IRO Journal on Sustainable Wireless Systems (ISSN: 2582-3167)
www.irojournals.com/irosws/

Geo-Fencing Based Cattle Monitoring System Using LoRa

Dakshayani J.[1], Gowthami K S.[2], Aishwarya C.[3], Navya Sree S.[4], Kodanda Ramaiah G N.[5]

[1,2,3,4]Student, [5]Director R & D, Professor and Head, Department of Electronics and Communication Engineering, Kuppam Engineering College, Kuppam, Andhra Pradesh, India.

E-mail: [1]daksha10305@gmail.com, [2]gowthamiks2210@gmail.com, [3]caishwarya401@gmail.com, [4]navyasreeshambu@gmail.com, [5]hod_ece@kec.ac.in

Abstract

The current research work proposes a geo-fencing-based cattle monitoring system that uses LoRa (Long-Range) technology for livestock tracking and boundary monitoring in smart agriculture applications. In the proposed monitoring system, RSSI is used to calculate the distance from the base station to the cattle collar unit. Based on the distance from the base station, the movement of the cattle is categorized as falling within the safe, warning, and critical zone regions. In the proposed geo-fencing-based monitoring system, ESP32 microcontroller, LoRa communication module, GPS, GSM, and buzzer are used to provide effective long-range communication and real-time alerting capabilities. In order to conserve energy, the GPS sensor remains off except when there is a need to determine whether the cattle have moved out of the specified geo-fencing region. Experimental testing revealed that the proposed monitoring system can communicate effectively up to 1 km range while ensuring low packet losses and power efficiency with about 93% geo-fencing accuracy. About 35% of battery-saving efficiency was achieved due to conditional GPS operation.

Keywords: Long-Range Technology (LoRa), Geo-Fencing, Cattle Monitoring, RSSI, ESP32, GPS, GSM, IoT, Smart Agriculture, Livestock Tracking.

DOI: https://doi.org/10.36548/jsws.2026.2.003
Extended version of article received from **National Conference on Electrical, Electronics & Communication Technologies (NCEET 2026)**
Received: 07.03.2026, received in revised form: 09.04.2026, accepted: 29.04.2026, published: 08.05.2026

1. Introduction

The rapid evolution of the Internet of Things (IoT) and wireless communications, intelligent agricultural systems have been created to improve productivity and automate farming processes, as well as manage farm resources. Livestock monitoring is one of the most important technologies in relation to ensuring safety around cattle, preventing theft of livestock, and improving the management of Farms through the use of intelligent farming systems. Traditional livestock monitoring has relied on human supervision for monitoring farm animals which can be extremely time consuming, labor intensive and ineffective for monitoring large grazing areas. Several technologies such as global positioning system (GPS), wi-fi and bluetooth based tracking systems have been developed to improve livestock monitoring. GPS monitoring allows for very accurate location tracking but constantly operating a GPS based device causes high levels of power consumption, drains batteries quickly, and therefore limits the ability to deploy GPS for any extended period of time in remote farming regions.

Wi-fi and bluetooth based communication also only provide limited range and require supporting infrastructure that may not exist in many remote agricultural areas. Low power wide area network (LPWAN) technologies, such as LoRa have gained great popularity for use within intelligent agriculture due to their extended range and low power consumption properties. LoRa is a wireless communication technology that provides for the transmission of reliable data wirelessly over a distance, making it well suited for use in livestock monitoring applications found within remote and large scale farming environment. This article describes a cattle tracking system that monitors cattle location using the LoRa wireless low-frequency technology to geofence cattle using only Received Signal Strength Indicator (RSSI) readings for calculating the distance between each cattle collar and the base station (the location where all collars are connected back to the internet). This allows the user to determine which zone (safe, warning, critical) the cattle are in (based on the distance calculated from the RSSI measurements). To save battery life, the GPS only sends information when the cattle move outside of their geofenced boundaries, usually in less than 30-second intervals. If the cattle are determined to be in a safe condition, the system will not send any alerts to the owner until the cattle leave their assigned zone. In cases determined to be critical situations, the system will alert the owner via a GSM text message of the cattle's current location and also activate a buzzer at the user's location to provide an immediate warning that the cattle are at risk. The whole system incorporates ESP32 microcontrollers, a LoRa communication module, GPS/GSM modules, and IoT monitoring applications to provide the end-user with a low-power, reliable, and effective means for monitoring livestock.

The main aim of this monitoring system is to minimize the amount of power used by the system, increase the safety of the cattle, reduce the need for manual monitoring of the animals, and to provide a flexible, scalable system for managing livestock in rural farming areas.

2. Literature Review

In recent years, there has been a rapid development of Internet of Things (IoT) technologies that have helped to improve the livestock monitoring industry through real-time tracking, remote monitoring, and automated alerts to farmers when animals may be in distress. Traditional methods of cattle monitoring are mostly based on manual supervision, and therefore, they can be very labour-intensive for the vast expanse of land that cattle have to graze [4]. To eliminate many of these issues, the livestock monitoring industry is increasingly using IoT-enabled monitoring systems combined with wireless communication technologies.

Because of its low power, long-range capabilities, and ability to transmit reliable data in rural areas while maintaining energy efficiency, LoRa technology has become a very popular technology used in IoT-enabled agricultural monitoring applications [1], [8]. There has been multiple studies showing that LoRa based monitoring systems can transmit data reliably to rural areas with great energy efficiency [1]. In addition to LoRa technology, geo-fencing techniques have also been introduced into livestock monitoring systems to provide virtual fencing to cattle to increase their safety and boundary management [2].

Real-time animal location tracking and prevention of cattle theft are two benefits of using IoT-based livestock monitoring combined with GPS and wireless communication technology in their daily operations [9], [10]. The continuous use of GPS will increase battery usage and potentially prevent years of effective monitoring from continuing. There are a number of researchers who are proposing hybrid monitoring methods that combine LoRa communication with intermittent GPS activation to improve energy efficiency [3].

Low Power Wide Area Network (LPWAN) technologies such as LoRaWAN are highly suitable for remote agricultural environment are ideal for remote agricultural applications because they allow for low-cost, long-range communications with minimal infrastructure

[5][7]. Recent studies have shown that optimised LoRa communication means that devices use significantly less power compared to traditional wireless communications [6].

There are livestock monitoring systems already in existence with geo-fencing capabilities, however, many of these systems still rely on continuous GPS tracking or do not have effective means to manage power. An energy-efficient system to monitor cattle with the ability to produce real-time alerts, use LoRa communication methods, provide conditional GPS activation and estimate distance using RSSI is therefore warranted. The proposed solution will address these needs by creating a reliable method for using geo-fencing technology to monitor cattle while reducing the amount of power consumed and the distance over which they can communicate.

3. Methodology

This system will make it possible to monitor cattle using geo-fencing techniques. A distributed IoT architecture made up of two key components will form the foundation of the proposed system to accomplish this goal. One part is the collar unit that is placed on the cattle, and the other is a base station that will receive the data being transmitted from the collar unit. The communication technology of choice in the proposed system will be LoRa, a long-range, low-power wireless solution designed for agricultural and rural usage. The overall methodology focus on monitoring of cattle in real-time through the use of RSSI-based distance measurement and by planning when the GPS will be activated based on the location of the collar and the location of the monitoring station in order to conserve battery life.

The collar unit (Figure 1) will consist of a collar that is placed on the cattle, combined with hardware that will include an ESP32 microcontroller, LoRa transceiver, GPS receiver, and regulated power source. The ESP32 device will control data collection from the collar's hardware and the transmission of this data to the base station. The collar will transmit a packet of data to the base station every time the collar transmits using its LoRa module; this packet of data will contain the collar's ID, signal strength, and GPS coordinates. The GPS will be in a dormant state most of the time in order to conserve battery power.

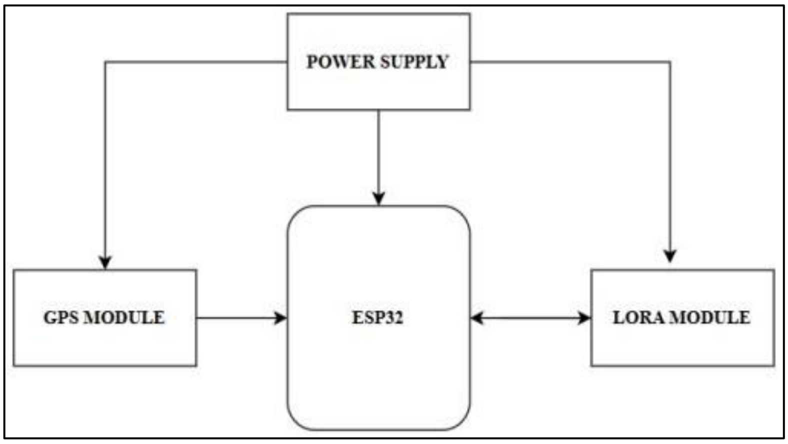

Figure 1. Block Diagram of the Cattle Collar Unit

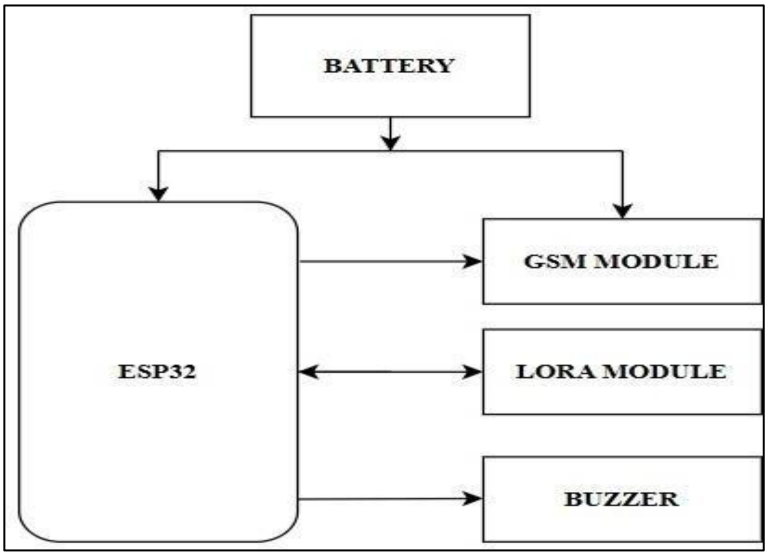

Figure 2. Block Diagram of the Base Station Unit

The base station unit (Figure 2) will consist of a controller that is an ESP32 microcontroller combined with a LoRa receiver, GSM module, buzzer, and display for viewing the received packets from the collar. The base station will continue to receive LoRa packets transmitted by the collar and will measure the RSSI value of each packet. Using the RSSI measurements as a basis for estimating the distance between the cattle and the base station, the system will continuously monitor the distance throughout the day. The estimated distance is used to compare against pre-defined geo-fencing limit values to identify if the cattle movement is in Safe, Warning, or Critical Zone. The system continuously monitors the cattle in its Safe Zone but disables the GPS module to reduce battery power. Once the cattle travels into the Warning Zone, the system will enable the GPS module for accurate location co-ordinates. The system will provide close monitoring and update its monitoring status on the cattle when the cattle travels into the Critical Zone. The GSM module will transmit SMS alerts that include the cattle's location to the user's phone when the cattle is in the Critical Zone. An alert will be made locally at the base station by the Buzzer module. The proposed method of operation assists in the efficient monitoring of livestock by combining low power transmission using LoRa with the selective activation of the GPS module to significantly reduce the power consumption while still providing reliable long-range monitoring and real-time alerts. The continuous monitoring architecture makes the proposed monitoring solution easily scalable, which will be beneficial to large scale agricultural operations.

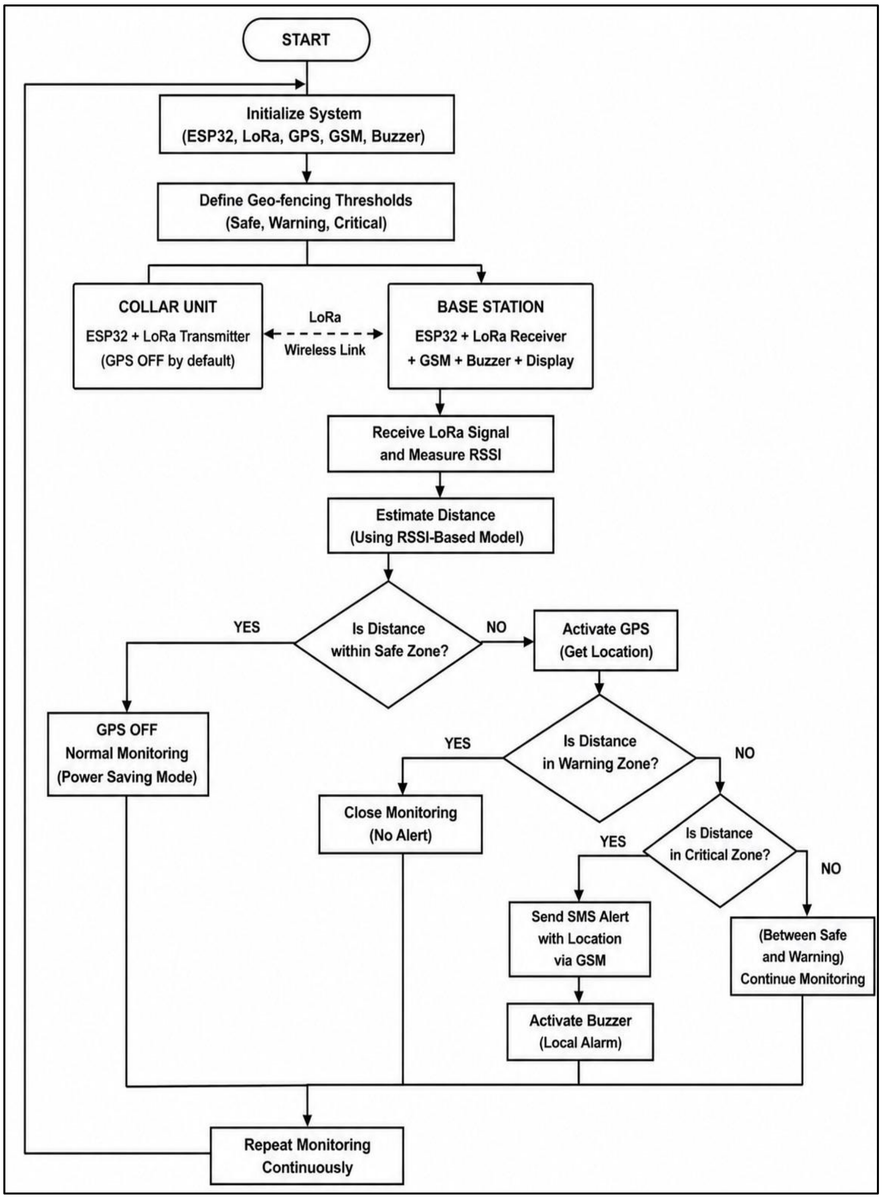

Figure 3. Workflow of the Proposed Geo-Fencing Cattle Monitoring System

Figure 3 depicts a proposed system workflow. Initially, all hardware components receive power. These component types include ESP32, Lora, GPS, GSM, and a buzzer. Each collar unit is programmed to transmit LoRa radio frequency signals over time to a central base station and measure RSSI values received at the base station. The RSSI values are used to provide an estimated distance of the cattle relative to the central monitoring location.

The distance measured by the base station is then compared to preset geo-fencing distances for the purpose of determining the status of the cattle with relation to either the safe zone or the unsafe zone. If the cattle are inside the safe zone, the GPS component on the collar is powered off to conserve battery life. However, if the cattle move outside this safe zone, then the collar's GPS component is powered on. If the cattle enter a critical area, the GSM component will send SMS notifications to the farmer, and the buzzer component will create a local visual alert for the farmer. As a result, the overall process functions continuously for real-time remote monitoring and geo-fencing protection of livestock.

Algorithm 1: Geo-Fencing Based Cattle Monitoring

```
Begin

    Initialize ESP32
    Initialize LoRa Module
    Initialize GPS Module
    Initialize GSM Module
    Initialize Buzzer

    Define Safe_Zone_Threshold
    Define Warning_Zone_Threshold
    Define Alert_Zone_Threshold
    Define Critical_Zone_Threshold

    While (System_Status = ON) do

        Transmit LoRa signal from Collar Unit
        Receive LoRa signal at Base Station

        Measure RSSI value
        Estimate distance between Collar Unit and Base Station

        If (Distance < Safe_Zone_Threshold) then
```

```
        Turn GPS OFF
        Continue Monitoring

    Else if (Distance >= Safe_Zone_Threshold
            and Distance < Warning_Zone_Threshold) then

        Turn GPS ON
        Perform Close Monitoring

    Else if (Distance >= Warning_Zone_Threshold
            and Distance < Critical_Zone_Threshold) then

        Turn GPS ON
        Send Warning SMS through GSM Module

    Else if (Distance >= Critical_Zone_Threshold) then

        Turn GPS ON
        Send Alert SMS with Location
        Activate Buzzer Alarm

    End if

  End while

End
```

3.1 Mathematical Formulation

3.1.1 RSSI-Based Distance Estimation Model

The proposed system estimates the distance between the collar unit and the base station using the logarithmic path loss model.

$$d = 10^{\frac{(A - RSSI)}{10n}}$$

Where:

- $d =$ Estimated distance between collar unit and base station (meters)
- $A =$ RSSI measured at 1 meter reference distance (dBm)
- RSSI = Measured received signal strength (dBm)

- $n =$ Path loss exponent
- Typical values of n :
- $n = 2$ for free-space environments
- $n > 2$ for agricultural or rural environments with obstacles

The equation indicates that signal strength decreases logarithmically as distance increases.

3.1.2 Formal Geo-Fencing Formulation

The cattle movement is classified into different monitoring zones based on the estimated distance d.

Let:

- T_n = Safe Zone threshald
- $T_s =$ Warning Zone threshold
- $T_c =$ Critical Zone threshold

The geo-fencing classification is defined as:

$$\text{Zone } (d) = \begin{cases} \text{Safe Zone,} & d < T_x \\ \text{Warning Zone,} & T_x \leq d < T_x \\ \text{Alert Zone,} & T_x \leq d < T_c \\ \text{Critical Zone,} & d \geq T_c \end{cases}$$

3.1.3 GPS Activation Condition

The GPS module is activated only when the cattle move beyond the Safe Zone threshold.

$$GPS = \begin{cases} 0, & d < T_x \\ 1, & d \geq T_x \end{cases}$$

Where:

- GPS $= 0$ indicates GPS is OFF to conserve power

- $\text{GPS} = 1$ indicates GPS is activated for precise tracking

3.1.4 Alert Generation Condition

The GSM alert mechanism is triggered when cattle enter the Alert or Critical Zones.

$$\text{Alert } = \begin{cases} 0, & d < T_w \\ 1, & d \geq T_w \end{cases}$$

Where:

- $\text{Alert} = 0$ indicates normal monitoring
- $\text{Alert} = 1$ indicates SMS notification and buzzer activation

4. Results and Discussion

The implementation of a geo-fencing-based cattle monitoring system utilizes multiple hardware modules and software tools (summarized in Table 1). The performance of this system was evaluated in an actual outdoor agricultural environment to benchmark communications reliability, geo-fencing accuracy, alert generation, and energy efficiency.

Table 1. Hardware and Software Specifications of the Proposed System

S.No	Parameter / Component	Specification / Description
1	Microcontroller	ESP32
2	LoRa Module	SX1278 LoRa Transceiver
3	GPS Module	NEO-6M GPS Module
4	GSM Module	SIM800L GSM Module
5	Communication Technology	LoRa
6	Operating Frequency	433 MHz
7	Transmission Range	Up to 1 km
8	Geo-Fencing Thresholds	5 m, 10 m
9	Buzzer Unit	Local alert indication
10	Power Supply	Battery with Voltage Regulator
11	Programming Environment	Arduino IDE
12	Programming Language	Embedded C

A collar unit was developed along with a base station to process the Received Signal Strength Indicator (RSSI) to generate alerts to users regarding the location of the cattle, as shown in Figures 4 and 5 respectively. The collar unit transmitted Low Power Wide Area Network (LoRa) packets to the base station periodically to provide continuous real-time monitoring of the cattle. Using the information provided by the RSSI values received by the base station, the system calculated the distance between the cattle and the monitoring station, and categorized the movement of the cattle into predefined geo-fencing zones.

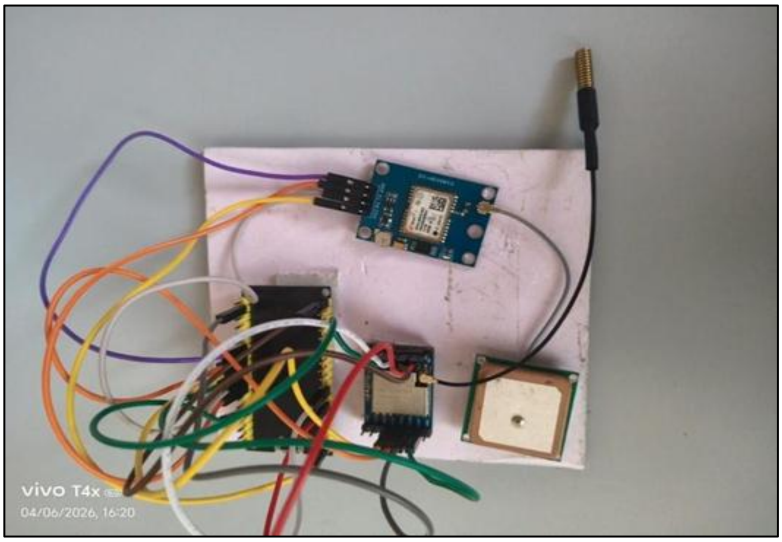

Figure 4. Hardware Implementation of the Collar Unit

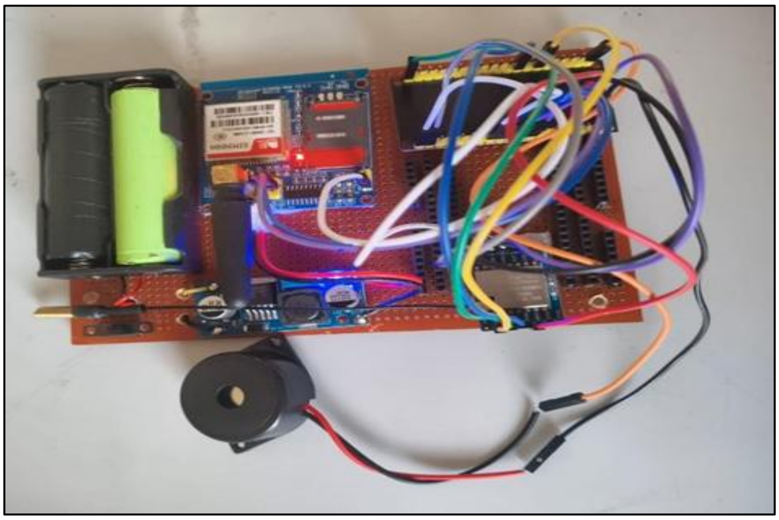

Figure 5. Hardware Implementation of the Base Station Unit

When the cattle exceeded the limits of the geo-fencing boundaries, the GPS component of the collar was activated, and the coordinates of the location of the cattle were determined.

Alert messages were then sent via Global System for Mobile Communications (GSM) to the user in the form of Short Message Service (SMS) messages. The SMS alerts received by the user are shown in Figure 6 and are provided in real-time along with the geographical location of the cattle in Figure 7. The results support the proper implementation of both the geo-fencing mechanism and the alert generation mechanism.

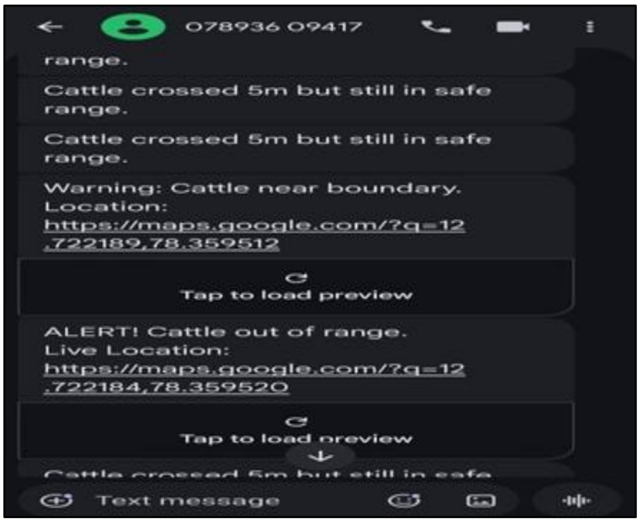

Figure 6. GSM-based SMS Alert Generated by the Proposed System

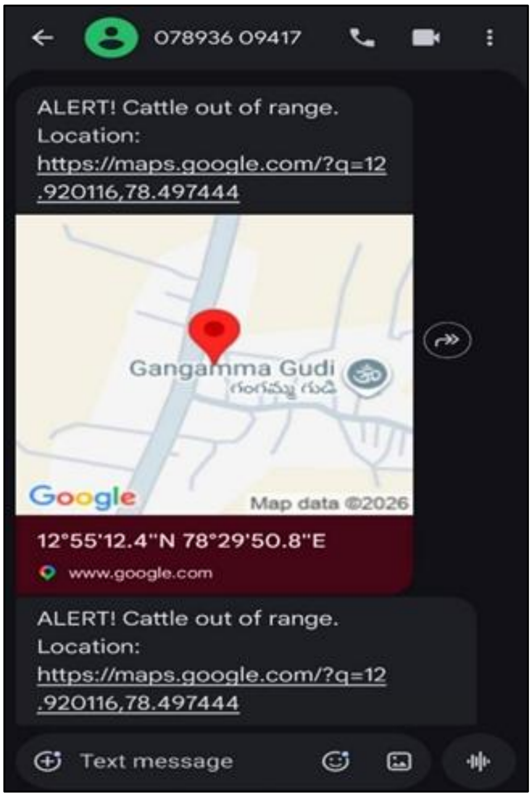

Figure 7. Real-Time Cattle Location Notification Received by the User

Table 2. Experimental Performance Metrics of the Proposed System

S.No	Performance Metric	Measured Value	Description
1	Packet Loss	2.10%	Percentage of LoRa packets lost during transmission
2	Average Latency	1.8 s	Time delay between packet transmission and reception
3	Communication Range	Up to 1 km	Maximum reliable LoRa communication distance
4	RSSI Range	–45 dBm to –102 dBm	Signal strength variation during monitoring
5	GPS Activation Time	3.2 s	Time required to obtain GPS coordinates
6	SMS Alert Delay	4.5 s	Delay in sending GSM alert messages
7	Battery Saving Efficiency	35%	Power reduction achieved using conditional GPS activation
8	Geo-Fencing Detection Accuracy	93%	Accuracy in identifying cattle boundary conditions
9	System Uptime	98.50%	Operational reliability during continuous monitoring
10	Power Consumption	0.85 W	Average power consumed by the collar unit

The experimental performance metrics of the proposed system are presented in Table 2; from Experiments Completed, an operational distance of up to 1 km was demonstrated with reliable LoRa communication and low packet loss and stable signal-strength variation. The average communication latency and SMS alert delay demonstrate the capabilities of the system to provide real-time monitoring solution applications. The geo-fencing mechanism successfully provided an accurate detection of cattle movement as they moved within the geo-fenced boundary.

The proposed system also exhibited an improvement in its energy efficiency through the use of conditional GPS activation. The GPS module remains inactive during normal operation requiring unnecessary power. Experiment analysis showed the proposed system had approximately 35% greater battery savings compared to continuous GPS-based monitoring systems. Additionally, the improved energy-stability of LoRa communication improved overall system operation for long-term agricultural-use deployment in remote areas. While RSSI-based distance estimation methods are subject to potential impacts from environmental influences on signal-interference and obstructions, the system was able to provide reliable monitoring capabilities throughout the experimental evaluations. The combination of LoRa communication, RSSI-based geo-fencing, selective GPS activation, and GSM alert mechanisms will provide an effective and energy-efficient solution for smart cattle monitoring applications.

5. Conclusion

This study proposed a geofencing based cattle monitoring solution that leverages LoRa technology in order to perform real-time cattle tracking and energy efficient monitoring within smart agriculture solutions. RSSI-based distance estimation was used to detect the movement of cattle within geofencing zones and the GPS module was activated based on condition in order to improve the system efficiency. Experimental results revealed successful communication performance up to 1 km with minimal packet loss and 93% geo-fencing accuracy. Conditional activation of the GPS module resulted in improved system efficiency due to minimization of GPS activation during normal operations. The proposed solution also decreased the need for continuous manual monitoring while increasing the safety level of cattle in rural agricultural farms. Potential future developments may include advanced localization performance improvement by applying more sophisticated filtering techniques and machine learning algorithms. Various additional sensors and modules for the collection of cattle health-related data and other data could also be considered for development of more intelligent and scalable systems capable of performing real-time data analysis for smart livestock management.

References

[1] Kumkhet, Boonyarit, Nisit Pukrongta, Noraset Wichaipanich, Pubet Sangmahamad, Tanaporn Pechrkool, Virote Pirajnanchai, Patchadaporn Sangpet, Utthapon Issara, and Attaphongse Taparugssanagorn. "Low-Cost LoRa-based System for Continuous GHGs Monitoring in Cattle: Enhancing Agricultural Sustainability." IEEE Access 13 (2025): 17963-17982.

[2] Nosouhi, Mohammad Reza, Keshav Sood, Robin Doss, Gang Li, Zubair Baig, Anandakumaran Sellathurai, and Anjali Kaushik. "A Reliable Monitoring of Livestock Location and Geo-Fencing Application." IEEE Internet of Things Magazine (2025), doi: 10.1109/MIOT.2025.3639008

[3] Mohapatra, Hitesh. "A LoRa IoT Framework with Machine Learning for Remote Livestock Monitoring in Smart Agriculture." 2025, arXiv preprint arXiv:2510.07322.

[4] Pandey, Bharati, Lakshmi Sonkusale, and Awdhesh Kumar Mishra. "Smart Solutions for Livestock Management and Health Monitoring." PAKISTAN VETERINARY JOURNAL 46, no. 2 (2026): 256-271.

[5] Diane, Ass, Ousmane Diallo, and El Hadji Malick Ndoye. "A Systematic and Comprehensive Review on Low Power Wide Area Network: Characteristics, Architecture, Applications And Research Challenges." 2025, Discover Internet of Things 5, no. 1: 7.

[6] Lorincz, Josip, Marko Kusačić, Edin Čusto, and Zoran Blažević. "A Comprehensive Multiple Linear Regression Modeling and Analysis of LoRa User Device Energy Consumption." 2025, Journal of Sensor and Actuator Networks 15, no. 1: 5.

[7] Torres-Sanz, Vicente, Pablo Donate, Julio A. Sanguesa, and Piedad Garrido. "LoRaWAN for ITS: Overcoming Connectivity Challenges in Remote Areas." In 2025 34th International Conference on Computer Communications and Networks (ICCCN), 1-6.

[8] Kashyap, Monika, Gourav Verma, and Vidushi Sharma. "Empowering IoT Connectivity with LoRa Technology: A Deep Dive into Long-Range Communication." Engineering Research Express 7, no. 1 (2025): 015429.

[9] Sowmiya, P., R. Sujitra, M. R. Srinidhi, B. P. Bhuvana, and V. Yokesh. "IoT-Based Rural Animal Monitoring and Theft Prevention System." In 2025 Innovations in Power and Advanced Computing Technologies (i-PACT), 1-5.

[10] Sandlana, Muzi, Topside E. Mathonsi, Deon du Plessis, and Chunling Tu. "A Real-Time Internet of Things-Based Wireless Livestock Tracking System for Theft Prevention." The Indonesian Journal of Computer Science 3 (2025), Vol. 14, Issue 3: 4349-4366.