Design, Deployment, and Validation of a Low-Cost IoT Platform based on LoRa for Precision Dairy Farming

Guilherme P. Piedade, Samuel B. Mafra, Danilo M. de Oliveira and Mateus R. da Cruz

Abstract— **Precision farming has become essential for increasing food production in the previously used cultivation area. Therefore, animal health monitoring and estrus detection are essential to increase dairy farming production. Wireless Sensor Networks play an important role in replacing manual methods impractical for large herds, and they can be used to collect a large amount of data in real-time. Furthermore, long-range transmission techniques can be used on large farms. This paper proposes applying and validating a Wireless Sensor Network integrated with a database and long-range communications techniques capable of monitoring the dairy herd, generating health, estrus, and theft alerts. The results achieved by integrating system elements, such as the LoRa gateway, MongoDB database and dashboard, demonstrate the viability of the proposed WSN.**

Keywords— **Dairy Farming, Internet of Things, LoRa Network, Wireless Sensors Network.**

I. INTRODUCTION

The idea of precision dairy farming goes towards meeting all other innovative concepts in the intelligent development of a country, which makes use of technology for the benefit of its population. The demand for dairy products is growing exponentially due to exponential population growth. The number of people consuming dairy foods is estimated to increase from 1.9 billion in 2010 to 4.8 billion in 2030 [1].

Animal health monitoring and accurate estrus detection are crucial to improving milk production and reproductive efficiency in the dairy and beef industry. Dairy farms need to accurately track the fertility period of cows and complete the mating or artificial insemination process during the short period of estrus. Traditional methods of estrus detection include visual observation, rectal palpation, vaginal measurements [2], tail painting [3], etc. However, manual detection methods often misdiagnose the period of estrus, which leads to a decrease in the pregnancy rate, losses with artificial insemination at the wrong time and a reduction in milk production. Some solutions try to solve the problem of failure to identify estrus by injecting hormones to induce it. This costly solution is harmful to milk quality and dairy cows. There are several technologies available on the market that help with this task, such as activity sensors, cervical mucus detection systems and motion detection devices. With the advent of Internet of Things (IoT) technology on a large scale, applications have recently been developed and introduced in agriculture. IoT solutions are being proposed for greenhouses, livestock and crop monitoring. These applications use Wireless Sensor Networks (WSN) to connect devices and exchange data in real-time [4].

According to IoT characteristics, the main challenges in application development are to minimize energy consumption and maximize network coverage [5]. For communication with wide coverage in rural areas, Long Range (LoRa) has been proposed as an ideal solution. LoRa is a radio frequency technology that offers long-range communication, low power consumption and flexibility. These features are essential for agricultural IoT applications and enable area coverage with low power consumption and hardware cost.

With the advancement of technologies aimed at the IoT market, several devices have been developed in recent years, which meet the necessary characteristics for field implementations. For example, the ESP32, Arduino and Raspberry Pi are rapid prototyping platforms [6]. These boards support several technologies such as LoRa, Computer Vision (CV) and Machine Learning (ML). This paper proposes a WSN using LoRa nodes for data collection, LoRa gateway for transmitting the collected data to the monitoring system and database for storing the collected data. The development of this project aims to reduce hours of manual labor, costs with artificial insemination and increase milk production capacity, especially to meet the demand for agribusiness in Brazil, which in addition to demand telecommunications network coverage on farms with large areas of pasture, faces the problem of herd theft.

The rest of this paper is organized as follows. Section II presents a brief review of the literature and some technologies used in IoT solutions for agriculture and livestock. Section III describes the proposed IoT application architecture and presents a detailed workflow of each developed block. Section IV presents and analyzes the results. Finally, Section V

Guilherme Pires Piedade, Instituto Nacional de Telecomunicações, Santa Rita do Sapucaí-MG, e-mail: guilherme.pires@mtel.inatel.br; Samuel Baraldi Mafra, Instituto Nacional de Telecomunicações, Santa Rita do Sapucaí-MG, e-mail: samuelbmafra@inatel.br; Danilo Machado de Oliveira, Instituto Nacional de Telecomunicações, Santa Rita do Sapucaí-MG, e-mail: danilomachado@mtel.inatel.br; Mateus Raimundo da Cruz, Instituto Nacional de Telecomunicações, Santa Rita do Sapucaí-MG, e-mail: mateusraimundo@mtel.inatel.br. This work is partially supported RNP, with resources from MCTIC, Grant No. 01245.020548/2021-07, under the Brazil 6G project of the Radiocommunication Reference Center (Centro de Referência em Radiocomunicações - CRR) of the National Institute of Telecommunications (Instituto Nacional de Telecomunicações - Inatel), Brazil, Huawei, under the project Advanced Academic Education in Telecommunications Networks and Systems, contract No PPA6001BRA23032110257684, Brazil, the National Council for Scientific and Technological Development-CNPq (403827/2021-3), FAPESP (2021/06946-0),and by Minas Gerais State Agency for Research and Development (FAPEMIG) via Grant No. TEC - APQ-03283-17

TABLE I: Comparison of different sensors and applications.

Way of wearing sensor			
	Neck collar	**Ear tag**	**Pedometer**
Applications	Activity Estrus	Activity Body temperature	Activity Step counter
Advantages	Captures the most data	Use of the identification earring present	Identifying changes in the movement pattern
Disadvantages	No precision in body temperature	Big noise in the activity data	No rumination and feeding data

concludes the paper and suggests future work.

II. Related Work

Research on IoT use in agricultural applications leads to different approaches to collecting and processing data. Where most applications aim to increase production efficiency, product quality, sustainability, cost reduction and environmental impacts caused by some processes in agriculture [7].

With the technological advancement in image processing, video monitoring systems have been developed for estrus detection [8]. However, this type of monitoring makes deployments in large areas of pasture unfeasible. Currently, many papers propose WSN for estrus detection. The sensors intended for this application can be separated according to the way of use, e.g., neck collar, ear tag and pedometer. A comparison of the applications of these three types of sensors is presented in Table I, adapted from [4].

As shown in Table I, each monitoring application has specific sensors and the most appropriate ways to position the sensors according to the data type to be collected. Each application has its characteristics, which must be taken into account when implementing it in the field, for example, devices in the ear are more suitable for collecting the body temperature of the cows, but it demands the use of noise cancellation techniques for data processing, since that the natural movement of the animal can add interfering noise to the collected data. In addition to sensors, there are applications based on positioning monitoring and livestock tracking to detect diseases. This approach is necessary as the cattle herd grows, as well as production costs [9].

All collected data needs to be sent to the cloud through the communication network, so that it can be treated and presented effectively to the farmer. Systems have been designed to automatically monitor and transmit the daily status of dairy cows. Most of them use short distance communication networks due to limitations of high battery power consumption and cost for longer range networks such as satellite networks. The pedometer from Afimilk company adopts a Bluetooth communication approach, where the number of cow steps is only accessible at milking, therefore, it cannot offer real-time monitoring. The system developed by Li et al. [10] performs real-time monitoring, collecting data and transmitting it to a gateway through the ZigBee short-range communication. However, due to the low coverage capacity, it demands the deployment of many ZigBee gateways to monitor large herds, which makes the deployment high-cost.

With the increasing of demand for IoT industry use, technologies such as Low Power Wide Area Networks (LPWANs) have been developed. LPWANs represent a communication model that complements cellular technologies and short distance wireless to address the diversity of IoT applications. These technologies are designed to offer a set of features, including large-scale, wide-area connectivity for low power, low-cost, low data rate devices [11]. Narrowband IoT (NB-IoT) is a LPWAN, which the standard developed is based on the Long Term Evolution (LTE) cellular mobile communication system. The system developed by N. Ma et al. [4] uses NB-IoT as network of transmitting the data collected by the neck collar sensors on the cows to the cloud, after processing the data, the detection of the period of estrus of the cows is carried out. This system approach is dependent on the signal coverage of the cellular mobile network operator, which makes deployment in remote areas unfeasible.

The Long Range Wide-Area Network (LoRaWAN) protocol is one of the most popular and successful technologies in the LPWANs scope. LoRaWAN consists of a protocol that operates at the LoRa physical layer in unlicensed bands. The characteristics of this protocol are: Low power consumption, low data rate, low implementation complexity, different classes of operation for various applications, coverage range between 2-5 km in urban areas and up to 15 km in rural areas. The LoRa gateway is capable of supporting a high number of connected nodes [12].

Once the data has been collected and transmitted to a processing center, several IoT solutions are being developed to process the data. Every application has the same challenge of storing large amounts of data and accessing it quickly when needed. Performance studies have been developed to evaluate which type of database, between relational and non-relational is the most suitable for data processing and storage [13].

III. System Architecture

This section presents the proposed IoT application for precision dairy farming. The IoT application consists of the main components shown in Figure 1.

The main objective of this WSN system is to perform health monitoring, detect the period of estrus and generate theft alerts for dairy cows, using low-cost, low-energy and scalable devices according to the premises of IoT system. The solution

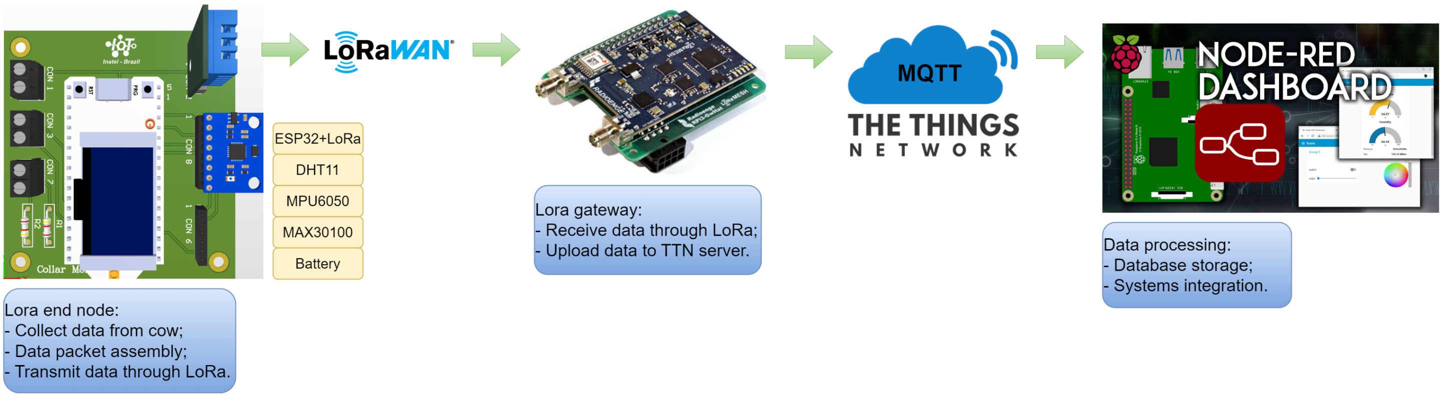

Fig. 1: Architecture of proposed system.

proposes the design of a WSN application capable of offering accurate dairy herd data in real-time to the farmer, regardless of herd size and pasture area, through the LoRaWAN protocol.

The sensing platform captures movement data through a 3D gyroscope and accelerometer (MPU6050), temperature and humidity data (DHT11), heart rate data (MAX30100), monitoring the presence of the animal within a predetermined perimeter and monitoring the presence a collar around the neck of the animal. A 3D-printed case was developed to protect the WSN hardware from weather conditions and the dairy herd application, shown in Figure 2. The case material is polylactic acid (PLA), a thermoplastic monomer derived from renewable energy, besides the solution is low-cost and scalable. The case is attached to the collar, which is attached to the neck of each dairy cow in the herd. Each dairy cow with the collar becomes an end node of the LoRa network, which sends the collected data periodically, with programmable sending time to meet different needs according to the application. The end node uses an ESP32 microcontroller, which offers an ideal development platform for IoT systems, offering wireless connectivity through LoRa, Wi-Fi and Bluetooth interfaces. It has low-cost, low power consumption and integration with battery charge management system. In addition to performing periodic readings, the developed end node is responsible for assembling and transmitting the data packet through the LoRa network. The block diagram of the developed end node is shown in Figure 3.

Fig. 2: 3D-printed case for neck collar.

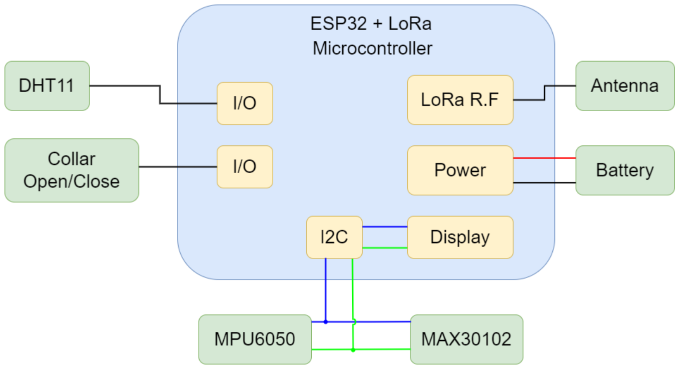

Fig. 3: Lora end node diagram.

Data packets transmitted by the end node are received by the LoRa gateway, which main function is to receive data from sensors and send them to the server. The LoRa gateway comprises the LoRaMESH Radioenge module, which operates with a Raspberry Pi 3 development board. This set offers eight simultaneous channels of LoRa communication with the end nodes, Ethernet and Wi-Fi interfaces for communication with The Things Network (TTN) server. The main characteristics of the gateway used are described in Table II.

TABLE II: Transmitter/Receiver specifications.

Specification	Description
Frequency	902.5-907MHz/915-928MHz
Data rate	21.9kbps
Bandwidth	125kHz/250kHz/500kHz
Output power	+27dBm
Frequency tolerance	±5.0ppm
Modulation/Scattering	LoRa/CSS
Sensitivity (BER 0.1%)	-137dBm
Input level	-20dBm
Connector	SMA-M

The WSNs and IoT applications make use of multiple devices to collect data at the same time. Also, some dairy farming scenarios can require solutions with long-range communication. In this context, LoRa plays a critical role in enabling these applications. LoRa uses spread spectrum communication, and it has a lower probability of collision and interference when compared to similar technologies. In addition, LoRa does not require a license or signature for use in Brazil, enabling everyone to implement and exploit the service, it uses industrial, scientific and medical (ISM) radio bands. The main operating ranges for LoRa in Brazil are 902-907.5MHz and 915-928MHz. All these characteristics increases the scalability and possible scenarios of implementation [14].

The TTN system is a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN [15]. It offers several integration interfaces for developing cloud IoT applications and services, such as Amazon Web Services – AWS IoT, Azure IoT, and Message Queuing Telemetry Transport (MQTT) protocol. In this paper, integration with the MQTT protocol is chosen, it is a lightweight, efficient, and scalable protocol widely used in IoT applications. TTN receives LoRa packets from the Gateway and makes the data from the end nodes available to the application interface in JavaScript Object Notation (JSON), that is a lightweight data-interchange format, accessible for humans to read and write, easy for machines to parse and generate files. The data is transmitted from the TTN system to the next step through the MQTT protocol, transferring the sensor data converted into messages in JSON format [16]. The final message stage is on the NodeRED, which is a programming tool for wiring together hardware devices, Application Programming Interfaces (APIs) and online services. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime. All these tools and services as part of the Internet of Things, where all the applications in WSN are connected. The NodeRED is used on a Raspberry Pi 3 development board, where all the processing of the received data is carried out. In this scenario, NodeRED has four main functions: (I) Receive data from the TTN system through the MQTT interface, (II) Store the data received through the Database, (III) Perform data processing and (IV) Presentation of the results in Dashboard.

Data periodically received by the MQTT interface are stored in the MongoDB database, which is a non-relational document database with scalability and flexibility with high performance in the querying and indexing process, ideal for IoT applications [17]. It is necessary to store dairy herd data for future processing, herd behavior history and future applications according to the needs of each farmer. Once the information is stored, periodic readings are made in the database, according to the needs of each processing. After processing, the results are presented in a dashboard through the API available in NodeRED, which offers a local presentation of the data. To increase the flexibility for presenting the results, the free public MQTT broker from HiveMQ company is used. An MQTT broker, which is the heart of the MQTT Publish/Subscribe protocol, is a server that receives all messages from the MQTT clients and then routes the messages to the appropriate subscribing clients. Therefore, any desktop or mobile WEB application can access the processing results available on the broker [18]. The application developed in NodeRED sends the data in parallel to be presented in the local dashboard and publishes it to the HiveMQ broker in specific topics. Any remote application that wants to receive the data and present it in a dashboard may subscribe to the required topic.

IV. System Validation and Analysis

This section presents data capture and sending tests by end nodes to validate the proposed system, which analyzes LoRa communication with the gateway, database storage and dashboard. First, the LoRa tests aim to measure the distance and Received Signal Strength Indication (RSSI) presented in rural areas. Second, the transmission of data from the end node and reception by the TTN server through the Lora Gateway is presented, as well as a dashboard with some results.

The RSSI is the received signal power in milliwatts and is measured in dBm. The measurements are used to verify how well the receiver receives the signal from the sender. A stronger signal stays around -30dBm, and a weak signal, on the other hand, is around -120dBm.

In order to establish a radius of operation of the developed WSN, measurements were carried out in a rural area, taking into account the minimum RSSI value that it is still possible for the gateway to receive data from the end node. Table III presents the measurements carried out on a farm located in Santa Rita do Sapucaí municipality, Minas Gerais, Brazil. In this test scenario, one LoRa gateway located at point P0 and four end nodes located at points P1 to P4 were used, as shown in Figure 4. In this case, the coverage area achieved is approximately 39,860 km^2. Some points have different RSSI values for the same distance from the gateway, this is explained by the difference in terrain elevation and obstacles such as trees. For this farm, it is possible to establish a safe area smaller than the maximum area reached, generating theft alerts by monitoring the RSSI limit values according to the defined area.

TABLE III: Measurements of distance vs RSSI.

	Distance [km]	RSSI [dBm]
P1	3.68	-108
P2	3.24	-110
P3	3.57	-103
P4	3.76	-107

Fig. 4: Measuring points for LoRa RSSI in rural area.

The data is captured by the sensors and processed by the microcontroller, which performs one reading per minute. The payload is assembled and transmitted to the gateway at each reading through the LoRa radio present in ESP32. The LoRa packet containing the sensor data consists of 19 bytes. The gateway receives the packet in Hex format, through a parsing system developed on the TTN server and converts it to JSON format, shown in Listing 1. The data received periodically are converted into a JSON file and stored in the MongoDB database through a system developed at NodeRED, which the integration with MQTT was developed too to receive data from the TTN server and dashboard for presenting the results, as shown in Figure 5.


```
{
 "decoded_payload": {
    "accelX": 2.10418701171875,
    "accelY": -0.1293182373046875,
    "accelZ": 9.77783203125,
    "collarState": 1,
    "temperature": 23.40087890625,
    "gyroX": -0.0667572021484375,
    "gyroY": -0.011724233627319336,
    "gyroZ": -0.025582313537597656,
    "heartRateBPM": 78,
    "humidity": 74.0234375,
    "gateway_ids": {
        "gateway_id": "iot-group-inatel-
         b827ebfffe3644e2",
        "eui": "B827EBFFFE3644E2"
    },
    "timestamp": 1686361112,
    "channel_rssi": -51
  }
}
```


Listing 1: Data received by TTN from end node.

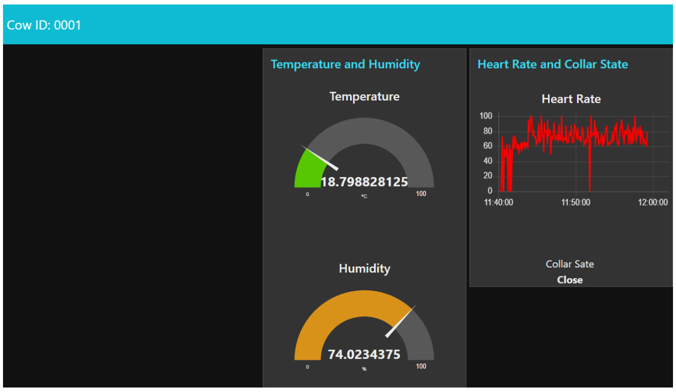

Fig. 5: NodeRED dashboard illustration.

V. Conclusion and Future Works

The paper studied and proposed a low-cost LoRa WSN for precision dairy farming applications. The proposed WSN is part of major work, which aims to identify patterns and detect certain herd behavior through ML. In this step developed, the results were satisfactory, proving the good functioning of the integration between data capture by the end node, sending through the LoRa network, reception through the gateway and sending to the TTN server, conversion of data into JSON files, stored in a database to create a dairy herd dataset and dashboard presentation.

Considering the good functioning of the integration of the systems described, it is possible to mention some future work such as the development of ML techniques, through the herd dataset, identify behavior patterns, detection periods of estrus, diseases and generate theft alerts from the herd trough collar and security perimeter, using previously known RSSI values. Also, it is possible to use a reduced size solar panel on the neck collar to increase solution sustainability. The present solution was based only on LoRa, technologies such 5G might be suitable for farm environment with extensive areas.

References

[1] S. Debdas, S. Mohanty, B. Biswas, A. Chhangani, S. Samanta, and S. Chakraborty, "Iot based fog and cloud analytics in smart dairy farming," in *2021 International Conference in Advances in Power, Signal, and Information Technology (APSIT)*, 2021, pp. 1–6.

[2] R. Foote, "Estrus detection and estrus detection aids," *Journal of Dairy Science*, vol. 58, no. 2, pp. 248–256, 1975.

[3] Z. Xu, D. McKnight, R. Vishwanath, C. Pitt, and L. Burton, "Estrus detection using radiotelemetry or visual observation and tail painting for dairy cows on pasture," *Journal of Dairy Science*, vol. 81, no. 11, pp. 2890–2896, 1998.

[4] N. Ma, L. Pan, S. Chen, and B. Liu, "Nb-iot estrus detection system of dairy cows based on lstm networks," in *2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications*, 2020, pp. 1–5.

[5] M. S. Farooq, S. Riaz, A. Abid, K. Abid, and M. A. Naeem, "A survey on the role of iot in agriculture for the implementation of smart farming," *IEEE Access*, vol. 7, pp. 156 237–156 271, 2019.

[6] A. Polianytsia, O. Starkova, and K. Herasymenko, "Survey of hardware iot platforms," in *2016 Third International Scientific-Practical Conference Problems of Infocommunications Science and Technology (PIC ST)*, 2016, pp. 152–153.

[7] C. Cambra, S. Sendra, J. Lloret, and L. Garcia, "An iot service-oriented system for agriculture monitoring," in *2017 IEEE International Conference on Communications (ICC)*, 2017, pp. 1–6.

[8] C.-J. Yang, Y.-H. Lin, and S.-Y. Peng, "Develop a video monitoring system for dairy estrus detection at night," in *2017 International Conference on Applied System Innovation (ICASI)*, 2017, pp. 1900–1903.

[9] X. Shi, X. An, Q. Zhao, H. Liu, L. Xia, X. Sun, and Y. Guo, "State-of-the-art internet of things in protected agriculture," *Sensors*, vol. 19, no. 8, 2019.

[10] J. Li, J. Fang, Y. Fan, and C. Zhang, "Design on the monitoring system of physical characteristics of dairy cattle based on zigbee technology," in *2010 World Automation Congress*, 2010, pp. 63–66.

[11] M. Mohammadkarimi, M. A. Raza, and O. A. Dobre, "Signature-based nonorthogonal massive multiple access for future wireless networks: Uplink massive connectivity for machine-type communications," *IEEE Vehicular Technology Magazine*, vol. 13, no. 4, pp. 40–50, 2018.

[12] W. Ayoub, A. E. Samhat, F. Nouvel, M. Mroue, and J.-C. Prévotet, "Internet of mobile things: Overview of lorawan, dash7, and nb-iot in lpwans standards and supported mobility," *IEEE Communications Surveys Tutorials*, vol. 21, no. 2, pp. 1561–1581, 2019.

[13] T. Mladenova and I. Valova, "Performance study of mysql and mongodb for iot data processing and storage," in *2022 International Conference Automatics and Informatics (ICAI)*, 2022, pp. 60–63.

[14] A. N. de Telecomunicações, "Espectro," https://www.gov.br/anatel/pt-br/regulado/espectro, 2023, accessed 22 May 2023.

[15] M. M. Suwaid, M. H. Habaebi, and S. Khan, "Embedded lorawan for agricultural sensing applications," in *2019 IEEE 6th International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, 2019, pp. 1–5.

[16] A. N. Rosli, R. Mohamad, Y. W. Mohamad Yusof, S. Shahbudin, and F. Y. Abdul Rahman, "Implementation of mqtt and lorawan system for real-time environmental monitoring application," in *2020 IEEE 10th Symposium on Computer Applications Industrial Electronics (ISCAIE)*, 2020, pp. 287–291.

[17] W. Y. Mok, "A logical database design methodology for mongodb nosql databases," in *2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2021, pp. 1451–1455.

[18] S. Tripathi and B. K. Chaurasia, "Broker clustering enabled lightweight communication in iot using mqtt," in *2023 6th International Conference on Information Systems and Computer Networks (ISCON)*, 2023, pp. 1–6.