Journal of Engineering Science and Technology
Vol. 20, No. 1 (2025) 50 - 66

ENHANCING SWIFTLET FARMHOUSE ENVIRONMENTAL MONITORING THROUGH IOT TECHNOLOGY: A CASE STUDY IN MENUMBOK, SABAH

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Abstract

This research focuses on the development and validation of an Internet of Things (IoT)-based system specifically tailored for environmental monitoring at the HN Swiftlet Farmhouse in Menumbok Sabah. The lack of effective monitoring systems in swiftlet farmhouses presents challenges in maintaining optimal conditions for swiftlet health and productivity. To address this, the study implements IoT technology for real-time data collection and analysis, aiming to sustain optimal breeding conditions. The system integrates a NodeMCU ESP 32 board with a DHT11 sensor to monitor temperature and humidity, providing timely notifications and facilitating automated control procedures. Over a nine-day observation period, temperatures ranged from 31.23 °C to 33.33 °C, and humidity levels ranged from 59.63% to 77.38%, with fluctuations influenced by monsoon activity. The findings indicate that the IoT-based system effectively assists swiftlet farmers in maintaining optimal environmental conditions, thereby enhancing swiftlet health and productivity. The research demonstrates that the implementation of IoT technology in swiftlet farmhouses significantly enhances environmental monitoring, leading to improved swiftlet health, increased productivity, and overall sustainability in swiftlet farming practices.

Keywords: Edible bird nest, Internet of things, Modern agriculture, Swiftlet farmhouse.

1. Introduction

The Swiftlets, small birds known for their unique ability to produce nests from their saliva, have long been integral to the cultural and economic landscape of Southeast Asia, particularly in Malaysia [1]. Swiftlet farming, the practice of cultivating swiftlets for their nests, has emerged as a lucrative industry in recent years, driven by the high demand for edible bird nest (EBN) prized for their purported health benefits [2, 3].

To meet this demand, swiftlet farmers have established specialized facilities known as swiftlet farmhouses, where swiftlets are provided with ideal conditions for nesting and breeding. These farmhouses, often located in rural areas, are equipped with artificial nesting structures and environmental controls to mimic the natural habitats of swiftlets, fostering optimal conditions for nest production.

In Malaysia, the swiftlet farming industry has experienced significant growth, with thousands of swiftlet farmhouses scattered across the country. These farmhouses vary in scale, from small-scale operations managed by individual farmers to large-scale commercial facilities run by corporations [4-6]. In particular, states such as Perak, Penang, Selangor, and Sarawak are known to have a high concentration of swiftlet farmhouse [7-11].

Perak, located in the west coast of Peninsular Malaysia, boasts a significant number of swiftlet farmhouses, particularly in urban areas like Ipoh and Taiping. Penang, an island state known for its bustling city of George Town, also has numerous swiftlet farmhouses scattered across its urban and rural landscapes. Similarly, Selangor, Malaysia's most populous state and home to the capital city of Kuala Lumpur, hosts a considerable number of swiftlet farmhouses, with clusters found in districts such as Klang and Petaling.

In East Malaysia, the state of Sarawak, known for its rich biodiversity and diverse ecosystems, is another prominent hub for swiftlet farming, with farmhouses established in cities like Kuching and Miri. While these states stand out as key regions for swiftlet farming activity, swiftlet farmhouses can be found in varying numbers across other states in Malaysia, highlighting the widespread nature of the industry nationwide.

However, despite the economic promise of swiftlet farming, the industry faces challenges related to environmental management within farmhouses [12, 13]. One of the key issues is the lack of comprehensive monitoring systems to assess and regulate environmental parameters crucial for swiftlet health and productivity. Swiftlets are extremely sensitive to environmental factors such as temperature, humidity, and air quality, which can significantly impact their nesting behaviour and reproductive success. Without proper monitoring, swiftlet farmhouses risk suboptimal conditions that may lead to decreased nest production and compromised bird welfare.

Therefore, there is a pressing need for the implementation of advanced environmental monitoring systems in swiftlet farmhouses to ensure optimal conditions for swiftlet breeding and nest production. By leveraging technologies such as the Internet of Things (IoT), which enables real-time data collection and analysis, swiftlet farmers can gain valuable insights into environmental conditions within their facilities [14, 15]. These insights can inform proactive management strategies to mitigate potential risks and optimize productivity. Addressing this need for environmental monitoring represents a critical step towards sustaining the growth and viability of the swiftlet farming industry in Malaysia.

IoT finds diverse applications in agriculture which including precision farming, livestock management, and greenhouse operation that had been categorized under distinct monitoring domains [16, 17]. These applications rely on IoT-based sensors or devices within wireless sensor networks (WSNs) for facilitating data collection for farmers.

Ibrahim et al. had conducted a study at a swiftlet farmhouse in Terengganu, highlighting that optimal conditions involving temperature, humidity, luminance, and oxygen can augment the yield of edible bird nests [18]. The researchers utilized wireless sensor networks such as LoRaWan and video analytics techniques to emulate a favourable habitat within the artificial birdhouse. A high-density infrared camera also was installed in each of the Swiftlet house to capture the picture at an interval of one minute at Network Video Recorder. The picture plus an intrusion algorithm is used to count the number of birds entering or leaving the bird house which were done through Network Unique Counter.

The data will be sent to the server and users that can be access through their Android-based smart phones or computers. Wireless sensors also were deployed within the birdhouses to amass data on humidity, temperature, and oxygen levels. This combined dataset, in conjunction with bird entry and exit counts, was employed to simulate an ideal internal environment within the birdhouse.

Besides, Azizan et al. had devised an IoT system utilizing the WeMos-D1 microcontroller for swiftlet monitoring [19]. This project used AM2302 Digital Humidity Temperature DHT22 sensor with an analogue to digital converter is connected to the WeMos-D1 MCU. The DHT22 sensor are made of two parts which are capacitive humidity sensor and thermistor. In addition, the WeMos-D1 microcontroller unit (MCU) used that is an Arduino based MCU with an ESP8266-12 chip which can enables WIFI connectivity within the same MCU board.

This technology also facilitated the real-time and remote collection of temperature and humidity data from a swiftlet farmhouse located in Rawang, Selangor. The resultant system enabled the automatic sensing and continuous monitoring of crucial parameters, with data accessibility through a dedicated website although the controlling of humidifier that implemented was not reported and there is no comparison on the productivity of EBN.

A microcontroller based environmental control for swiftlet nesting with SMS notification also had been developed by Tristanto and Uranus [20]. Although the project does not used IoT, this project is able to compare the sensor readout with the commercial comparing equipment and able to scaling a miniature model to a realistic nesting house by proposing a volume scaling ruled to indicate the required water to be fogged in the realistic and miniature model.

Other studies give greater attention to subjects within the realm of social science, such as suitable ranching practices in successful edible bird nest swiftlet houses in Terengganu by Rahman et al. [21] and the impact of swiftlet farming house on local communities by Md. Yassin et al. [12]. The survey and interviews conducted for the research were with 246 EBN operators namely 82 operators in coastal, rural, and urban areas in Terengganu respectively that are registered with the Terengganu Department of Veterinary Services in 6 months from March 2016 until August 2016.

It mainly discusses on the data which are related to types of EBN swiftlet houses, ranching system, cleaning and maintenance programmes, guano disposal method, odour program and the most important knowledge on signs of disease that are common in EBN swiftlets.

The two major impacts of swiftlet farmhouse on the communities in the study area are noise pollution and disturbance of the city appearance while other effects like air pollution, health potential diseases and security issue are less likely to be affected by the communities. Most respondents agreed that SFH produced problem of noise pollution and made disturbance on the city appearance which it was due to the swiftlet tweeters sound system installed on SFH premises to attract swiftlets.

In this study, we concentrate on enhancing the environmental monitoring capabilities of swiftlet farmhouses through an advanced IoT-based system. While previous research has explored various challenges associated with swiftlet farming, such as noise pollution and urban aesthetic concerns, our focus is on technological solutions that can directly improve swiftlet health and productivity. Our research expands on the functionality of current systems by incorporating a NodeMCU ESP 32 board with DHT11 sensors. This integration enables more precise and uninterrupted monitoring of crucial environmental variables, including temperature and humidity.

Moreover, the utilization of the Blynk platform for data visualization and immediate alarm alerts greatly improves user engagement, allowing swiftlet growers to remotely observe and modify conditions, as necessary. This upgraded approach not only overcomes the constraints of previous models but also offers a more resilient and user-friendly solution, resulting in enhanced management of swiftlet habitats and eventually boosting production and bird's well-being.

2. Methods

The integration of IoT with humidity and temperature monitoring has ushered in a new era of data-driven insights and remote sensing capabilities. This project delves into the development and implementation of an IoT-based system aimed at monitoring humidity and temperature sensitivity in diverse settings.

The primary objective of this research methodology is to develop and validate an IoT-enabled solution for humidity and temperature monitoring located in HN Swiftlet Farmhouse, Menumbok, Sabah, as shown in Fig. 1. The proposed system will leverage high-tech sensors and communication protocols to ensure accurate and timely data acquisition. The collected data will then be processed and analysed using data analytics techniques, yielding actionable insights for decision-makers and farmers.

To build an effective swiftlet farmhouse, the most important parameters to consider are temperature and humidity in designing the structure [22, 23]. The absence of ventilation holes and water containers in swiftlet farmhouses has been identified as the primary issue regarding differences in the production of edible bird nests between swiftlet houses. This is because the absence of these structures affects the average air temperature and humidity within the swiftlet farmhouse.

The optimal temperature for a swiftlet habitat ranges from 22 °C to 25 °C. If temperature readings fall below 22 °C, it can lead to the death of young swiftlets, while temperatures exceeding 25 °C discourage nesting in manufactured structures. Additionally,, the suitable humidity range for swiftlet birds is between 80% and 90%. Low humidity environments can affect the nest's adhesion to wall surfaces, while high humidity levels promote fungal growth within the nests, resulting in nests covered with fungus. Both decreased and increased levels of these parameters lead to sluggish productivity and compromised quality of the edible bird nests.

Fig. 1. HN Swiftlet farmhouse Menumbok, Sabah.

2.1. Block diagram project

The block diagram outlines an IoT-based system for real-time humidity and temperature monitoring is illustrated in Fig. 2. Humidity and temperature sensors interface (DHT11), paired with the NodeMCU ESP 32 microcontroller, which serves as the core processing unit for data collection and transmission. These components work together to provide real-time environmental data essential for maintaining optimal conditions within the swiftlet farmhouse. The real time data of temperature and humidity will display on the LCD display.

Then, an IoT Gateway, which transmits data to Blynk platform using communication protocols like Wi-Fi. The Cloud platform will be processing the data through advanced analytics and providing valuable insights for temperature and humidity data. A user Interface using Blynk applications will allows users to visualize trends and receive real-time alerts. This block diagram provides a functional view of a system and can be used to easily illustrate the essential components of a software design or engineering system, as well as the flow of data in a process flowchart.

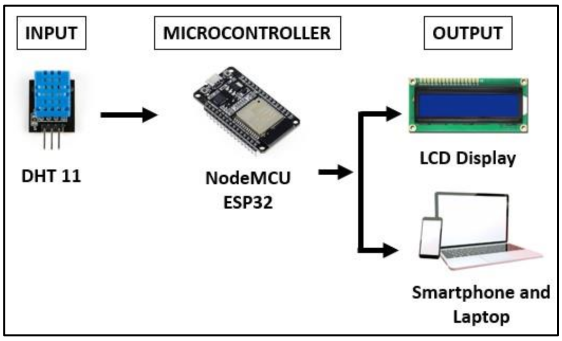

Fig. 2. Block diagram.

2.2. System design and features overview

The system design for monitoring the environment within the HN Swiftlet Farmhouse in Menumbok Sabah integrates several key components to ensure real-time data collection and analysis of temperature and humidity levels. At the heart of the system is the NodeMCU ESP 32 microcontroller, which serves as the central processing unit, coordinating data flow from the sensors to the cloud-based platform.

The DHT11 sensor plays a crucial role in this setup by continuously monitoring the temperature and humidity within the farmhouse. This sensor provides accurate and reliable readings, which are essential for maintaining the optimal conditions required for swiftlet breeding. The sensor data is transmitted via Wi-Fi to the Blynk platform, which serves as the cloud-based interface for data storage, analysis, and user interaction.

The system's functionality is further illustrated by the flowchart as shown in Fig. 3, which outlines the process from data collection to user notification. When the sensor detects changes in the environmental parameters, the data is immediately sent to the Blynk platform. This platform not only stores the data but also enables users to access real-time updates and historical trends through a user-friendly dashboard. By integrating these features within a cohesive system design, the IoT-based solution effectively supports swiftlet farmers in monitoring and managing the environmental conditions within their farmhouses. This approach ensures that the swiftlets' habitat remains conducive to breeding, thereby enhancing productivity and sustainability.

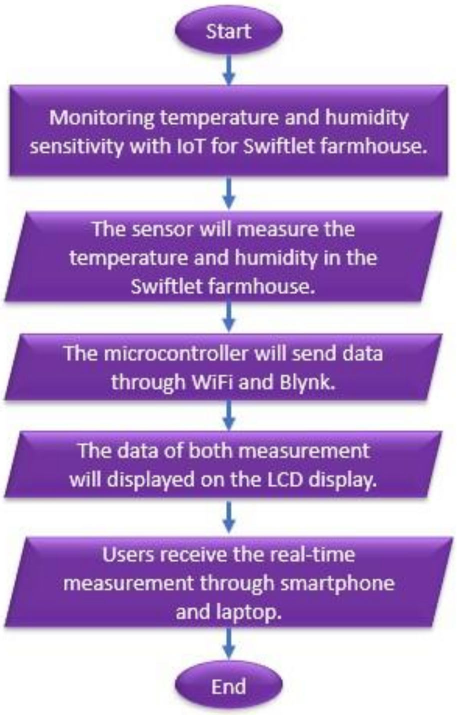

Fig. 3. System flowchart.

2.3. Hardware installation

Figure 4 is the IoT box, has been installed within the HN swiftlet farmhouse, and its performance has been validated through the collection and analysis of environmental data. The completed packaging of the IoT box, which houses all the components outlined in the earlier block diagram (as shown in Fig. 2). This packaging integrates the DHT11 sensor and NodeMCU ESP 32 microcontroller, along with other essential components, into a compact, functional unit. The design ensures that all parts are securely enclosed while still allowing efficient data collection and transmission.

A 5V 3A power supply with 3 pin sockets also had utilized to power the components, ensuring stable and reliable operation of the system. The Printed Board Circuit (PCB) serves as the project component board, facilitating the connection and organization of the various hardware components. Lastly, an LCD screen is incorporated to display live temperature, humidity, and water level values, providing swiftlet farmers with real-time insights into environmental conditions within the farmhouse.

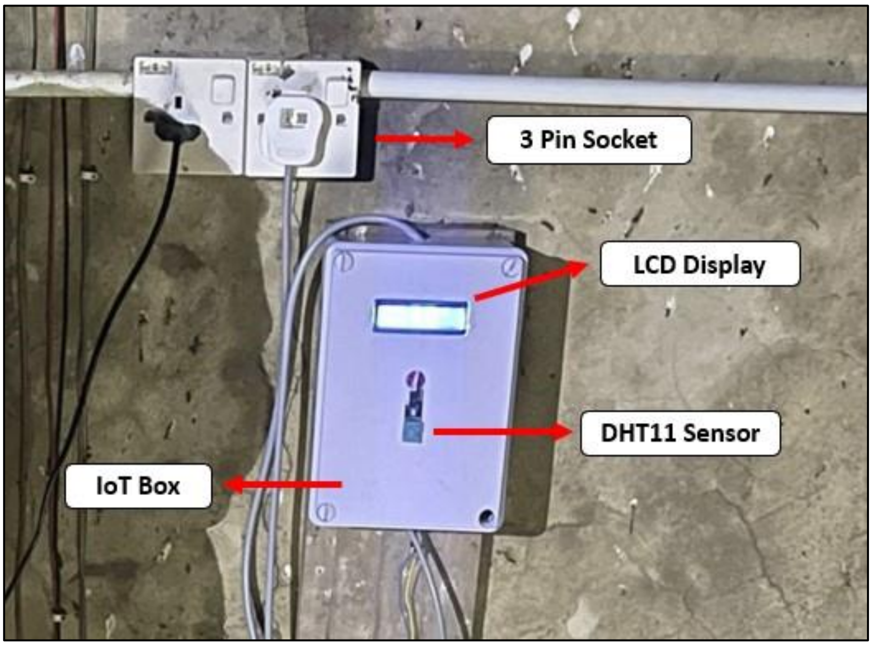

Fig. 4. Device installation in the Swiftlet farmhouse.

2.4. Software applications

Figures 5 and 6 show the web and mobile dashboard of Blynk applications for monitoring and collecting real-time data from sensor. Real-time monitoring system that can monitor the temperature and humidity levels in the swiftlet farmhouse in real-time through a user-friendly dashboard accessible from any device with an internet connection. The mobile application also used to collect data that can be analysed to identify trends, patterns, and potential correlations between environmental conditions and swiftlet behaviour.

This information can help in optimizing the environment to enhance swiftlet nesting and productivity. Besides, the system will send alerts and notifications to your designated devices if the temperature or humidity goes beyond the predefined thresholds. This feature allows user to take immediate action and prevent any adverse effects on the swiftlets.

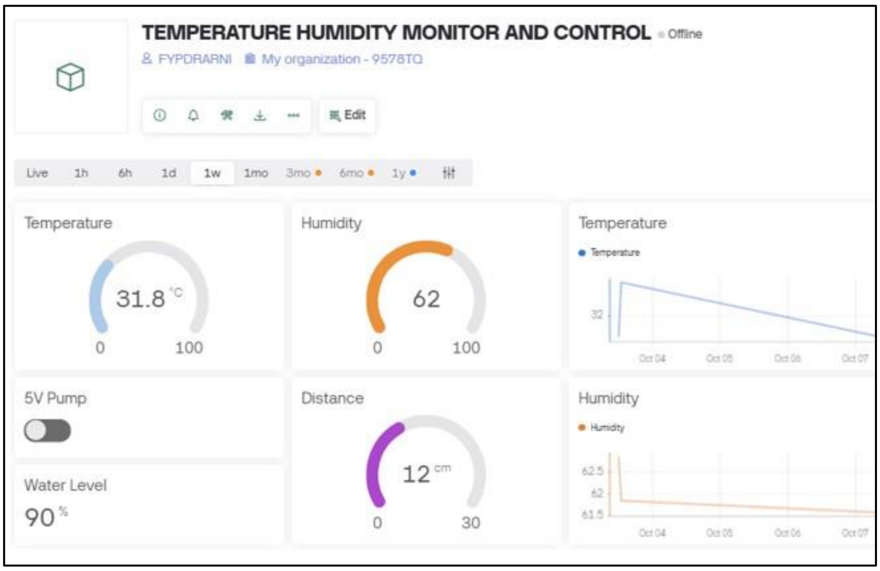

Fig. 5. Blynk web dashboard.

The Blynk application dashboard described above encompasses several key features aimed at providing users with comprehensive access to real-time sensor data. Users of the application can seamlessly monitor live temperature and humidity sensitivity readings through various display styles, including Number Display, Gauge View, Super Chart View (which presents live readings), and access to historical data spanning up to one month.

This multi-faceted approach to data visualization enables users to observe and analyse environmental conditions within the swiftlet farmhouse with precision and flexibility, facilitating informed decision-making and proactive management strategies. Whether tracking current conditions or delving into past trends, the Blynk application dashboard offers a user-friendly interface that empowers users to effectively monitor and optimize the swiftlet breeding environment for optimal productivity and bird welfare.

Data storage through cloud using Blynk platform have been used so that historical data storage also allows user to review past trends and making informed decisions based on long-term environmental patterns which can also be beneficial for auditing or reporting purposes. The ability to remotely monitor and receive timely alerts can prevent potential damages or losses due to unfavourable environmental conditions. This proactive approach can save resources and reduce the risk of financial setbacks.

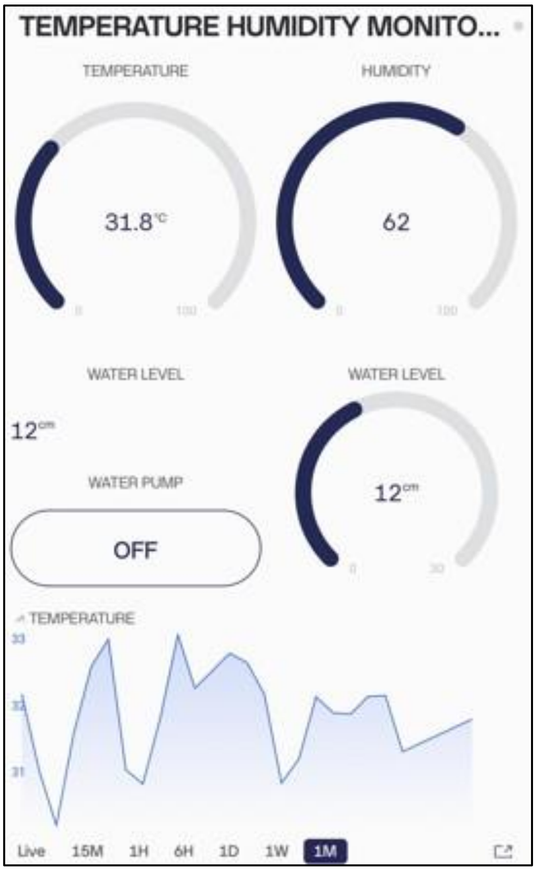

Fig. 6. Blynk mobile dashboard.

3. Results and Discussion

The results and discussion section explain the outcomes of the IoT-based project, centred on the development of a comprehensive monitoring system designed specifically for tracking temperature and humidity sensitivity within a swiftlet farmhouse.

3.1. Temperature analysis

The analysis of temperature data, as shown in Figs. 7 and 8, provides a comprehensive examination of the performance of both the capacitive temperature sensor and the DHT11 sensor over a 9-day period during the installation of the monitoring system within the swiftlet farmhouse in Menumbok, Sabah. The initial test results confirm the proper functioning of the sensors under varying environmental conditions.

Figure 7 presents temperature readings ranging from a minimum of 30.8 °C to a maximum of 34.2 °C throughout the testing period, offering valuable insights into the temperature levels within the farmhouse, especially during periods when the swiftlet birds were either inside or outside the structure. The 9-day monitoring period spanned from January 1, 2024, to January 9, 2024, with Fig. 8 specifically illustrating the temperature variations observed on January 1, 2024.

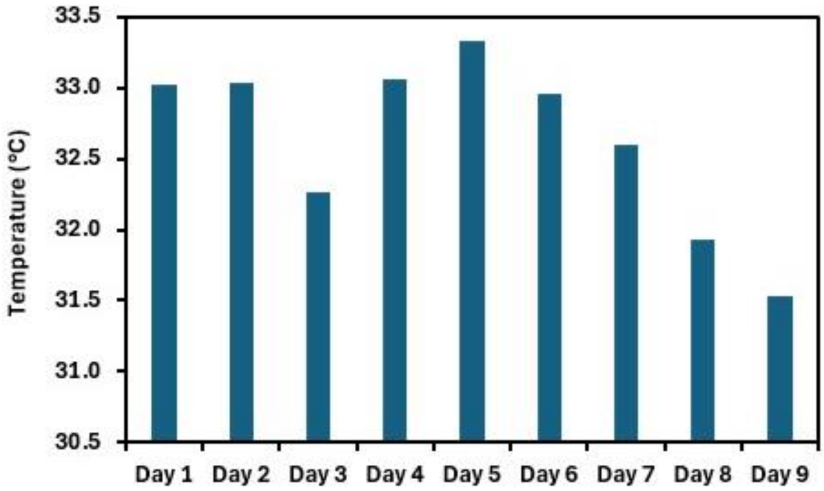

Fig. 7. Temperature of Swiftlet farmhouse for 9 days.

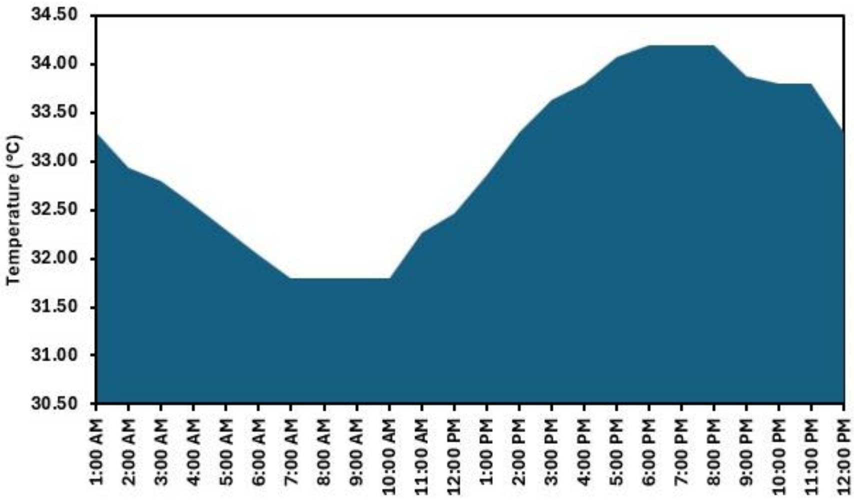

Fig. 8. Temperature of Swiftlet farmhouse for a day.

Interestingly, the lowest recorded temperature value of 30.8 °C often occurred after midnight and towards sunrise, coinciding with the period when swiftlet birds are typically inside the farmhouse engaged in nest production. While literature suggests that the optimal temperature for swiftlet habitat ranges from 22 °C to 25 °C, the specific location of the farmhouse must also be taken into consideration, as some may be situated in open areas or near the sea [22]. According to the HN Swiftlets farmers in Menumbok, Sabah, the selection of the farmhouse location was influenced by the presence of swiftlet calls in the area, serving as an indicator of potential swiftlet populations.

Crucially, the testing was conducted with the equipment directly exposed to cave-like environmental elements, including high humidity and low light conditions. This real-world exposure led to significant variations in data readings due to ambient circumstances. Factors such as bird droppings, for instance, may have influenced temperature readings, while external elements such as rain and wind could have impacted humidity levels inside the swiftlet farmhouse. The presence of these environmental factors highlights the necessity for strong monitoring systems that can precisely collect and analyse data in ever-changing and difficult conditions. This will improve the efficiency of swiftlet farming methods and guarantee ideal conditions for the health and productivity of swiftlets.

3.2. Humidity analysis

The examination of humidity data, as depicted in Figs. 9 and 10, within the swiftlet farmhouse environment in Menumbok, Sabah, provides valuable insights over both a one-day period (1 January 2024) and a nine-day period (1-9 January 2024). A meticulous analysis of seasonal humidity trends unveils significant observations, correlating variations with seasonal changes and emphasizing their potential impact on swiftlet comfort and body temperature regulation. Through this analysis, optimal humidity ranges are identified and deviations scrutinized, leading to discussions on their consequences for swiftlet health.

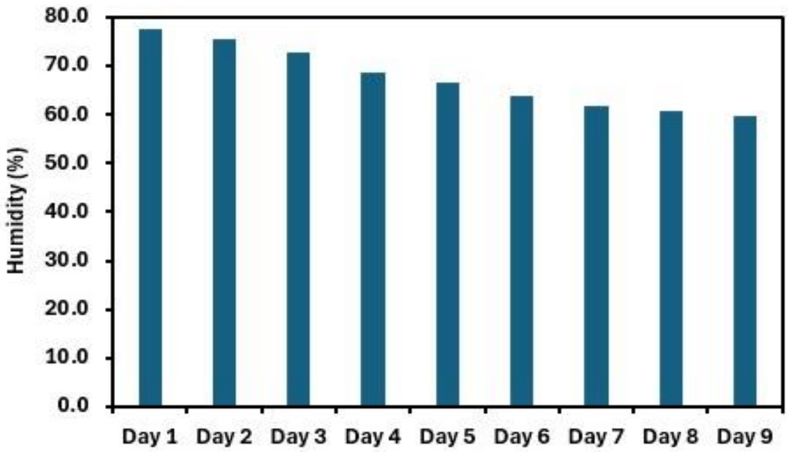

Fig. 9. Humidity of Swiftlet farmhouse for 9 days.

Notably, high humidity levels are recognized for their potential to induce discomfort and increase susceptibility to diseases, while low humidity levels can adversely affect eggshell quality. Moreover, daily humidity variations have been explored, revealing correlations with swiftlet behaviour and suggesting the need for adjustments in farm management practices to accommodate preferences at different times of the day. The recorded minimum humidity value of 59.63% and maximum value of 75.37% highlight the dynamic nature of environmental conditions within the swiftlet farmhouse area.

Understanding and interpreting these fluctuations are crucial for optimizing farming strategies and ensuring the well-being of swiftlets. Additionally, these findings underscore the resilience of the DHT11 sensors in capturing real-time data, serving as a valuable tool for swiftlet farmers in monitoring and managing farmhouse conditions effectively. As such, these insights contribute to the enhancement of swiftlet farming practices, promoting the creation of optimal environments conducive to swiftlet health and productivity.

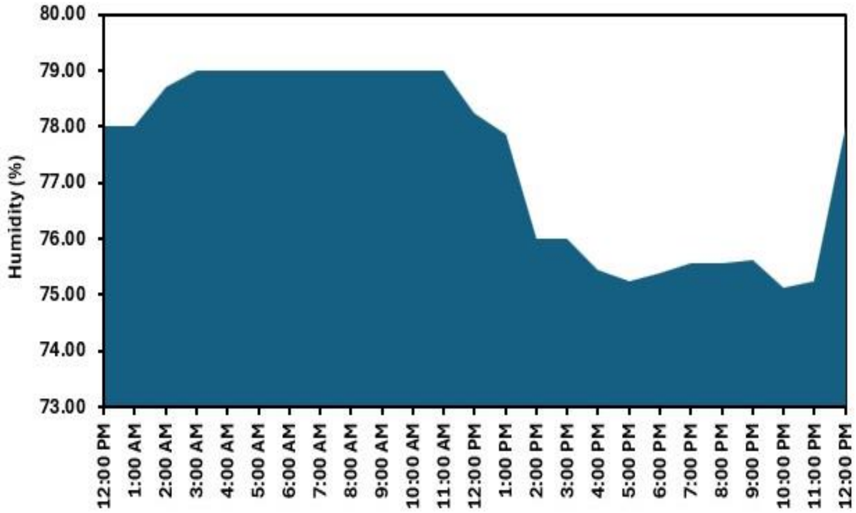

Fig. 10. Humidity of Swiftlet farmhouse for a day.

3.3. Data analysis and implications for swiftlet farming

The analysis of temperature and humidity data presented in Table 1 offers valuable insights into the prevailing climatic conditions within the swiftlet farmhouse environment in Menumbok, Sabah, particularly considering the influence of monsoon seasons and weather patterns during the testing period.

Table 1. Temperature and humidity measurements data.

Day	Date	Temperature (°C)	Humidity (%)
Day 1	1/1/2024	33.03	77.38
Day 2	2/1/2024	33.04	75.37
Day 3	3/1/2024	32.27	72.65
Day 4	4/1/2024	33.07	68.69
Day 5	5/1/2024	33.33	66.63
Day 6	6/1/2024	32.95	63.74
Day 7	7/1/2024	32.59	61.84
Day 8	8/1/2024	31.23	60.84
Day 9	9/1/2024	31.54	59.63

Over the sequence of nine days, the average temperature ranged from 31.23 °C on Day 8 to 33.33 °C on Day 5, indicating a relatively consistent warm environment throughout the observation period. These temperature values align with the expected tropical conditions for the region. However, it's important to note that Sabah experiences distinct monsoon seasons, with the southwest monsoon typically occurring from May to September and the northeast monsoon from November to March. Therefore, the observed temperatures may reflect variations associated with these monsoon patterns, with the testing period potentially coinciding with either monsoon season.

Similarly, the average humidity levels ranged from 59.63% on Day 9 to 77.38% on Day 1, with notable fluctuations throughout the testing period. The observed decrease in humidity from Day 1 to Day 9 can be attributed to the gradual reduction in monsoon activity, which typically brings higher humidity levels. This reduction in humidity could potentially impact the swiftlets by creating a drier environment, less conducive to stable nest formation, which could affect the health and productivity of the birds.

Furthermore, an inverse relationship between humidity and temperature for each day is evident from the table, where higher temperatures correspond to lower humidity readings and vice versa. This observation is consistent with meteorological principles, as warm air has the capacity to hold more moisture, resulting in lower relative humidity. Understanding the influence of monsoon seasons and weather patterns on temperature and humidity fluctuations is crucial for swiftlet farmers, as it allows them to anticipate and adapt to changes in environmental conditions. By considering these factors alongside temperature and humidity data, swiftlet farmers can implement targeted interventions to maintain optimal conditions within the farmhouse environment, thereby ensuring the continued health and productivity of their swiftlet populations.

Table 2 presents temperature and humidity data from existing studies conducted in various locations across Malaysia including the various tools and technologies used for the measurement. The data captured provides valuable insights into the environmental conditions within swiftlet farmhouses in different regions of the country. In Pontian, Johor, data loggers were utilized to monitor temperature and humidity, with recorded values ranging from 33.03 °C to 33.04 °C for temperature and 75.37% to 77.38% for humidity. These readings indicate relatively consistent temperature levels and moderate to high humidity levels, which are conducive to swiftlet breeding activities and nest production.

Similarly, in Rawang, Selangor, temperature and humidity data were collected using a DHT11 sensor, revealing average values of 32.27 °C for temperature and 72.65% for humidity. These readings are comparable to those observed in Johor, suggesting consistent environmental conditions conducive to swiftlet breeding. In Terengganu, multiple studies utilized different monitoring devices to assess temperature and humidity levels. Data loggers and sensor nodes recorded temperatures ranging from 33.07 °C to 33.33 °C and humidity levels ranging from 66.63% to 68.69%. These readings indicate slightly higher temperatures compared to other regions, likely influenced by the coastal location and tropical climate of Terengganu.

In Sarawak, temperature and humidity data were collected using a BME280 sensor, with recorded values of 32.95 °C for temperature and 63.74% for humidity. These readings suggest slightly lower humidity levels compared to other regions, which may be attributed to the inland location and forested surroundings of Kota Samarahan. Finally, in Menumbok, Sabah, the present study utilized a DHT11 sensor to monitor temperature and humidity, yielding average values of 32.59 °C for temperature and 61.84% for humidity. These readings align with the tropical climate of Sabah and indicate optimal environmental conditions for swiftlet breeding activities.

Table 2. Temperature and humidity data from existing studies in Malaysia.

Ref.	**Measurement Tools**	**Temperature (°C)**	**Humidity (%)**	**Location**
[23]	Temperature and Humidity Data Logger	33.03	77.38	*Pontian, Johor*
[23]	Temperature and Humidity Data Logger	33.04	75.37	*Pontian, Johor*
[19]	DHT 11	32.27	72.65	*Rawang, Selangor*
[22]	Data Logger, Thermometer (TES1315), Thermal hygrometer (ATM, HT-92130)	33.07	68.69	*Kuala Terengganu, Marang, Setiu, Besut, Dungun, Kemaman and Kuala Berang, Terengganu*
[18]	Sensor Node	33.33	66.63	*Terengganu*
[24]	BME280 sensor	32.95	63.74	*Kota Samarahan, Sarawak*
This Work	DHT 11	32.59	61.84	*Menumbok, Sabah*

This variability is evident in the recorded values from Pontian, Johor, Rawang, Selangor, Terengganu, Sarawak, and Menumbok, Sabah. While temperature readings generally fall within a similar range across these regions, ranging from approximately 32 °C to 33.5 °C, there are notable differences in humidity levels, which range from around 61.84% to 77.38%.

Understanding the variability in temperature and humidity levels is critical for swiftlet farmers, as it enables them to adapt their management practices to suit the specific environmental conditions of their region. For example, regions with higher humidity levels may require additional ventilation or humidity control measures to prevent mold growth and ensure optimal conditions for swiftlet breeding. Conversely, regions with lower humidity levels may require strategies to increase humidity to maintain ideal nesting conditions.

Meanwhile for the tools of measurement, data loggers equipped with temperature and humidity sensors were commonly used, providing accurate and continuous measurements over time. Additionally, the DHT11 sensor, a popular choice for its affordability and reliability, was employed in some studies to collect temperature and humidity data. Other studies utilized a combination of tools, including data loggers, thermometers, and thermal hygrometers, to capture comprehensive environmental data.

Furthermore, sensor nodes and advanced sensors like the BME280 were utilized to monitor temperature and humidity in specific locations. Each tool has its advantages and limitations, influencing factors such as measurement accuracy, data granularity, and cost-effectiveness. Despite these differences, the collective findings contribute to our understanding of environmental conditions in various regions of Malaysia and underscore the importance of employing suitable measurement tools tailored to specific research objectives and environmental contexts.

IoT sensors can be strategically deployed throughout the farmhouse to monitor temperature, humidity, and other environmental factors continuously. These sensors provide accurate and timely data, allowing farmers to detect deviations from optimal conditions and take corrective actions promptly. Additionally, data analytics platforms enable farmers to analyse historical data trends, identify patterns, and make informed decisions to enhance farming practices further. Furthermore, integrating IoT monitoring systems with automated alerts can provide swiftlet farmers with real-time notifications of any environmental anomalies or emergencies. This proactive approach allows farmers to respond swiftly to potential threats, minimizing risks to swiftlet health and nest production.

4. Conclusion

In conclusion, the monitoring system project aimed at assessing temperature and humidity within the HN Swiftlet farmhouse environment in Menumbok, Sabah, has provided invaluable insights for optimizing farm management practices. This IoT system has been successfully developed and validated as an IoT-based system for real-time monitoring of temperature and humidity in the HN Swiftlet Farmhouse in Menumbok, Sabah. The system, utilizing a NodeMCU ESP 32 board and DHT11 sensor, provided accurate and timely data, ensuring optimal environmental conditions crucial for swiftlet health and productivity.

Over a nine-day observation period, the system demonstrated its effectiveness by maintaining temperatures between 31.23 °C and 33.33 °C and humidity levels between 59.63% and 77.38%, influenced by monsoon activity. These findings highlight the system's potential to significantly enhance swiftlet farming practices, contributing to the sustainability and success of the industry by enabling precise environmental control and proactive management.

Acknowledgement

The authors would like to thank the Universiti Teknologi MARA for funding this research work under Geran Penyelidikan Inovasi Sosial (GIS) grant number 600-RMC/GIS 5/3 (002/2023).

Abbreviations

EBN	Edible bird nest
IoT	Internet of Things
MCU	Microcontroller unit
WSN	Wireless sensor networks

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