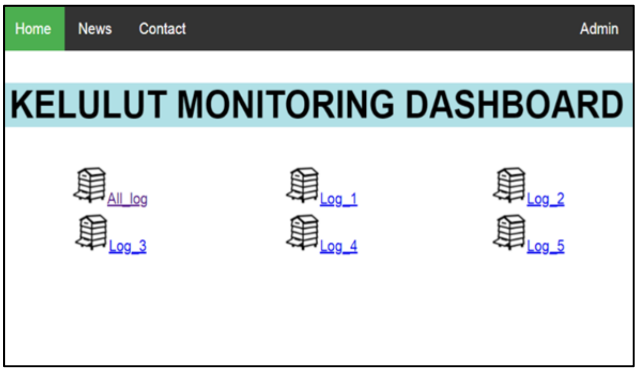
Figure 4. Node-red flows are used to retrieve data from the TTN server

Node-red is a free and open-source programming tool for developing event-driven applications that use a flow-based editor to link hardware devices, APIs, and web services. It includes pre-built libraries and functions, and nodes that simplify the construction of sophisticated applications. The node-red flow depicted in Figure 4 is the one utilized in this project to retrieve data from the TTN server and transmit it to both the local database and the hosted database. According to the TTN format, the received data consists of various fields, including the payload, device ID, device type, time, and counter. This information will be retrieved and delivered to the databases using the "extract payload" node illustrated in Figure 4. The local database was linked to a user interface (UI) application created in node-red and accessible over the local network. Meanwhile, another database was housed on the hostinger.com platform and linked to a web-based monitoring dashboard programme accessible via an internet browser from any device.

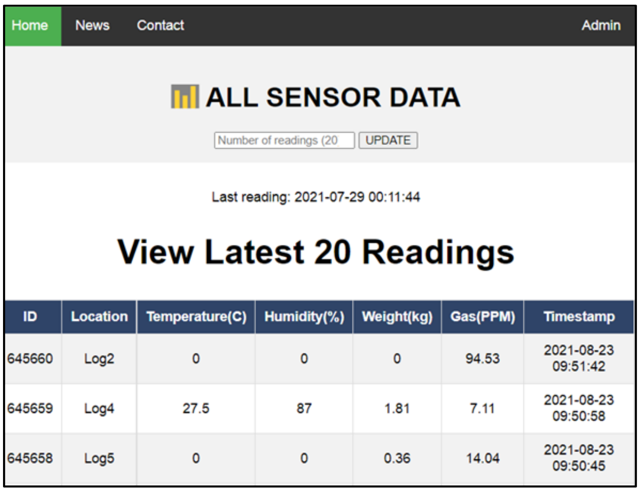
3. Results and Discussion

3.1. User Interface

The web-based user interface landing page developed for this project is seen in Figure 5(a). The interface page had a short header with navigation buttons that identified all active stingless beehives. Users may either click on any beehive icon to get sensor data at that place or on the "All log" icon to view the most recent readings from all sensors, as illustrated in Figure 5(b). The quantity of data displayed on this page can be customized to the user's desire, or it can default to displaying up to 20 readings.



(a)



(b)

Figure 5. (a) The landing page for the monitoring dashboard. (b) The user interface to list the sensor readings from all sensors in table form

3.2. Data Collection Test

Figure 6(a) indicated the average daily temperature of the stingless beehives within the 16 days observation period. As can be seen from the figure, all locations indicated almost identical temperature variations, with the highest average temperature recorded on day 16 at 29°C and the lowest average temperature recorded on day 11 at 26°C. Daily, the fluctuation of hive temperature was observed between 24°C to 34°C, where the lowest temperature was recorded early in the morning between 6.30 am to 7.30 am while the highest temperature was recorded around 2.30 PM to 3.00 pm. Meanwhile, the input from humidity sensors placed inside the hive manages to record the hive's humidity reading between 85 to 90 %RH, as depicted in Figure 6(b). It was apparent that the humidity reading in each hive was maintained at a certain level throughout the 16-day period, with log 4 indicating the highest humidity reading at around 90%RH while log1 indicated the lowest humidity at around 85 %RH.

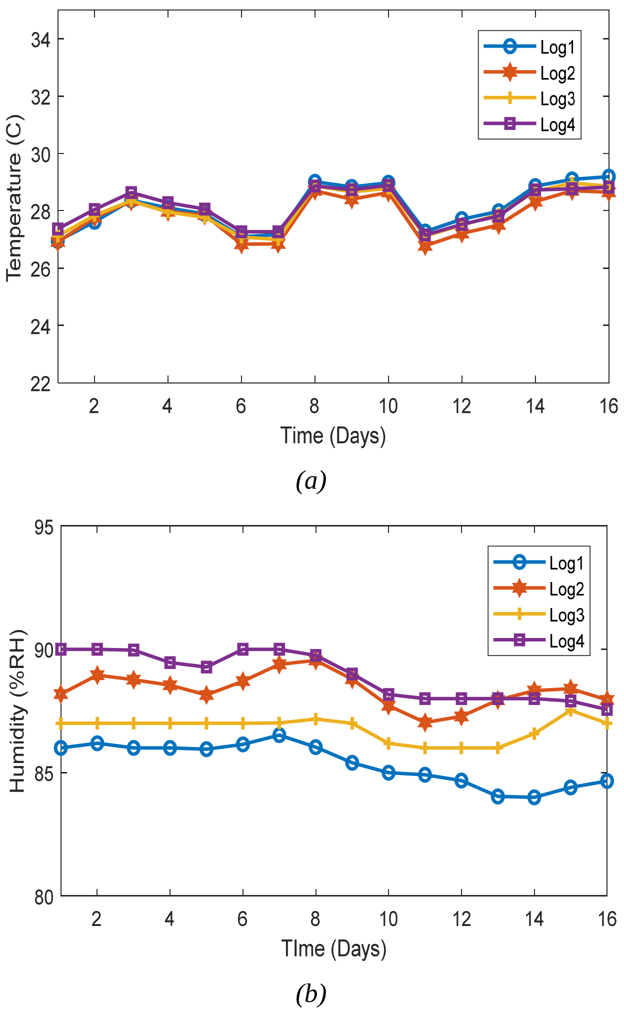


Figure 6. (a) Temperature variation within the 16-day observation period. (b) Humidity level variation within the 16-day observation period

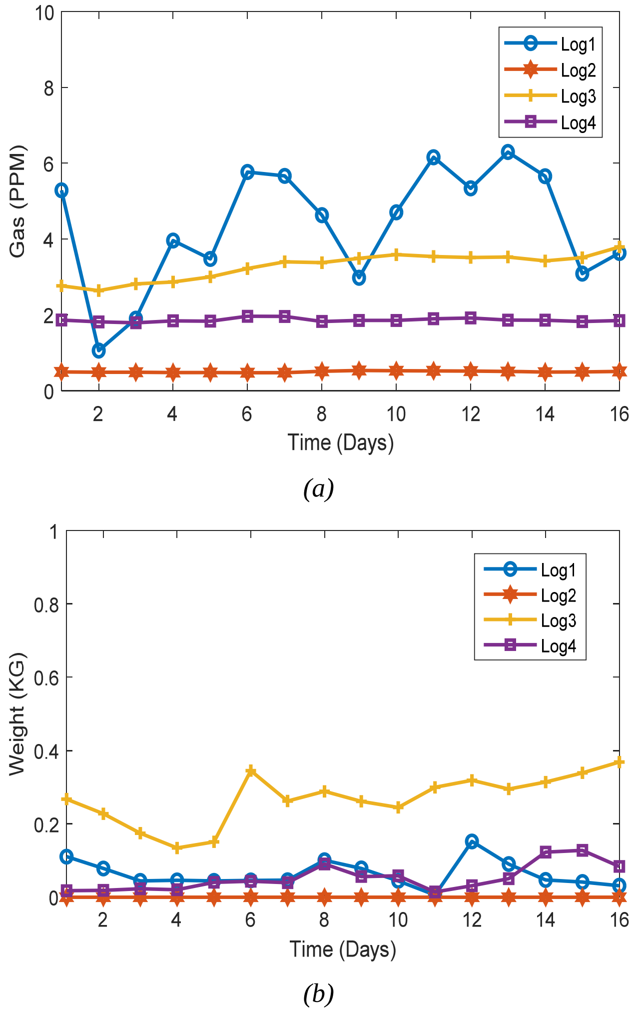


Figure 7. (a) Readings from MQ135 gas sensor. (b) Readings from weight sensors

Besides, Figure 7(a) illustrates the readings obtained from MQ135 sensors placed near each hive. Results indicated that all hives had not been exposed to any substantial amount of smoke in the vicinity as all readings were recorded below 10 PPM. Even though the input from log 2 indicated some inconsistency as compared to other logs, these values can still be accepted and showed that there was no smoke within the area during the deployment period. The variety of the readings was due to the sensitivity settings of each MQ135 sensor and needed to be recalibrated from time to time.

As for the weight sensors data presented in Figure 7(b), beehive number 3 demonstrated an increasing trend throughout the 16-days period. The rest did not provide a clear indication of the weight increment of the hive. The results demonstrate two things. First, the 16-day duration might be too short for the amount of honey inside the hives to show a significant increment. Second, the strong wind might have disrupted the sensor reading since the deployment site is near the coastal area.

3.3. System Functionality Test

A summary of the system functionality is given in Table 3. The results demonstrated that almost all the expected features for this work are fully functional, and a further adjustment is required on the weight sensor reading.

Table 3. The monitoring system functionality test

Function	Status
Temperature reading	Fully functional
Humidity reading	Fully functional
Weight sensor reading	Partially functional
Smoke sensor reading	Fully functional
Data transmission from bee log to the gateway	Fully functional
Uplink from the gateway to TTN server	Fully functional
TTN server to web integration	Fully functional
Web dashboard	Fully functional

4. Conclusion

In conclusion, a basic testbed for monitoring the stingless beehive was constructed and tested satisfactorily. Based on the findings, there are lots of space for improvement. The usage of a weight sensor should be revisited because it proved ineffective owing to severe winds in the area, particularly during the monsoon season. A higher-grade smoke sensor is required to produce consistent readings. There is also a need to consider using a waterproof temperature and humidity sensor to replace DHT22 since there is a lot of rain throughout the year, which might alter the sensor's reading. An accelerometer can also be used to measure vibration caused by wind and other external causes.

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