

INTEGRATION OF LORA IOT WITH CLOUD PLATFORM IN STINGLESS BEEHIVE REMOTE MONITORING SYSTEM

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ABSTRACT: Stingless bee colonies require constant monitoring to ensure hive health and optimal honey production. However, conventional monitoring practices are time-consuming and labor-intensive, especially for beekeepers in rural or remote areas. Without access to real-time hive data, beekeepers may struggle to detect changes in temperature, humidity, and other vital conditions that could impact bee health and productivity. Most studies rely on Wi-Fi modules for communication between local and cloud servers. However, using Wi-Fi for bee monitoring requires that the stingless bee hives be located near buildings with Wi-Fi access. To address this issue, a prototype of a remote monitoring system for a stingless bee colony was developed using Long Range (LoRa) technologies due to the low data rate, low power, and operability in an outdoor environment. This system aims to help beekeepers monitor the beehives remotely. The prototype comprises two nodes: a beehive sensor node and a LoRa gateway node. The beehive monitoring sensor node is equipped with the ESP32 as a microcontroller, LoRa SX1278, BME680, and KY-037. The LoRa gateway comprises ESP32 and LoRa SX1278 and is interfaced with Ubidots through Node-Red. The developed prototype was tested at four locations at varying distances in the Mahallah Ruqayyah Kelulut farm. The result shows that LoRa is feasible for remote monitoring because it can reliably transmit data up to 58 meters despite a higher data rate. The Ubidots dashboard displays the temperature, humidity percentage, air quality, pressure, sound levels, and RSSI value for thorough insights into the bee's condition, as it can be accessed using web and mobile applications. Overall, the stingless bee remote monitoring system using LoRa communication is a promising solution for outdoor applications between the sender and receiver for data transmission in remote areas.

ABSTRAK: Koloni lebah kelulut memerlukan pemantauan berterusan untuk memastikan kesihatan sarang dan pengeluaran madu yang optimum. Walau bagaimanapun, amalan pemantauan konvensional memerlukan banyak masa dan tenaga, terutamanya bagi penternak lebah di kawasan pedalaman atau terpencil. Tanpa akses kepada data sarang secara masa nyata, penternak lebah mungkin menghadapi kesukaran untuk mengesan perubahan suhu, kelembapan, dan keadaan penting lain yang boleh menjejaskan kesihatan serta produktiviti lebah. Kebanyakan kajian menggunakan modul Wi-Fi untuk komunikasi antara pelayan tempatan dan awan. Walau bagaimanapun, penggunaan Wi-Fi untuk pemantauan lebah memerlukan sarang lebah kelulut diletakkan berhampiran bangunan dengan akses Wi-Fi. Bagi mengatasi isu ini, satu prototaip sistem pemantauan jauh untuk koloni lebah kelulut telah dibangunkan menggunakan teknologi Long Range (LoRa) yang mempunyai kadar data

rendah, penggunaan tenaga yang rendah, serta sesuai untuk persekitaran luar. Sistem ini bertujuan membantu penternak lebah memantau sarang lebah dari jauh. Prototaip ini terdiri daripada dua nod: nod sensor sarang lebah dan nod pintu gerbang LoRa. Nod sensor pemantauan sarang lebah dilengkapi dengan ESP32 sebagai mikropengawal, LoRa SX1278, BME680, dan KY-037. Pintu gerbang LoRa pula menggunakan ESP32 dan LoRa SX1278 yang dihubungkan dengan Ubidots melalui Node-Red. Prototaip ini telah diuji di empat lokasi berbeza pada jarak yang berbeza di ladang Kelulut Mahallah Ruqayyah. Hasil menunjukkan bahawa LoRa adalah sesuai untuk pemantauan jarak jauh kerana, walaupun pada kadar data yang lebih tinggi, ia boleh menghantar data dengan baik sehingga jarak 58 meter. Papan pemuka Ubidots memaparkan suhu, peratusan kelembapan, kualiti udara, tekanan, tahap bunyi, dan nilai RSSI untuk memberikan gambaran lengkap mengenai keadaan lebah, yang boleh diakses melalui aplikasi web dan mudah alih. Secara keseluruhan, sistem pemantauan jauh lebah kelulut menggunakan komunikasi LoRa adalah penyelesaian yang menjanjikan untuk aplikasi luar di kawasan terpencil antara penghantar dan penerima bagi penghantaran data.

KEYWORDS: *LoRa SX1278, ESP32, Remote Monitoring, BME680, Ubidots.*

1. INTRODUCTION

Stingless beekeeping has gained prominence in recent years due to the valuable role these bees play in pollination and the unique qualities of their honey, particularly in tropical regions. Stingless bee honey is known for its sour taste compared to honeybees because it sustains biodiversity and acts as an important pollination agent in forests full of different kinds of plants. Stingless bees are defined as small to medium-sized bees with short stingers originating from tropical regions of the world, such as Australia, Africa, and Southeast Asia [1]. Unusual behaviors that are less likely to be understood are especially the intense conflicts between the colonies, in which one of the conflicts may lead to high mortality rates of the stingless bees when their colonies and stored resources are stolen [2]. The inter-colony attacks will give advantages to the attackers, allowing them to gain benefits such as the hive, honey, and propolis from the attacked colonies [3]. Therefore, the monitoring system for the stingless bee colony is needed because many external factors, such as temperature and humidity, may cause the stingless bees to become extinct [4].

Traditional monitoring methods often require physical presence and can be labor-intensive, making it challenging to track real-time hive conditions, especially in remote areas. As the demand for stingless bee honey and its related products rises, so does the need for effective management and monitoring systems to maintain healthy bee colonies. The existing monitoring system for stingless bee colonies is not well suited for stingless beehives placed in a remote area. A problem faced by the beekeepers when they started to monitor the hive remotely is that most of the monitoring system uses a Wi-Fi module as a medium to connect the sensor node at the beehives directly to the internet. Most stingless beehives are placed remotely, far from the buildings, without access to a Wi-Fi router. When this happens, the beekeepers encounter a hard time sustaining the well-being of the stingless bees and later find out about the health problems faced by the stingless bees, thus restricting the beekeepers from monitoring the stingless bees. This might be caused by the transmission delay from the sensor node into the cloud server due to poor internet connection. A GSM-based stingless bee monitoring system could solve this problem, but GSM systems are getting outdated and being phased out of the market. Therefore, this research aims to develop a small, simple, and reliable monitoring system for stingless bees based on current IoT technology and Long Range (LoRa) radio technology. LoRa offers long-range, low-power wireless communication, making it ideal

for IoT applications in remote and energy-constrained environments. The system aims to provide beekeepers with real-time information about the environmental parameters of the beehive, hence contributing to the colony's health and helping to optimize the stingless bee conditions to increase honey production.

2. RELATED WORKS

Heterotrigona itama and *Geniotrigona thoracica*, illustrated in Figure 1 (a) and (b), respectively, are stingless bee species found in Southeast Asia, particularly in countries like Malaysia, Indonesia, and Thailand [5]. These bees belong to the Apidae family and are highly valued for their pollination capabilities and honey production, especially in traditional and medicinal contexts. Malaysia's stingless bee industry has grown in demand in recent years. Rising in numbers, the agricultural community started their careers as stingless beekeepers. These beekeepers were guided to manage their hives, given information about the stingless bee, and acquired all techniques to cut down resources while having the same volume of honey production [6]. Stingless bee honey is known for its high quality, but it is expensive because of the limited quantity produced by the bees [7].

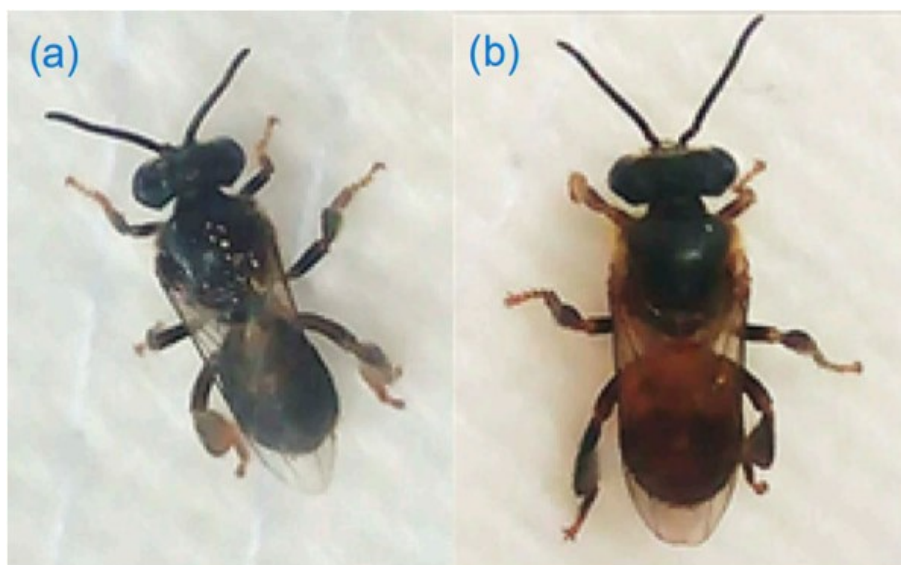


Figure 1. Stingless bee species: (a) *Heterotrigona Itama*, (b) *Geniotrigona Thoracica* [5].

Trigona Itama and *Trigona Thoracica* are the most frequently employed in Malaysia's stingless bee industry [4], and most beekeepers monitor the health of the stingless bees by observing them and examining their environment for any concerns [8]. The manual method has a record of success in beekeeping, but as time progresses, the number of stingless beehives has increased, and therefore, this method has become less efficient.

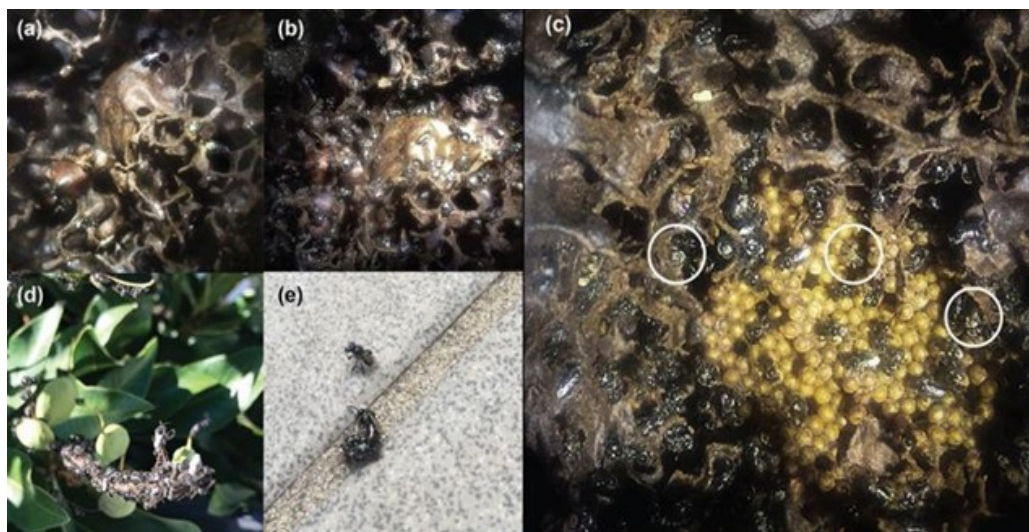


Figure 2. (a) Stingless beehive before the invasion, (b) Stingless beehive after the invasion, (c) New callows are present in the hive brood area, (d) Male stingless bee aggregates outside the hive, (e) Male stingless bee attempts to mate with the queen [2].

The stingless bee is a eusocial insect known for its exceedingly efficient foraging and resource-seeking behaviors facilitated by their complex social organization [2]. Although some unusual behaviors are less likely to be understood, especially the intense conflicts between the colonies, one of the conflicts may lead to high mortality rates of the stingless bees when their colonies and stored resources are stolen [2]. Figure 2 illustrates behaviors related to inter-colony fighting of stingless bees. When stingless bees attacked other colonies, they focused on two things: first, the stored supplies, and second, the hive. These attacks will give the attackers an advantage in benefiting from the attacked colonies [3].

Various crucial factors limit the volume of honey retrieved from the stingless beehive. Most of the factors come from the collapse of a stingless bee colony or a non-productive hive [4]. Stingless beehives should be placed near a food supply so that the stingless bee colony is healthy and can produce over 50% of propolis inside their hive. Also, stingless bees need a monitoring system because many external factors, such as temperature and humidity, may cause the stingless bees to become extinct [4].

A dependable beehive monitoring system should be created to collect high-quality data for processing. The technology involved in the design of the monitoring system should be affordable and capable of surviving the external climate of the beehives, which will constantly be in contact with rain, sun, wind, and other factors that are harmful to most electronic components [8].

A monitoring system must endure the hive's humidity and temperature variations both inside and outside, as well as potential disruptions or assaults from other colonies. The system must also ensure proper positioning of components within the hive to prevent harm to the bees and minimize disturbances to the stingless beehive environment. Additionally, high-quality video and audio recording capabilities are recommended to enhance the accuracy of the data collected for analysis [8].

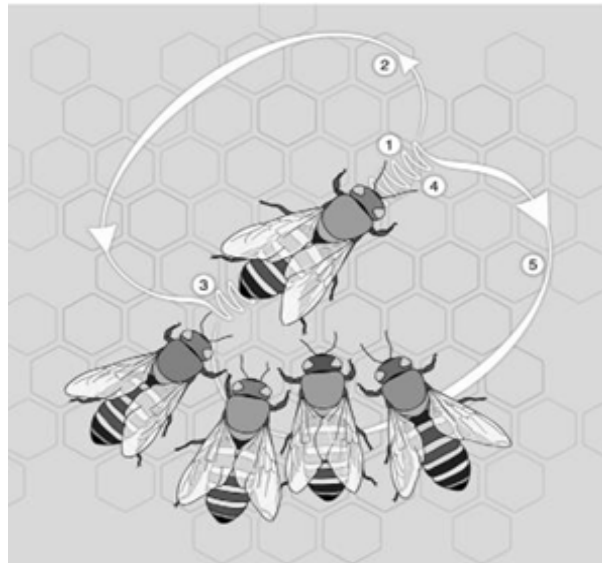


Figure 3. Waggle dance [3].

The waggle dance illustrated in Figure 3 produces a sound when the swarming bees want to send a message about a food discovery [3]. An audio monitoring system was invented to forecast bee swarming, where the audio data is captured at a sampling rate of 2 kHz [9]. This project involved 270 hours of sound recording in bee hives and recordings of temperature and humidity. Figure 4 shows the placement of the microphone and data logger inside the beehives.



Figure 4. The microphone and Hobo placement inside the beehives [9].

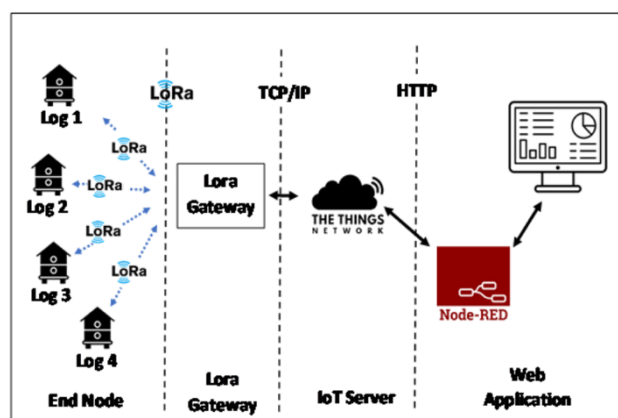


Figure 5. Lora-based test bed for stingless bee monitoring [4].

The Lora-based testbed for monitoring stingless beehives in Figure 5 was created to gather accurate data stored in the MySQL database and visualize it in a web-based dashboard. This allows beekeepers to monitor closely and avoid any possible chances of losing a stingless bee colony [4].

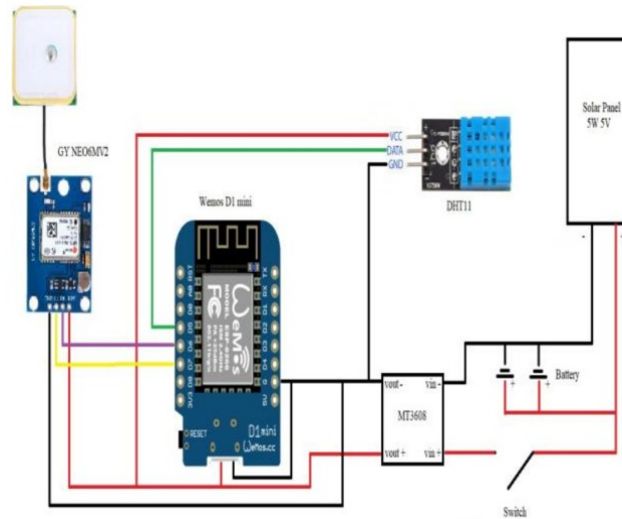


Figure 6. Wi-Fi-based iBees system [7].

The intelligent stingless beehive system (iBees) shown in Figure 6 was specifically crafted for beekeepers to keep track of the bees and monitor the hives [7]. iBees was built with a Global Positioning System (GPS) and sensors for temperature and humidity using DHT11 with a WeMo's D1 mini microcontroller. The purpose of iBees is to prevent the stingless bee colonies from being robbed.



Figure 7. Arnia remote hive monitoring system [10].

The developed iBees system was compared with other monitoring systems, such as Arnia, shown in Figure 7 [7]. Arnia is a remote honeybee hive monitoring system that allows its users to supervise the bee's health conditions at any time and provides information about the hive temperature and humidity [10]. This monitoring system starts by gathering data from the hive monitor and sending it to the gateway for analysis, which is later displayed to the users. However, the Arnia beehive monitoring system is designed for honeybee colonies.

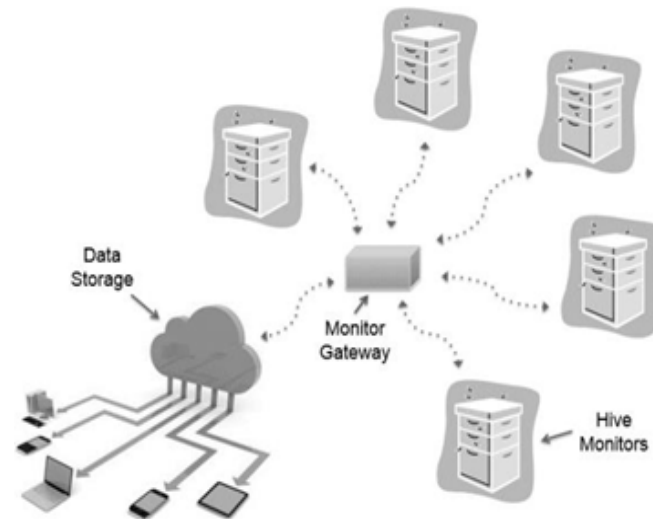


Figure 8. Arnia honeybee system configuration [10].

The Arnia electronic beehive monitoring system in Figure 8 includes temperature measurement with humidity sensors and a weight monitoring system for the honeybee hive. The sound of the bees is recorded to monitor and understand the colonies' behavior and health [10].

Another honeybee beehive monitoring system based on IoT, the Beemon system, as a comparison, is illustrated in Figure 9 [8]. The system focused more on analyzing the honeybee colony from the sound of bees, as this is a crucial component of bees' communication. They believed that research made from exploring bee noises is a growing field, where microphones and accelerometers must be positioned inside and outside the stingless beehives. Additionally, [8] highlighted existing research based on sound vibration in honeybee monitoring systems, noting that when a scouting bee discovers a food source and returns to the hive, it sends messages through the waggle dance upon returning.

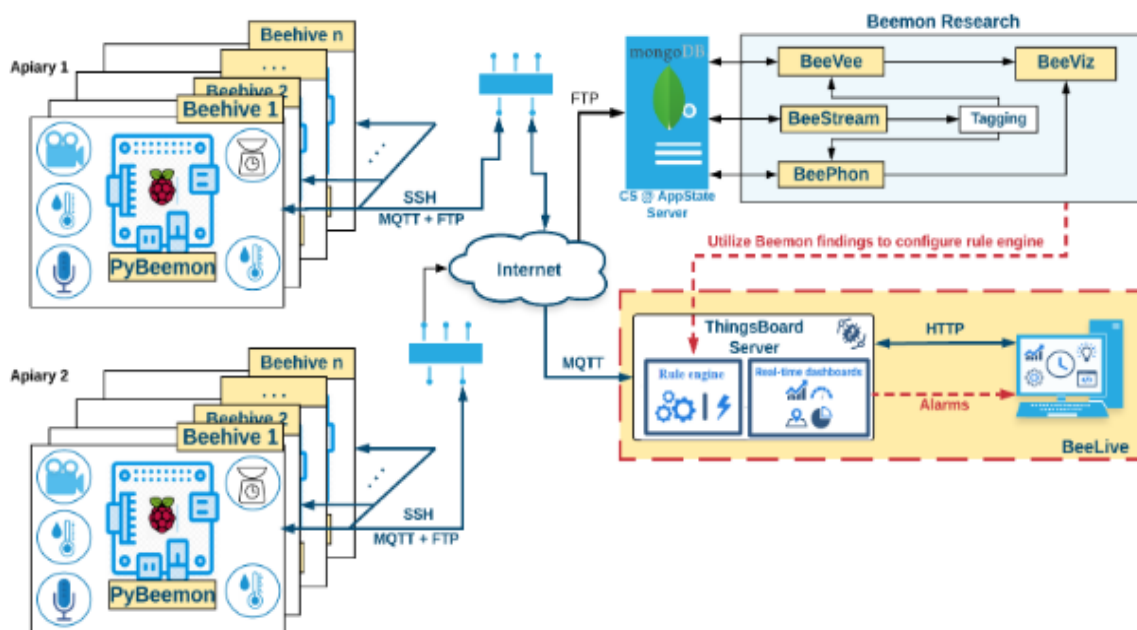


Figure 9. Beemon system for honeybee [8].

The Beemon system utilizes Raspberry Pi along with a collection of sensors and capturing devices to collect data from multiple beehives simultaneously and transmit it to a central server for further analysis. The Beemon system consists of Beemon hardware, "PyBeemon", "BeeVee", "BeePhon", "BeesStream", "BeeViz" and "BeeLive". Beemon hardware includes the sensors that are placed inside and outside the hive. "PyBeemon" is a software developed by [8] that operates on Raspberry Pi. "BeeVee" is a video and image processing tool, while "BeePhon" is an analysis component used to monitor audio recordings. "BeeStream" is a tool that allows beekeepers to observe their bees, and it can be useful for data mining, whereas "BeeViz" is a web tool for data analytics, and "BeeLive" is a platform for the end user to monitor the analysis results.

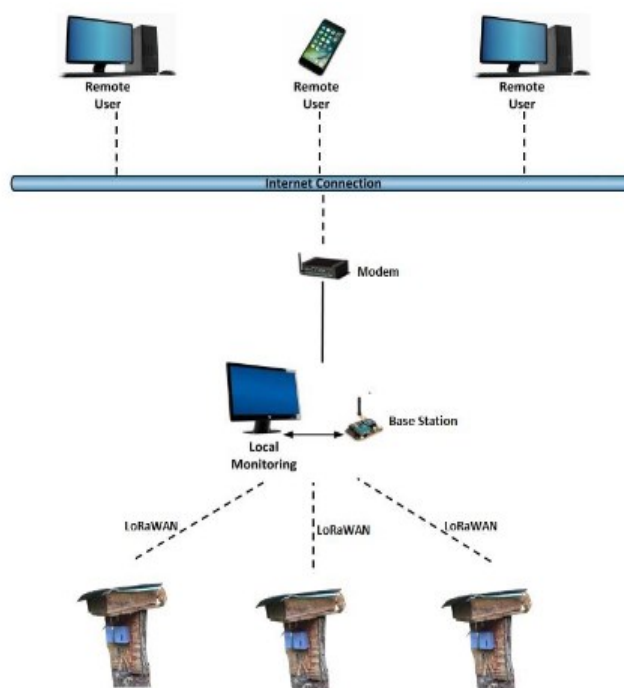


Figure 10. Air pollutant monitoring for stingless beehives [6].

Figure 10 shows a stingless beehive air pollutant monitoring system that is environmentally friendly, stable, robust, has real-time data monitoring, and consumes low power [6]. The system has a three-level stingless beehive monitoring system based on the chosen wireless communication, LoRa, with a simple architecture using Arduino Uno, DHT11, and MQ135 sensors to be sustained in any geographical conditions.

The fundamental criterion of a stingless bee monitoring system is low power [11]. The proposed system in Figure 11 is designed for low power and can remotely monitor the stingless bee colonies using a Wi-Fi connection. The system gathers all data and stores it in Google Firebase cloud storage, accessible anytime. The proposed system in Figure 11 uses two sensors: HX711 and DHT22. Both sensors were used with a buzzer as an alarm for the beekeepers to act when intruders are near the beehives.

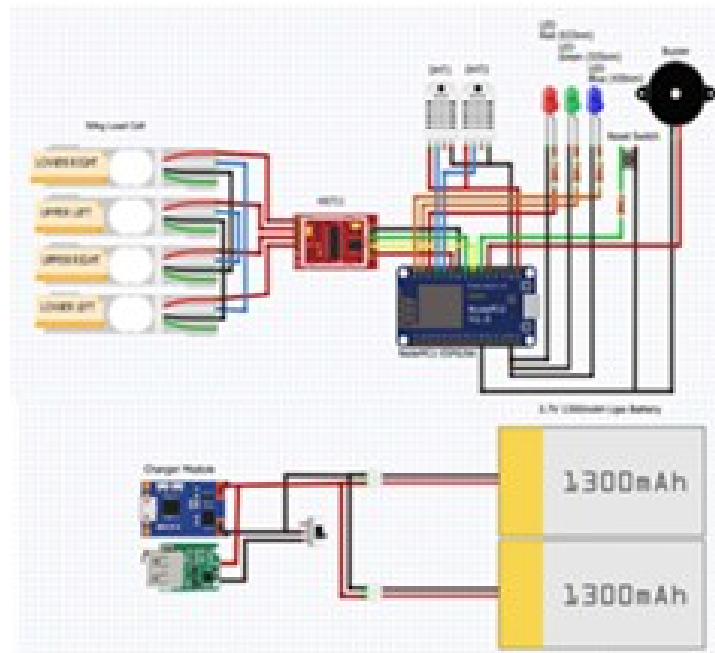


Figure 11. Wi-Fi-based low-powered stingless bee monitoring system [11].

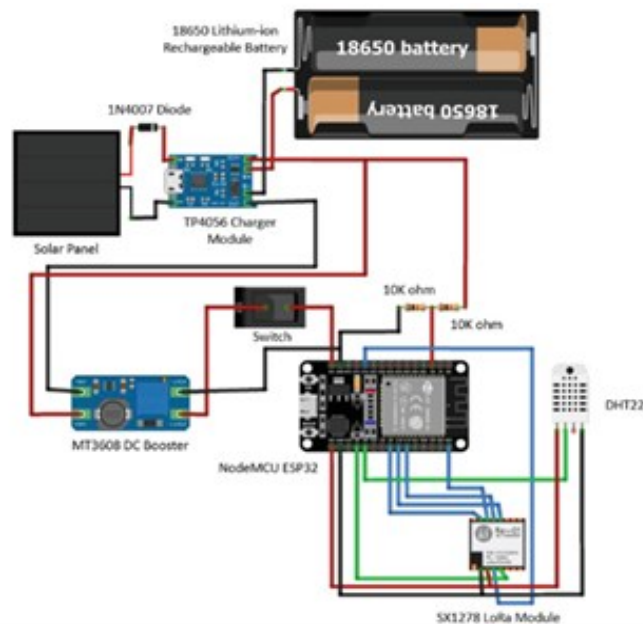


Figure 12. Temperature and Humidity IoT monitoring for stingless bees [12].

Figure 12 indicates a prospective stingless bee monitoring system that focused solely on the stingless beehive's temperature and humidity. The system includes three main parts: a single DHT22 sensor for temperature and humidity monitoring, LoRa Ra-01 as the gateway, and the Blynk app as a dashboard for the end user [12]. The DHT22 is placed inside the hives and is used to measure the hive's temperature and humidity. The DHT22 data were wirelessly sent to a centralized system using LoRa Ra-01. The centralized system, the gateway component, is the second part of the system. This component was tested under two main conditions: line-of-sight (LOS) at -60 dBm and non-line-of-sight (NLOS) at -88 dBm. Under these conditions, only three data packets were successfully received over a distance of 200 meters. The beekeepers, the end users, can view the processed data displayed on the Blynk app.

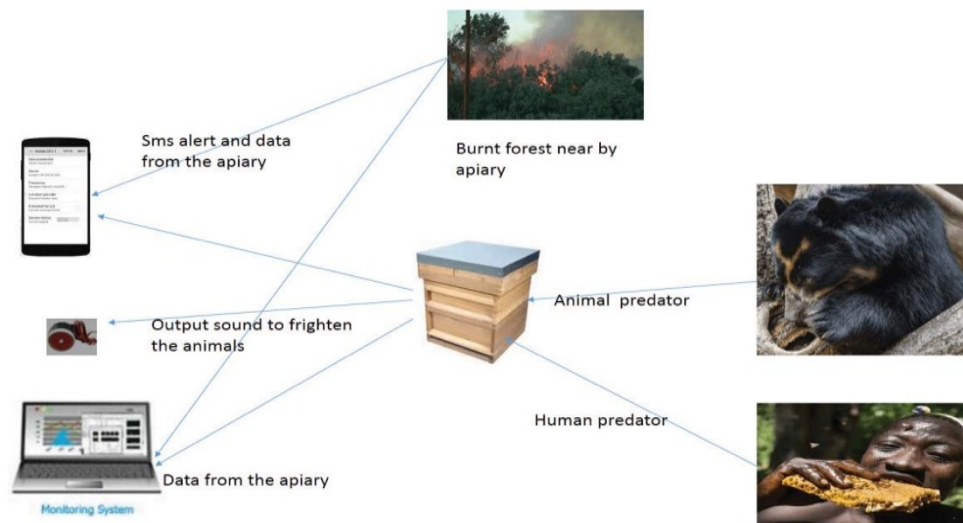


Figure 13. GSM-based honeybee monitoring system [13]

Figure 13 shows three levels of a hierarchical model: a wireless node, a local data server, and a cloud data server. These were proposed when designing the beehive monitoring system for honeybees in Rwanda, Africa. The system gathers and adjusts information in real time to monitor the bees using Arduino and a GSM module [13]. The system has three main parts: an Arduino Uno integrated with RFID for control, sensors for measuring the temperature and humidity, and a local cloud server to upload data. The system's main goal is to protect the beehive, using a flame sensor, air quality sensor, and digital siren [13].

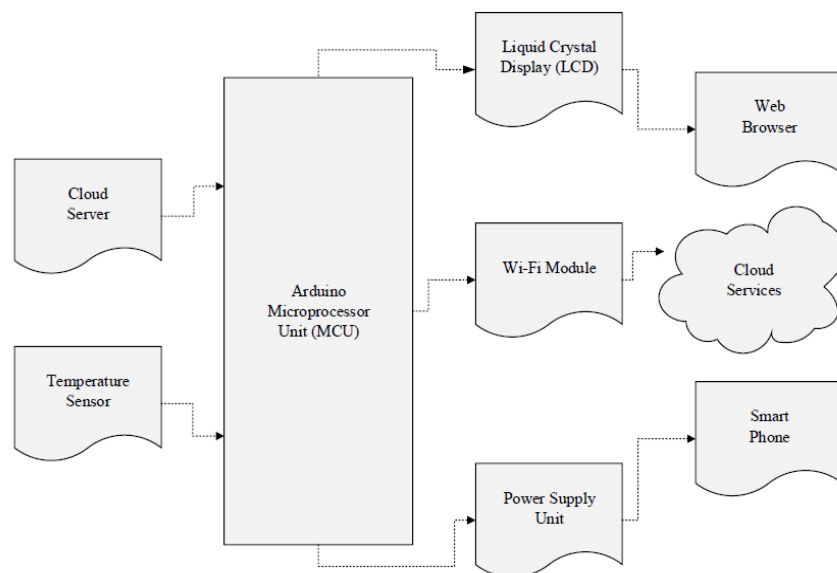


Figure 14. GSM-based honeybee beehive monitoring system [14].

Figure 14 illustrates a proposed monitoring system of wireless sensors configured with an Arduino microprocessor unit and Universal Asynchronous Receiver-Transmitter (UART) communication and GSM module in Lagos, Africa. Information is extracted from all sensors at the beehive in a Transmission Control Protocol (TCP) database [14]. The research aims to design and develop an affordable monitoring system for beekeepers to monitor temperature (°C) and sound levels (dB).

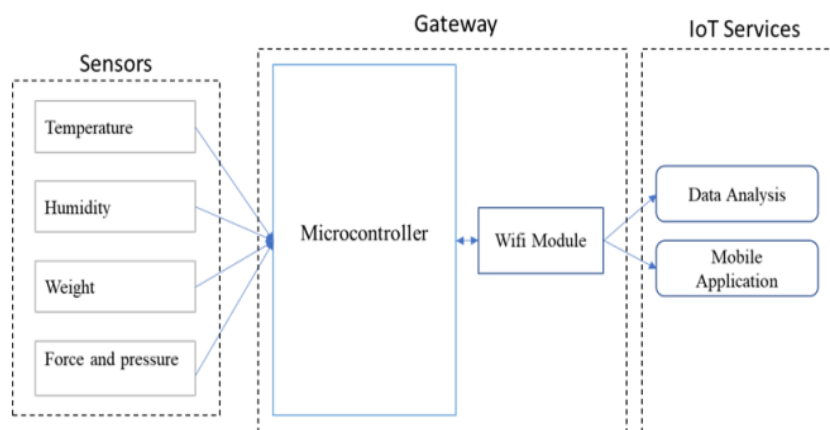


Figure 15. IoT-based monitoring system for stingless bee colonies in IIUM [15].

An IoT-based monitoring system was developed for stingless bee colonies in International Islamic University Malaysia (IIUM) with the system architecture as shown in Figure 15 [15]. The system aims to monitor the honey production of the stingless bee by measuring the hive's weight before and after honey harvesting and the bee colony parameters such as temperature, humidity, and intruder detection. The monitoring system comprises three main components: the sensors, gateway, and IoT services based on Wi-Fi. The monitoring system measured the hive's temperature, humidity, weight, force, and pressure using sensors interfacing with an Arduino Uno microcontroller board. The ESP 8266 was used to access the internet for data transfer. The Wi-Fi router inside the building is too far away from the stingless beehive, and it was replaced with a mobile hotspot for internet connectivity [15].

In summary, all authors highlight the importance of monitoring stingless beehive monitoring with various factors, such as the health of the stingless bees and the possibility of inter-colony fighting. The majority of research in this review monitors the temperature and humidity of the beehive. A stingless beehive's right temperature and humidity are vital for the bee colony's health and honey production. In addition, it is helpful to monitor the bee sound to check for signs of inter-colony fights.

This review highlights the three major sections of the stingless beehive monitoring systems: sensors, wireless communication methods, and gateways. Most studies rely on Wi-Fi modules for communication between local and cloud servers. However, using Wi-Fi for bee monitoring requires that the stingless bee hives be located near buildings with Wi-Fi access. Notably, some studies are showing the potential of adopting LoRa for communication. Building on these findings, this research is focused on advancing the application of LoRa-based technology for enhancing stingless bee colony remote monitoring systems, particularly for stingless bee hives in secluded areas without the reach of Wi-Fi. In addition, a more straightforward and reliable single-unit BME680 environmental sensor, a KY-037 sound sensor, and implementation with ESP32 are explored. The ESP32, KY-037, and BME680 modules are small and will have minimal interference with the stingless beehives. The Ubidots platform is explored as the IoT platform for this project as it offers a user-friendly interface, seamless data integration, real-time data monitoring, scalability, and data analytics capability suitable for stingless bee farmers.

3. METHODOLOGY

The methodology discussed encompasses the system architecture, hardware development, data collection, and data visualization, each designed to enhance the reliability of a prototype system for remote monitoring of stingless bee colonies using LoRa-based technology. LoRa technology is the communication protocol for this system, which was selected for its low power consumption. This research intends to enable and improve remote monitoring for stingless bee colonies in a location with limited Wi-Fi connectivity [15]. The previous system was restructured according to the current situation of the IIUM Kelulut (stingless bee) farm, where the beehive's logs are screwed to the stands, which eliminates the possibility of measuring the weight of the beehive before and after honey harvesting. The communication protocol of the previous system, which relied on a Wi-Fi module, was replaced with a LoRa SX1278 module due to the limited range of Wi-Fi connectivity.

3.1. System Architecture

The system can be divided into four main parts: the LoRa sensor node (transmitter), LoRa gateway node (receiver), Node-RED as an IoT tool, and Ubidots as the cloud platform and database, as shown in Figure 16. The system can provide essential parameters, including the Received Signal Strength Indicator (RSSI), temperature, humidity, pressure, and gas resistance.

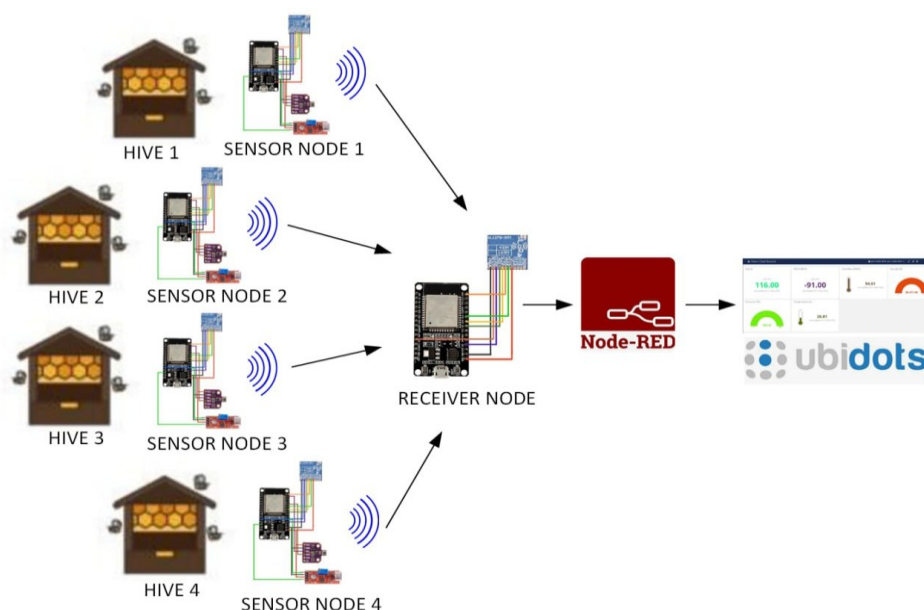


Figure 16. The system architecture for stingless bee remote monitoring system.

Figure 17 presents a flowchart of the monitoring system designed for stingless bee colonies, comprising two primary nodes: the beehive sensor node and the LoRa gateway node. The sensor node and LoRa gateway node were initialized to initiate the data transmission and establish a stable communication framework. Following this, Node-Red was launched using Node.js, providing the necessary platform for data processing within the system. Upon activation of Node-Red, the BME680 environmental sensor and KY037 sound sensor were engaged to commence data acquisition, capturing relevant environmental and sound data. It is essential at this stage to confirm the connection of the Com port and the link to the Ubidots server to ensure seamless data flow. With these components in place, Node-Red was configured to receive real-time data from the beehive sensor node. The incoming data was subsequently

stored locally and published to the Ubidots cloud server, enabling visualization and further analysis. This sequence operates in a continuous loop, where data acquisition resumes cyclically to maintain an uninterrupted monitoring system.

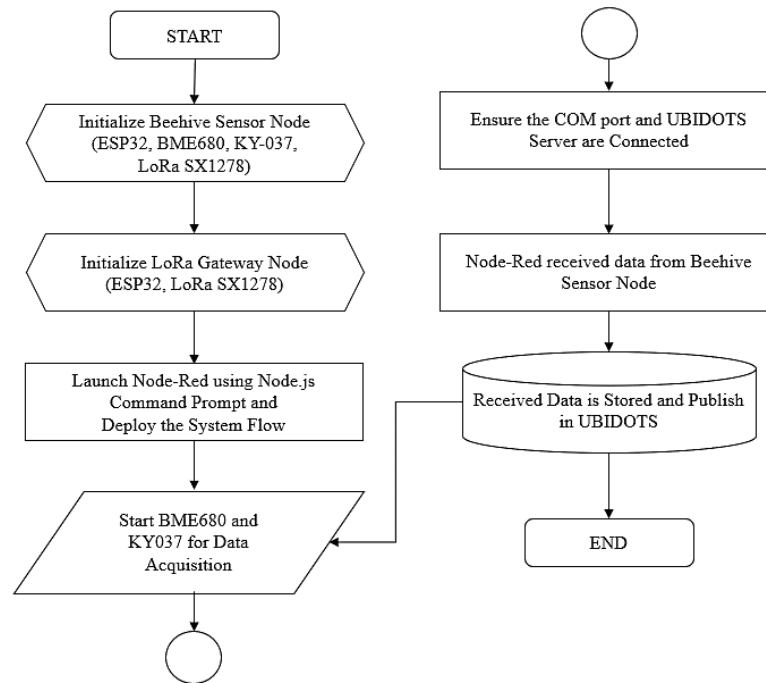


Figure 17. Flowchart diagram for stingless bee colony remote monitoring system using LoRa.

3.2. Hardware Development

Hardware development was initiated by selecting appropriate components and drawing a circuit diagram for pin connection for the sensor and receiver nodes. The sensor node was designed to have three main components: NodeMCU-ESP32 as the microcontroller, BME680 and KY-037 as the sensors, and LoRa SX1278 as the communication gateway (act as the transmitter). NodeMCU-ESP32 was chosen as it is cost-effective and compatible with the Arduino Integrated Development Environment (IDE) software application. The receiver node was built with NodeMCU-ESP32 and LoRa SX1278 (act as the receiver). The circuit diagram and the pin connection for the sensor node and receiver node are shown in Figures 18 and 19, respectively.

The LoRa SX1278 is a long-range radio transceiver commonly employed in developing prototype systems. In this research, the LoRa module serves a crucial function within the beehive sensor node by enabling extended-range communication, which is essential for the remote monitoring of beehive colonies. The SX1278 provides access to Serial Peripheral Interface (SPI) and DIO-0 pins that support LoRa mode only [13]. Operating at a frequency of 433 MHz, the SX1278 aligns with regulatory requirements for use in many Asian countries. To integrate the SX1278 transceiver with both the beehive sensor node and the LoRa gateway, an additional library, "LoRa" by Sandeep Mistry, was installed in the Arduino IDE. LoRa technology, which facilitates long-range data transmission, is fundamental to the Internet of Things (IoT); thus, the use of the SX1278 module underscores its pivotal role in the successful implementation of this project. The same pin connection between ESP32 and SX1278 was

implemented for the LoRa gateway node, as shown in Figure 18 (d), while the circuit diagram is illustrated in Figure 19.

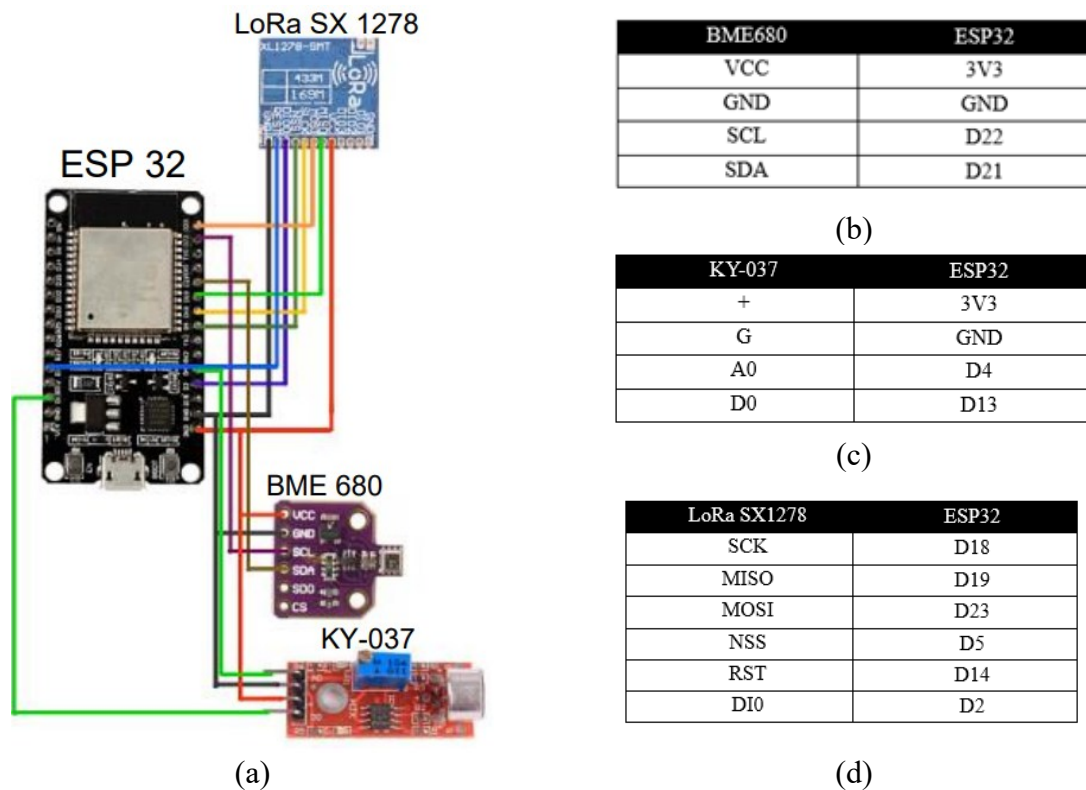


Figure 18. Circuit drawing for (a) beehive sensor mode and pin connection between ESP32 and (b) BME680, (c) KY-037, and (d) SX1278.

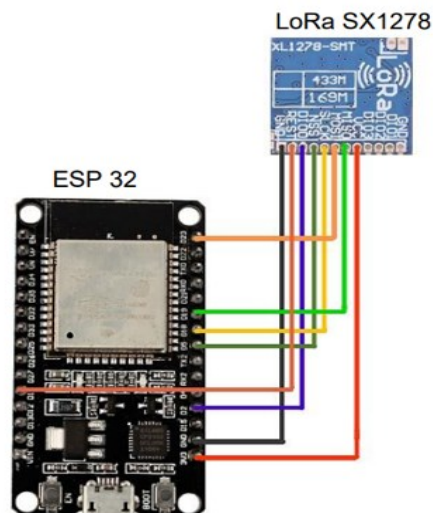


Figure 19. Circuit drawing for LoRa gateway node.

The sensors at the sensor node measure the parameters needed to monitor the stingless bee colony and the beehive, such as temperature, humidity, pressure, and gas resistance. BME680 has two communication protocols: Inter-Integrated Circuit (I2C) and SPI. The Adafruit_BME680 library and Adafruit_Sensor_Library were installed in Arduino IDE as required by the BME680 sensor. The sensor was placed near the top of the stingless beehive to measure environmental parameters such as temperature and humidity near the bee workspace.

The KY-037 sensor is a high-sensitivity sound detection module that detects sound intensity through a built-in microphone, commonly used in projects for audio-based triggering and monitoring applications. The module is equipped with a potentiometer that allows users to adjust the sensitivity of the microphone, enabling control over the sound threshold level required to trigger the sensor's output signal. It has four pins, which are A0 (Analog input), G (Ground), + (3.3V), and D0 (Digital input). No specific library is required for this module. Both pins of the sensor, digital and analog, were declared in the Arduino IDE code to employ it in the system. The microphone on the module was placed near the entrance of the stingless beehive to detect the sound level, which indicates the bee's productivity.

Figure 20 shows the output of the Arduino IDE serial monitor during the verification of the LoRa SX1278 module. This verification was done at a shorter distance, within 1 meter, to verify that both LoRa modules can send and receive data packets. The serial monitor in Arduino IDE also shows the output of the successful LoRa point-to-point communication without packet loss. All verification tests for the hardware have been done before data collection at site locations.

Sending packet: 1	Received packet 'hello 1' with RSSI -69
Sending packet: 2	Received packet 'hello 2' with RSSI -70
Sending packet: 3	Received packet 'hello 3' with RSSI -66
Sending packet: 4	Received packet 'hello 4' with RSSI -71
Sending packet: 5	Received packet 'hello 5' with RSSI -71
Sending packet: 6	Received packet 'hello 6' with RSSI -71
Sending packet: 7	Received packet 'hello 7' with RSSI -64
Sending packet: 8	Received packet 'hello 8' with RSSI -71
Sending packet: 9	Received packet 'hello 9' with RSSI -71
Sending packet: 10	Received packet 'hello 10' with RSSI -66

(a) (b)

Figure 20. Output displayed at the serial monitor for LoRa SX1278
(a) sender (b) receiver node

3.3. Data Collection and Data Visualization using Ubidots

Inside IIUM are known to be a few stingless bee species located in Mahallah Ruqayyah and Kulliyyah of Engineering. Currently, the stingless bee colony in IIUM is monitored manually by IIUM Union of Support Staff One (*Kesatuan Kakitangan Sokongan Satu*) (KESATU) members. The stingless bee species *Heterotrigona Itama* and *Homotrigona Binghami*, available at the IIUM Kelulut farm, were chosen for data collection in this research. These species were selected because they thrive on the Mahallah Ruqayyah Kelulut farm, which is located near a secluded area. This research aims to monitor the stingless bee colony in four different beehive locations at varying distances from the LoRa gateway node (located at a building with a Wi-Fi connection). The parameters such as the Received Signal Strength Indicator (RSSI), temperature, humidity, pressure, and gas resistance were measured using the developed monitoring system. The measured parameters were transferred to the cloud via Node-RED.

Node-RED is a flow-based development tool primarily for integrating and automating IoT, web, and cloud application data flows. In this research, the data flow is shown in Figure 21, and the process begins with a COM port, designated "COM6," which facilitates the connection between Node-Red flows and the ESP32 module with the LoRa gateway to upload incoming data. A debug node labeled "msg.payload" relays the data to subsequent nodes for each instance that data was loaded into the system. This flow includes two primary functions: the first transforms data from the beehive sensor node for the Ubidots platform, while the second refines

the payload for storage in a .csv file, serving as a backup. Upon receipt at the gateway, data is directed to the Ubidots server by configuring the settings of the API token and the device name. Additionally, data converted at the "JSON to string object" node was saved locally as a .csv file to provide a backup, as Ubidots retains data for a maximum period of 24 months.

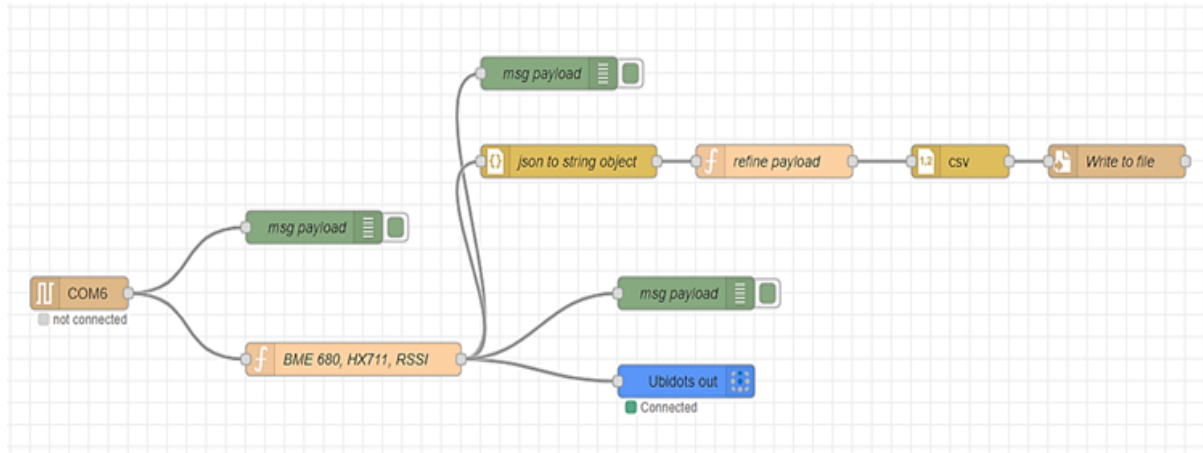


Figure 21. Node-Red flow for stingless bee remote monitoring system

A screenshot of the 'Edit ubidots_out node' configuration window in Node-Red. It has a 'Delete' button, a 'Cancel' button, and a red 'Done' button. Below is a 'Properties' section with a gear icon, a document icon, and a refresh icon. The settings include: 'Account Type' set to 'Ubidots' (dropdown), 'Name' set to 'Name' (text input), 'Token' set to '//Ubidots Unique API token' (text input), 'Device Label' set to 'ESP32' (text input), and a checked checkbox for 'Enable secure TLS connection'.

Figure 22. Ubidots settings in Node-Red

A platform called Ubidots is cloud-based and provides a range of features, including cloud functionality, dashboard visualization, and data analytics. Ubidots simplifies the integration of LoRa devices, providing a user-friendly platform to visualize and analyze data for beekeepers and accelerating IoT project development and deployment. Figure 22 shows the settings to connect the "Ubidots out node" in Node-Red flow by inserting the API token from Ubidots into Node-Red. In this research, the monitoring system is real-time based on data visualization and access to the Ubidots server. After deploying the flow in Node-Red, the Ubidots server attempted to connect with the flow. The message "Ubidots publisher connected" appeared in the Node.js command prompt when the connection was established. In the Ubidots devices section, the ESP32 device instantly appeared, allowing navigation through the dashboards to display real-time data from the beehive sensor node. Navigating through it, the parameters of the sensors in real-time data can be observed in the dashboard, as shown in Figure 23.

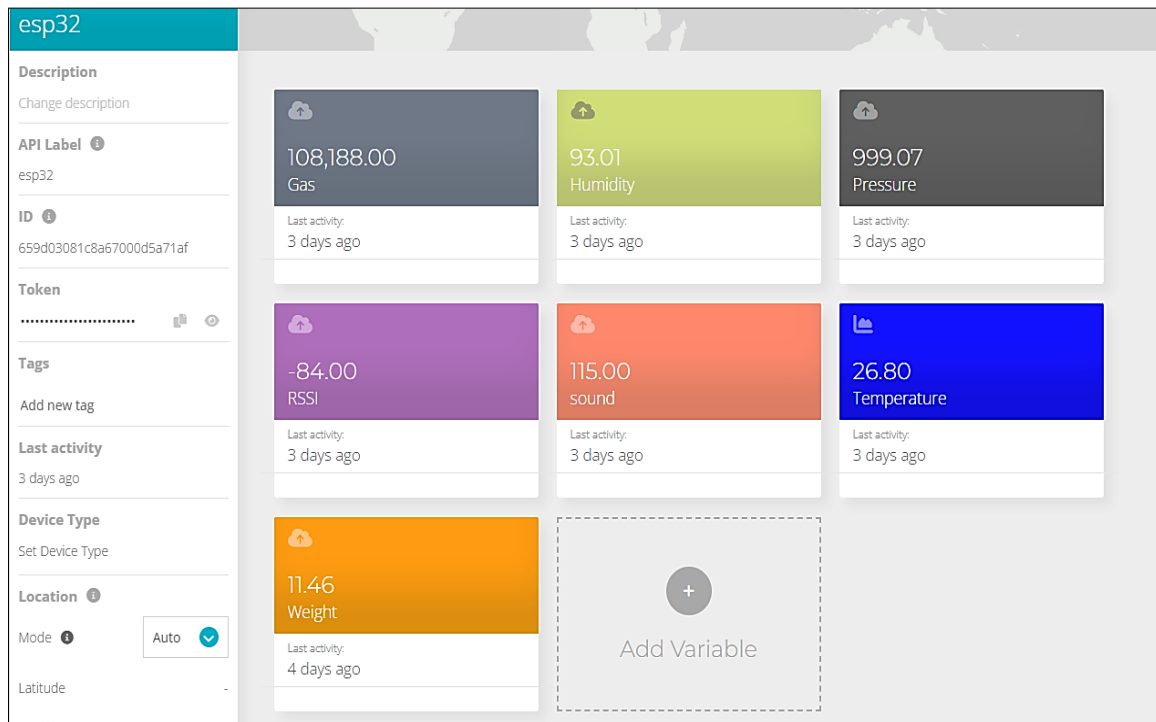


Figure 23. ESP32 device raw.

4. RESULTS AND DISCUSSION

LoRa-based technologies promote long-range with low-power wireless communications, specifically in a remote environment. The Received Signal Strength Indicator (RSSI) value was used to evaluate the LoRa communication, highlighting the system's performance and reliability in data transmission. The relationship between RSSI value over distances between the beehive sensor node and LoRa gateway is depicted in Figure 24. Four beehive locations were involved in the data collection, as shown in Figure 25 (a) to (d).

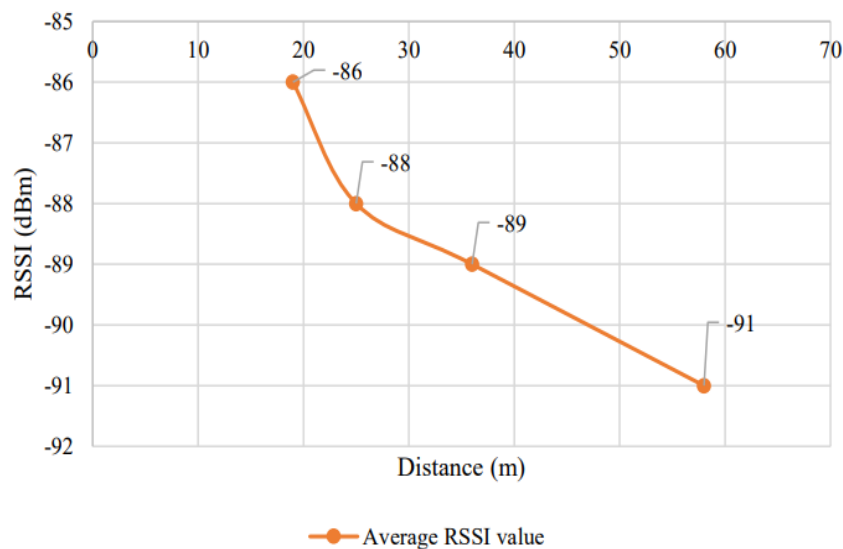


Figure 24. RSSI value (dBm) vs distance (m).



Figure 25. Hive located at (a) 19 meters, (b) 25 meters, (c) 36 meters, and (d) 58 meters elevated from the LoRa gateway node.

The distances vary from the nearest beehive located 19 meters from the gateway, and the farthest distance from the gateway is 58 meters. For the hive positioned 19 meters from the gateway, the measured RSSI values range from -84 dBm to -87 dBm, with an average of -86 dBm. As shown in Figure 24, the data transmission reflects moderate signal strength. The hive situated 25 meters away exhibits slightly reduced signal strength compared to the 19-meter hive. The LoRa transmission from the 58-meter hive shows a further decrease in RSSI, which impacts the data upload process to Ubidots, causing a brief delay in data visualization on the dashboard. The hive positioned at 36 meters, which is elevated higher than the others, displays the weakest signal among all the beehives.

The following section analyzes and discusses the results obtained from the remote monitoring system. The system uses data from the BME680 sensor and KY-037 sound module to monitor the stingless bee condition in IIUM Kelulut farm. The parameters measured in this research include temperature, humidity percentage, pressure, air quality control, and sound levels of the stingless bees. All parameters were measured and transmitted through the LoRa network and uploaded to the Ubidots cloud for data visualization.

The sensor measurement throughout the day shows that the afternoon temperature fits in the ideal range, with an average of 31.61°C, while the average temperatures during the evening and night are below the ideal range, at 28.01°C and 26.63°C, respectively. The temperature value of the hives for *H. Itama* dropped under the range because of weather changes since the data was taken after the rain.

The humidity levels at night, ranging from 93.01% to 92.81%, represent the peak of the humidity curve and could potentially lead to mold growth inside the beehive. This is expected as the temperature drops to its lowest point, 24.65°C, due to changing weather conditions, which impacts the humidity. Persistent conditions maintaining 90% humidity throughout the

day could concern beekeepers, causing Ubidots to send alert messages to their registered phone numbers. In summary, Figure 27 indicates an inverse relationship where an increase in temperature corresponds to a decrease in humidity.

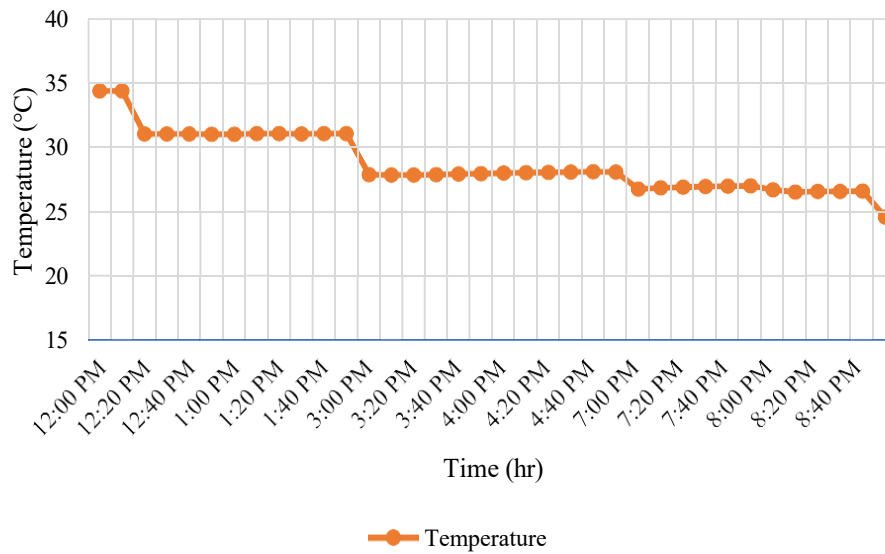


Figure 26. Beehive of H. Itama Temperature vs Time.

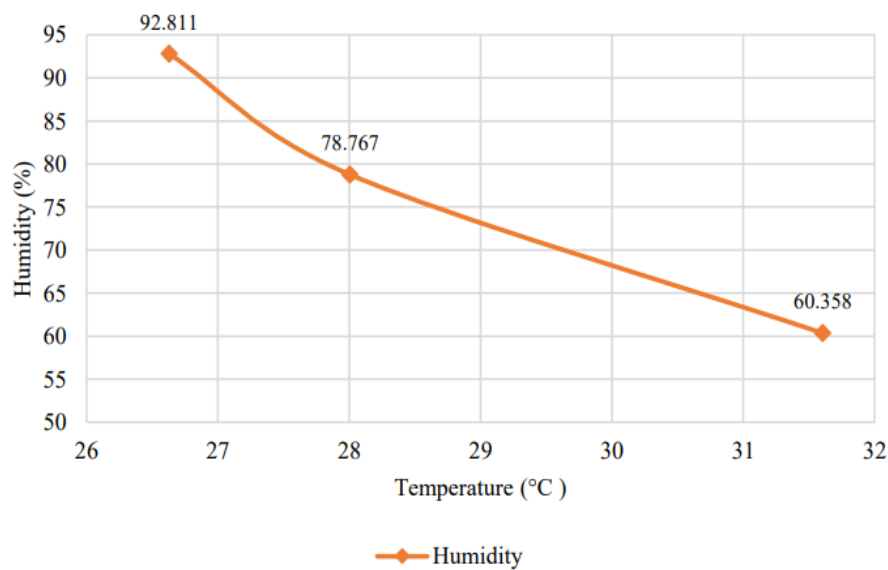


Figure 27. Humidity vs temperature of the beehive.

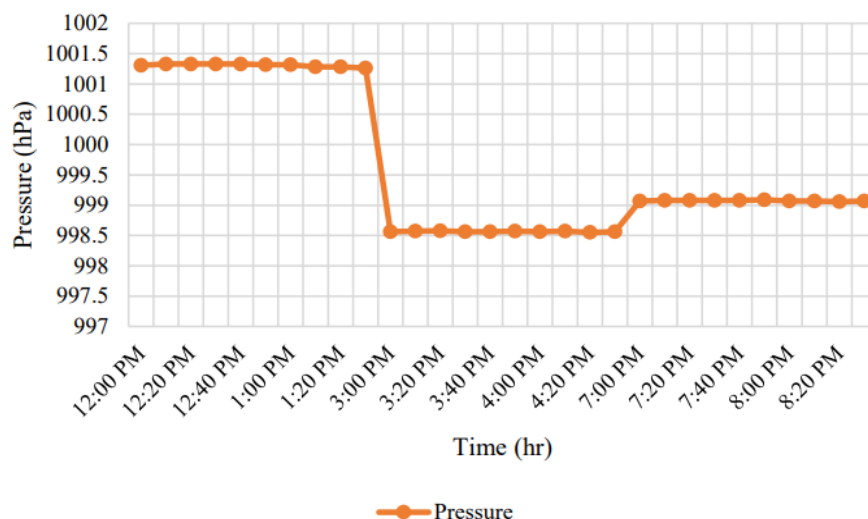


Figure 28. Pressure comparison of *Heterotrigona Itama* species in three different times.

The BME680 sensor provides pressure data, measured in hPa, and can help assess bee behavior, foraging activities, and hive ventilation both inside and outside. As shown in Figure 28, the highest pressure was recorded in the afternoon with an average of 1001.31 hPa, followed by 999.10 hPa at night, and the lowest pressure of 998.56 hPa occurred in the evening. In the afternoon, the stingless bees were most active, increasing their foraging as they searched for propolis and bee bread. The pressure drop in the evening may be linked to the bees' activities, such as swarming the hive before potential rainfall. The pressure then gradually increased at night, stabilizing at an ideal level.

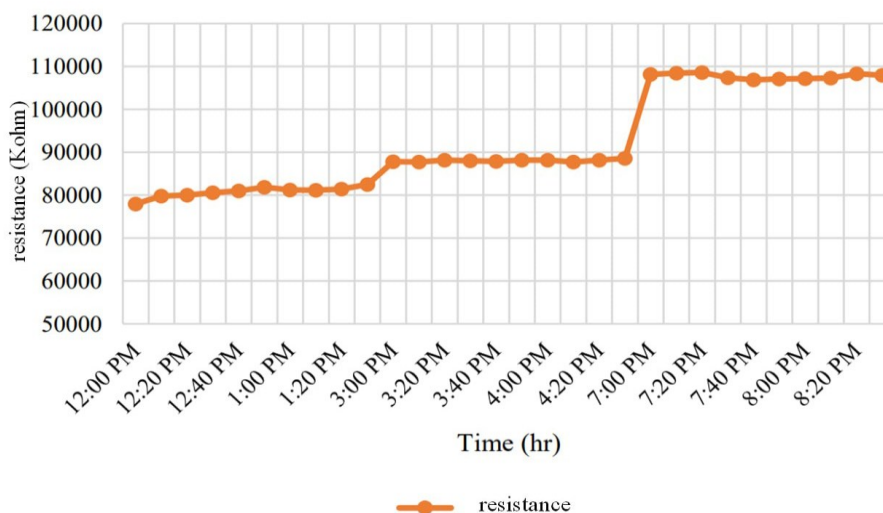


Figure 29. Air quality measurement of *H. Itama* vs Time

Air quality surrounding the beehives is determined using BME680 by measuring the changes in conductivity and a heater, which detects the volatile organic compounds (VOCs) by absorption of oxygen molecules on its sensitive layer and gives output in terms of resistance values. In Figure 29, during the night, the air quality around the beehives is better than during the day as it has a higher resistance value with an average of 107000 Kohm, while in the afternoon, the average value is 80740 Kohm, and in the evening, is 88050 Kohm. The beehives are located at IIUM Kelulut farm in Mahallah Ruqayyah, which is near the road. The presence

of buses and cars contributes to the low resistance value, indicating poor air quality during the day.

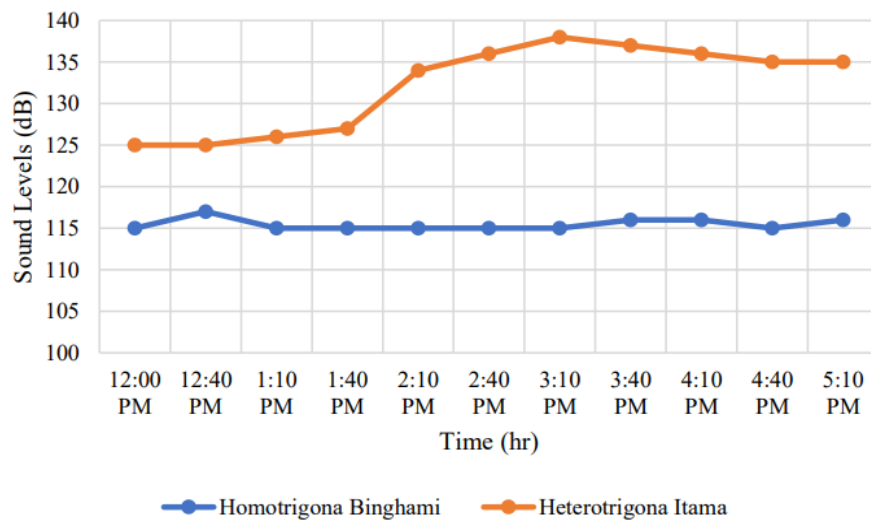


Figure 30. Sound level comparison for H. Itama and H. Binghami vs. Time

Homotrigona Binghami (H. Binghami) species are known to be less active than Heterotrigona Itama (H. Itama) as they forage in just a short period rather than H. Itama [16]. Figure 30 shows that the H. Itama species, with average sound levels of 132 dB in IIUM Kelulut farm, is more active than H. Binghami, with an average sound level of 115 dB. Lower sound levels prove that H. Binghami is less active as it generally produces honey in smaller amounts than H. Itama.

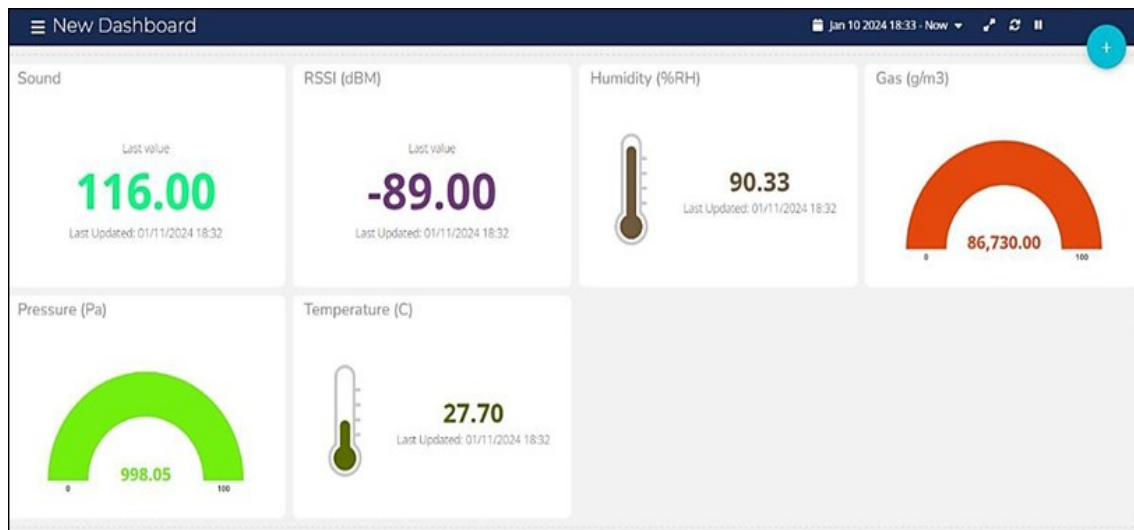


Figure 31. H. Binghami (19 meters from LoRa gateway).

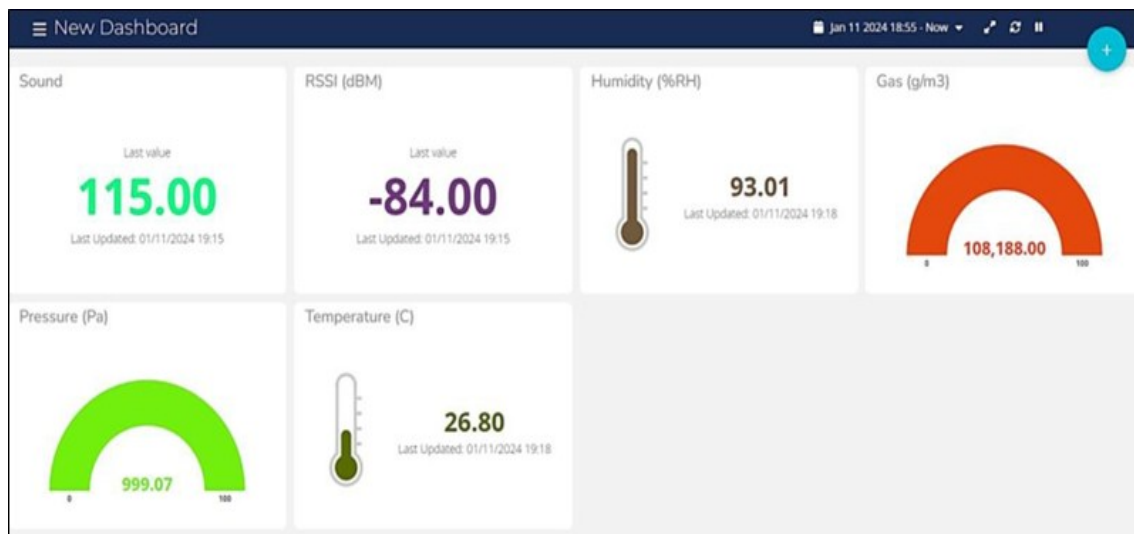


Figure 32. H. Itama (25 meters from LoRa gateway).

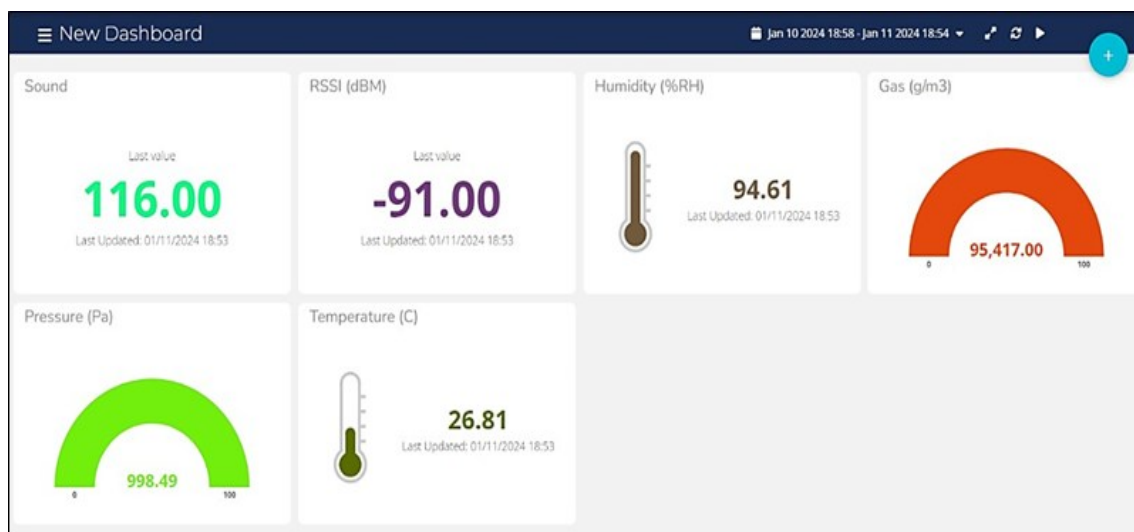


Figure 33. H. Itama (38 meters from LoRa gateway).

Data visualization using the Ubidots dashboard, portrayed in Figures 31 to 33, can be customized to represent it to the end user. All parameters transmitted using LoRa, which are temperature, humidity, gas resistance, pressure, sound levels, and RSSI value, are displayed in the dashboard. To access the dashboard, beekeepers must have Ubidots ID and password. Other than that, Ubidots also has a mobile app for Android and Apple users, named "Ubidots IoT," which is user-friendly and caters to the same information of data in Ubidots website dashboard, as shown in Figure 34.

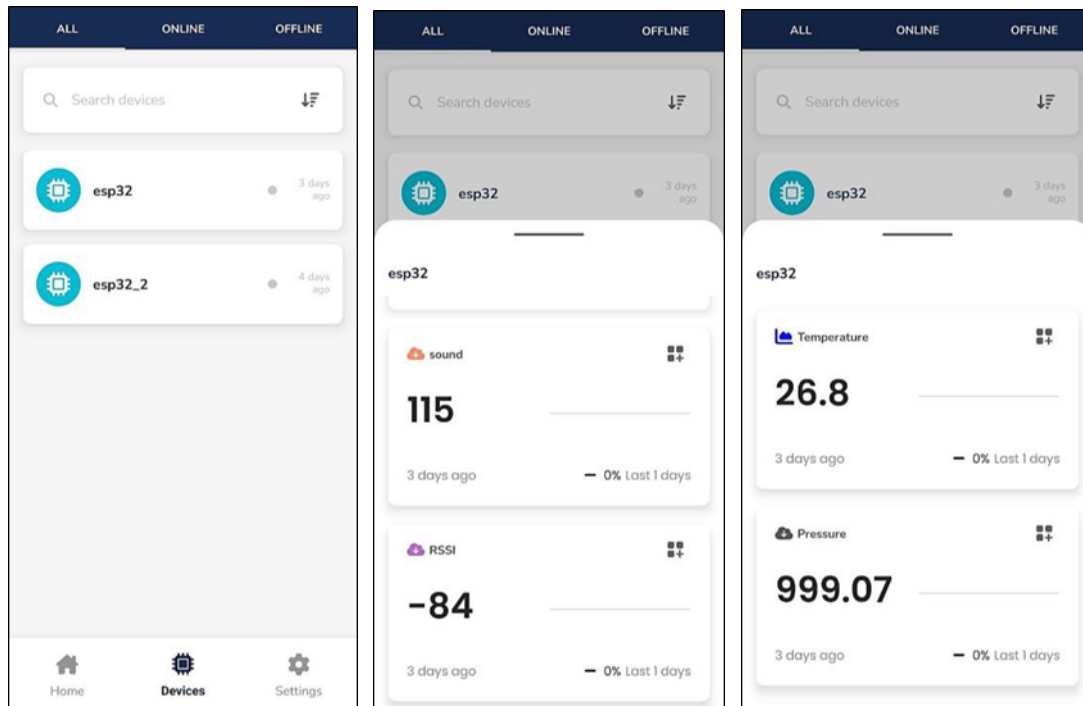


Figure 34. Ubidots IoT application.

The integration of LoRa IoT and the Ubidots platform in the system has demonstrated that remote monitoring of stingless beehives is feasible. The performance of LoRa in terms of RSSI is shown in Figure 25. The previous method [15] was unable to collect data such as temperature, humidity, and sound due to the lack of a WIFI connection in the Mahallah Ruqayyah Kelulut farm. Therefore, a comparison with the previous method is not possible.

5. CONCLUSION

In summary, this research successfully met its objective of developing a prototype for a remote stingless bee monitoring system, utilizing LoRa technology to monitor beehive conditions and establish reliable LoRa communication for data transmission in remote areas.

Compared to previous stingless bee monitoring systems using Arduino boards, this study employs the ESP32 microcontroller, which offers 4 MB of flash memory, significantly more than the Arduino Uno's 32 KB. Additionally, the ESP32 includes a built-in interface for USB, Wi-Fi, and Bluetooth, allowing seamless data uploads to the cloud via LoRa transmission. Upgrading from the DHT11 and DHT22 sensors to the BME680 sensor improves measurement accuracy, and the 4-in-1 sensor supports both I2C and SPI communication, making it compatible with the ESP32. New parameters like pressure and air quality monitoring further enhance this monitoring system.

The data collection approach involved using Node-Red and Ubidots, which offer a range of configuration options through MQTT, Serial Port, and HTTP protocols. Unlike other systems using Blynk and MySQL, Ubidots was selected for its user-friendly interface, offering data visualization on both the Ubidots website and its mobile application, "Ubidots IoT."

6. FUTURE WORKS

Enhancing real-world applications could involve improving the LoRa SX1278 module setup. This includes exploring different spreading factors to increase the range between sender and receiver nodes. Implementing LoRaMesh and LoRaWAN topologies could further expand the system's applicability. Additionally, parameters measured can be refined, and novel hive designs using materials like Styrofoam may replace traditional wood logs, promoting more accurate parameter measurements and advancing remote monitoring practices for beekeepers.

To further enhance the reliability and applicability of the system, additional data collection is necessary to accurately compute averages for temperature, pressure, and air quality. Expanding testing to diverse settings and collecting data over varied timeframes, hive setups, and environmental conditions will improve the system's generalizability. Incorporating statistical analyses, such as standard deviations and error margins, will validate the system's reliability. In addition, battery performance data will be collected. By understanding the energy requirements and battery life, the system can be optimized for remote deployments in isolated locations for a longer-term duration, such as one year. Upon longer-term data collection, a comparative analysis of the collected data against baseline values from traditional monitoring systems will be able to highlight the system's added value and its potential to provide more accurate and timely environmental insights.

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