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Monitoreo en tiempo real del ganado: Integración de LoRa, sensores y visualización de datos

Real-time monitoring of cattle: integration of LoRa, sensors, and data visualization

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Resumen

La producción ganadera en zonas rurales enfrenta importantes desafíos en el monitoreo de la salud y la localización de los animales debido a limitaciones tecnológicas y de conectividad. Para abordar este problema, se desarrolló un sistema de monitoreo en tiempo real basado en comunicación LoRa, diseñado para registrar y visualizar la temperatura corporal y la geolocalización del ganado. La investigación siguió un enfoque cuantitativo, aplicado y de diseño no experimental, validado mediante entrevistas y observaciones con ganaderos de la provincia de Santa Elena, Ecuador, con el fin de asegurar la representatividad del contexto productivo. El sistema implementado integró un Arduino Nano con sensores de temperatura infrarrojos, un módulo GPS y transmisores LoRa, junto con una pasarela basada en ESP8266, una base de datos MySQL y una interfaz gráfica desarrollada en Python. Las pruebas de campo realizadas con cinco reses monitoreadas demostraron una transmisión de datos estable hasta 3 km, confirmando la idoneidad de LoRa para entornos rurales. El análisis estadístico de los datos de temperatura mostró un promedio de 38,4 °C con una variabilidad mínima, mientras que los registros de geolocalización confirmaron una ubicación precisa dentro de los límites establecidos, sin detectar valores atípicos. Además, el mecanismo de alertas mediante la plataforma Blynk permitió la detección oportuna de anomalías de salud y eventos fuera de zona. Los resultados se alinean con las tendencias reportadas por Navia et al. (2024), reforzando la adopción global de sistemas de monitoreo de largo alcance y bajo costo. Sin embargo, a diferencia de enfoques más complejos, este estudio demuestra que una solución simplificada enfocada en la temperatura y la geolocalización puede aportar un valor significativo dentro de las limitaciones tecnológicas y económicas del entorno rural ecuatoriano. Los trabajos futuros se centrarán en la incorporación de parámetros fisiológicos adicionales, fuentes de energía renovables y analítica avanzada para mejorar la escalabilidad y sostenibilidad del sistema.

Palabras clave: Internet de las cosas; LoRa; Monitoreo Animal, Ganadería

Abstract

Livestock production in rural areas faces major challenges in monitoring animal health and location due to technological and connectivity limitations. To address this problem, a real-time monitoring system based on LoRa communication was developed, designed to record and visualize cattle body temperature and geolocation. The research followed a quantitative, applied, and non-experimental design, validated through interviews and observations with farmers in the province of Santa Elena, Ecuador, to ensure representativeness of the production context. The implemented system integrated an Arduino Nano with infrared temperature sensors, a GPS module, and LoRa transmitters, together with an ESP8266-based gateway, a MySQL database, and a graphical Python interface. Field tests with five monitored cattle demonstrated stable data transmission up to 3 km, confirming LoRa's suitability for rural environments. Statistical analysis of temperature data showed an average of 38.4 °C with minimal variability, while geolocation records confirmed accurate positioning within the established boundaries, with no outliers detected. In addition, the alert mechanism using the Blynk platform enabled timely detection of health anomalies and out-of-zone events. The findings align with the trends reported by Navia et al. (2024), reinforcing the global adoption of long-range, low-cost monitoring systems. However, unlike more complex approaches, this study shows that a simplified solution focusing on temperature and geolocation can provide significant value under the technological and economic constraints of rural Ecuador. Future work will focus on incorporating additional physiological parameters, renewable energy sources, and advanced analytics to enhance scalability and sustainability.

Keywords: Internet of Things; LoRa; Animal monitoring, Livestock farming

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1. Introduction

Stockbreeding in Ecuador is one of the most important economic activities in the agricultural sector, as it contributes significantly to the supply of meat, milk, and dairy products, as well as generating employment in rural areas and boosting the local economy. This activity is carried out in various regions of the country, taking advantage of the climatic and geographical diversity that allows for the breeding of different breeds and production methods (Jaramillo y Ríos, 2025). Like any activity, it faces challenges related to productivity, health management, and environmental sustainability. In this context, the use of modern technologies, such as monitoring systems, sensors, artificial intelligence, and data management platforms, is a key tool for improving efficiency, ensuring animal welfare, and boosting the competitiveness of Ecuadorian livestock farming (Tzanidakis et al., 2023).

Telecommunications systems play an important role in technological development across all sectors. Livestock farming, as a driver of rural development, faces significant challenges in incorporating tools that support aspects such as monitoring the health and location of livestock, among other issues (Ahmed y Gallardo, 2022); due to a lack of technological infrastructure and limited connectivity in remote areas. In this context, low-power wide-area network (LPWAN) technologies have emerged as promising solutions for smart agriculture, offering long-distance communication with low energy consumption, ideal for areas with poor cellular coverage (Jaramillo y Ríos, 2025).

The incorporation of technology in the livestock sector is developing greatly, influenced not only by the availability of equipment but also by the medium- and long-term benefits it brings to livestock production rates. There are many areas and processes in which technology is and would be a differentiating factor for continuous improvement (Xiao et al., 2022). Tasks such as environmental monitoring, real-time tracking, detection of atypical patterns, welfare, safety, and operational efficiency are some examples that require attention (Schulthess et al., 2024).

As part of the modernization of the livestock sector, monitoring critical variables such as the geographical location and body temperature of livestock is essential to ensure productivity and animal welfare (Montalván et al., 2024). The ability to track cattle movements in real time allows for optimized pasture management, loss prevention, and improved herd safety, while continuous monitoring of body temperature provides an early indicator of disease, heat stress, or physiological changes that directly affect health and productive performance (Ojo et al., 2022).

(Navia et al., 2024) conducted a systematic literature review on sensor-based systems and applications for livestock vital signs monitoring, applying the PRISMA methodology to identify trends and research gaps. Their study analyzed 21 scientific papers published between 2017 and 2023, as well as several commercial products. The results highlighted that the most widely used communication technologies are long-range ones, especially LoRaWAN, followed by WiFi and GSM-based solutions. Most of the reviewed proposals targeted cattle, employing fully mobile devices such as collars or ear tags, which enable monitoring in grazing and large-scale environments. In terms of monitored parameters, the predominant variables were geolocation, movement, and body temperature, while other vital signs such as heart rate, respiration, blood pressure, or oxygen saturation received less attention.

This background study supports the relevance of the present research, as it aligns with the trend of using LoRa-based communication for long-range monitoring, while addressing specific challenges of cattle management in rural Ecuadorian contexts. From this perspective, this study proposes a monitoring system that integrates both variables using LoRa communication, facilitating timely decision-making and promoting more efficient, sustainable, and innovative livestock management. This system seeks to generate alerts in the event of potential health risks or losses, facilitating timely intervention by the personnel in charge. The choice of LoRa technology is due to its ability to transmit data over long distances with low energy consumption, ideal for this type of environment (Rivera Guzmán et al., 2022).

The system design includes a modular structure consisting of collars equipped with sensors, a database for storing information, and a graphical interface that allows users to view readings for each animal. The solution represents a significant step forward in the modernization of agricultural practices, aiming to reduce the margin for human error and optimize response times to incidents, contributing to the operational efficiency of farms and the sustainability of local livestock production. The project is positioned as a viable, scalable technological solution aligned with the needs of the Ecuadorian countryside today.

2. Materials and Methods

The methodology of this research was designed to guarantee the validation of the proposed cattle monitoring system under real production conditions. A quantitative, applied, and non-experimental design was followed, structured in four phases:

Problem analysis: To identify the main challenges in livestock management, semi-structured interviews were conducted

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with local farmers and technicians, complemented by direct observation on several farms in the province of Santa Elena, Ecuador. This triangulation of techniques allowed the identification of technological limitations, environmental conditions, and infrastructure constraints. Based on this analysis, a representative case study farm was selected, with a total population of 70 cows, of which 5 were randomly chosen for daily monitoring during the experimental period.

Prototype development: Prototype monitoring was developed, consisting of collars equipped with infrared temperature sensors (MLX90614), a GPS module (Ublox Neo), and an Arduino Nano microcontroller connected to a LoRa SX1278 module for long-range wireless communication. A NodeMCU ESP8266 module was used as the receiver to store data on a local server. The design schematics were created in Proteus to validate the connections and ensure system stability.

Software design: The waterfall model was adopted for the development of software components. The system architecture comprised three layers: the graphical user interface, developed in Python with CustomTkinter; the backend processing module, also implemented in Python, responsible for receiving and processing sensor data via TCP/IP; and a MySQL database for storage and historical queries.

Field testing: Field tests were carried out on the selected farm over a period of four weeks. The monitoring collars transmitted temperature and geolocation data in real time to the LoRa receiver, which sent the information to the database. Data were analyzed to evaluate system performance in terms of communication stability, operational coverage, accuracy of location, and reliability of temperature readings. Additionally, an alert system was implemented using the Blynk platform to send automatic notifications by email when anomalies (thermal variations or out-of-zone movements) were detected.

3. Results and Discussion

The research includes architecture that uses innovative technologies capable of intelligently processing the measured variables. The results achieved are the Monitoring Equipment and Control Software.

3.1. Monitoring Equipment

The equipment consists of several components; Figure 1 shows the block diagram of the equipment; the transmitting device located on the cattle will be responsible for sending temperature and geolocation data to the receiver, while the receiver stores the data on a data server.

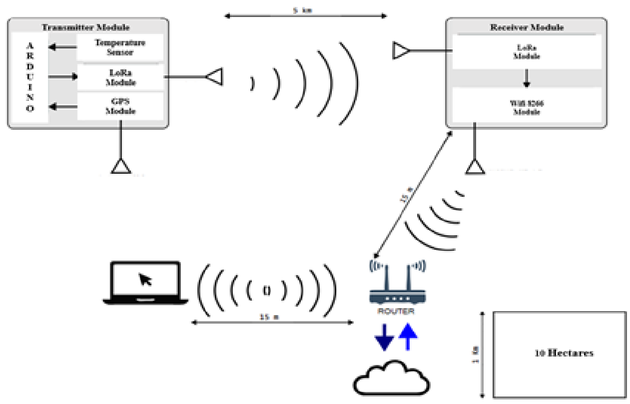

Figure 1. Block diagram: Transmitter and Receiver
Source: The authors

The materials and equipment used were evaluated and selected based on the environment where monitoring takes place. Two different microcontrollers are used, one for the transmitter and one for the receiver. The main components of the equipment are microcontrollers, GPS module, temperature sensor, LoRa module, and a voltage regulator.

Microcontroller: Arduino Nano ATmega328, used for reading the sensors, small size, low power consumption, and ease of programming. It is ideal for portable applications, such as cattle collars, as it can be installed in small spaces without compromising functionality (Taryana, 2021).

GPS, Ublox Neo, a module chosen for its cost-effectiveness, ease of use, and location accuracy, which allows real-time tracking of livestock, essential for identifying unusual movements. It also has an external antenna that improves reception in rural areas.

LORA module: SX1278, communication technology characterized by its wide range, which can reach up to 5 km in open field, and low energy consumption. The SX1278 module allows portable devices, such as collars, to send data to the central node without data loss.

Gy-906 Mlx90614 Infrared Temperature Sensor: a sensor that allows the body temperature of animals to be measured without direct contact, helping to prevent discomfort or infection in livestock. Among its features is that it uses the I2C protocol to establish communication with the microcontroller.

Power supply module mb102: This module was chosen because the microcontrollers and components have different voltage outputs of 5V and 3.3V; therefore, a voltage regulator was selected to ensure that the outputs are compatible with all the sensors and microcontrollers in the system.

Receiver microcontroller: A different microcontroller is used for the receiver device than for the transmitter, in this case the NODE MCU ESP8266. Among the other components used for data reception are the same LoRa module and voltage power supply module that were used in the transmitter device.

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The diagram of the transmitter solution is shown in Figure 2 and that of the receiver in Figure 3. The diagrams show the connections of all the system components: microcontroller, GPS module, temperature sensor, LoRa module, and power supply. The designs were created in Proteus, which allows us to validate and ensure that each connection is correct, orderly, and error-free.

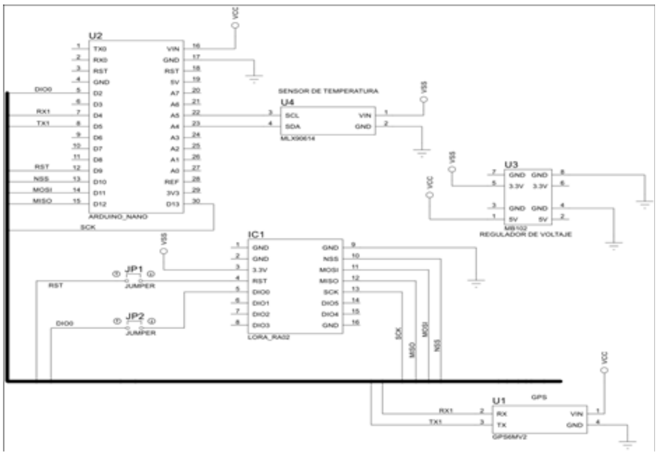

Figure 2. Transmitter Schematic Design
Source: The authors

In order for the sensors and the microcontroller (Arduino Nano) to communicate with each other, several protocols were implemented, each with different characteristics. The MLX90614 infrared temperature sensor uses the I2C protocol, which makes it easy to connect several devices with only two data cables (SCL and SDA). In contrast, the NEO-6M GPS module communicates via the UART protocol, which is asynchronous and ideal for sending location data. Finally, the LoRa SX1278 module uses the SPI protocol, which allows data to be sent faster and is very useful for the microcontroller to communicate with the radio frequency modules. The TCP/IP protocol is also used to send information from the receiving device to the server. This protocol ensures secure communication, making it possible for the data collected by the collars, both position and temperature, to reach the control system without loss of information (Harini Kolamunna, 2016).

3.2. Control Software

The waterfall model was used as a reference for the development of the system. This model rigorously orders the stages of the software development process, such that the start of each stage must wait for the completion of the previous stage (Rivera Guzmán et al., 2022). It includes phases such as requirements

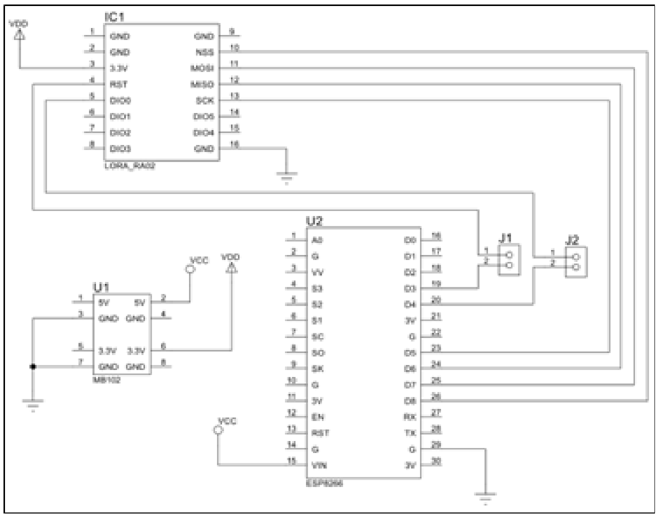

Figure 3. Receiver Schematic Design
Source: The authors

analysis, system design, implementation, testing, deployment, and maintenance. In each of the phases, the functional requirements that enable the project's objective to be met have been identified (Maida y Pacienzia, 2015).

The software architecture is based on three elements: the user interface (frontend), the processing logic (backend), and the database. Python with the CustomTkinter library was used for the frontend, which allowed us to create a graphical desktop interface that is intuitive for the end user. The backend, also developed in Python, acts as a bridge between the interface and the database. This module contains the business logic that processes data from IoT devices, which arrive via HTTP requests using the TCP/IP protocol. All the information collected is then stored in a MySQL database. This database organizes records on cattle and also facilitates queries and historical analysis.

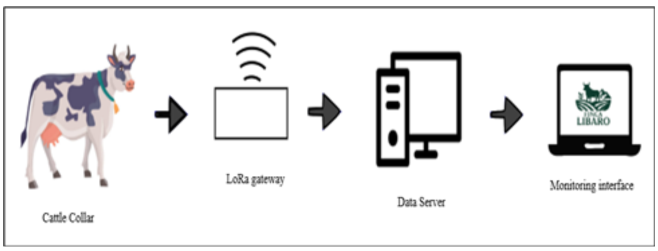

Figure 4. Communication scheme
Source: The authors

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Figure 4 shows the integrated solution, composed of: i) Cattle Collar, with Arduino, temperature sensor, GPS, and LoRa for long-range transmission; ii) LoRa Gateway (receiver), with LoRa and ESP8266 modules that relay data to a local server; iii) Data Server, which stores and processes the information in a MySQL database; and iv) Monitoring Interface (Python), a graphical system that displays livestock location, temperature, and alerts in real time or historically. The tests carried out have allowed us to obtain data associated with the variables: temperature, location and Out-of-zone alerts.

Temperature: Figure 5 shows the body temperatures recorded for the cow "Canela" on June 7, 2025. There is an upward trend in body temperature throughout the day, starting with values of 38.2°C at 7:00 a.m. and 9:00 a.m. and reaching a maximum of 38.9°C at 5:00 p.m. This progressive increase could be due to environmental factors such as midday heat or the animal's physical activity. It is important to note an anomaly at 1:00 p.m., where the temperature drops to 37.7°C, which may be due to an atypical reading or a brief pause in the animal's activity.

On the other hand, the most relevant data in the table in Figure 5 is that at 7:00 a.m., the cattle were recorded as being outside the monitoring area. This event could imply a possible risk of escape. However, for the rest of the day, Canela remained within the defined area. This type of information is essential for cattle management, as continuous monitoring allows for the anticipation of possible health problems and timely decisions on the farm.

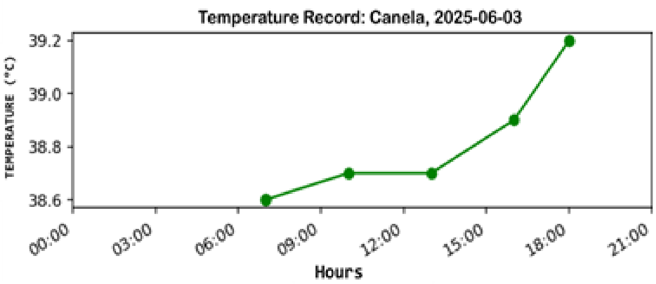

Figure 5. Temperature recorded by hour of the day
Source: The authors

Location: Figure 6 shows the route taken by the cow "Estrella" on June 8, 2025. Three elements stand out in the graph: the total boundary of the farm in blue line, the monitoring area established in green dotted line, and the recorded location points of the cow in red dots. All location records are within the monitoring area, indicating that the monitoring system is adequately fulfilling its tracking function within the defined operating limits. This ensures the control and safety of the animal without the need for manual location methods.

The location records were analyzed to determine spatial distribution within the monitoring area. All points fell within the defined boundary, confirming the accuracy of the GPS module. The concentration of positions in a reduced zone suggests limited mobility during the observation period, a pattern consistent with grazing behavior. From a statistical perspective, no outliers were detected in the dataset, which validates the stability of the geolocation system

In addition, the concentration of points in a specific area suggests that the cattle have remained within a limited range of movement during the observation period. This may be due to factors such as the availability of food or shade in that area. This information is crucial for farm managers, as it allows them to evaluate behavior patterns, make decisions about grazing rotation, or detect possible anomalies in cattle activity. Overall, route analysis supports the efficiency of the system and contributes to improving the productive and sanitary management of the cattle.

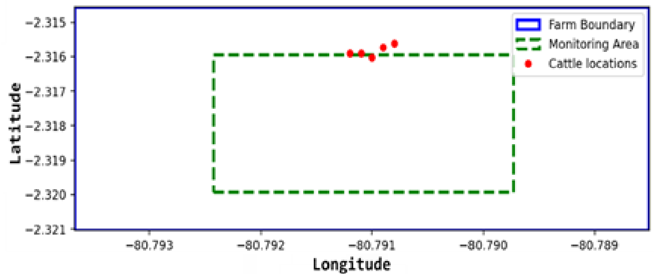

Figure 6. Location of cattle
Source: The authors

Out-of-zone alerts: The alert system uses the Blynk platform, together with an ESP8266 board, to send automatic email notifications. Sensors provide real-time data on each animal's body temperature and GPS location. If the temperature exceeds a threshold, the system generates an immediate alert that is sent by email, including the time, latitude, longitude, and exact temperature of the cattle. A similar process occurs when the cattle are outside the established limits, triggering an "Out of zone" alert.

The results demonstrate the effectiveness of the proposed system by jointly integrating body temperature and geolocation monitoring of cattle. The recorded thermal variations made it possible to identify patterns associated with environmental factors as well as potential anomalies in measurements, while location tracking confirmed the system's ability to keep animals controlled within defined boundaries. Furthermore, the automatic alert mechanism enhances responsiveness to health or escape risks, reducing reliance on manual supervision. Overall, these findings indicate that continuous monitoring through low-cost technologies such as LoRa and ESP8266 constitutes an effective tool to improve herd management and ensure animal welfare.

The results of this study align with the systematic review by (Navia et al., 2024) which highlights body temperature and geolocation as key parameters for livestock monitoring and confirms the predominance of long-range technologies such as LoRaWAN. The stable communication range of up to 3 km and the use of mobile collars in this research reinforce these global

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trends, demonstrating the feasibility of portable, animal-worn solutions in open grazing conditions. However, unlike many systems reviewed by Navia et al. that integrate multiple vital and behavioral signs or propose renewable energy options, the present prototype focused solely on temperature and geolocation, prioritizing simplicity, low cost, and adaptability to rural Ecuadorian contexts, while leaving future opportunities for expansion and energy autonomy.

Overall, the findings not only validate the global trend toward LoRa-based livestock monitoring but also contribute new evidence on its practical viability in Ecuadorian production systems, where cost, simplicity, and adaptability to connectivity limitations are decisive for adoption.

4. Conclusions

The development of the monitoring system enabled real-time management of cattle positioning and temperature. LoRa technology proved effective in maintaining stable communication between the transmitting nodes and the central server, even in areas with limited coverage, which supports its suitability for rural environments. The transmitting and receiving devices designed fulfilled their purpose, correctly integrating GPS and temperature sensors with Arduino Nano and ESP8266 microcontrollers. These devices were able to capture, process, and send the necessary information to the server, which allowed for the establishment of a functional network connecting the cattle to a monitoring center. The LoRa communication network was successfully established, achieving effective operational coverage of up to 3 kilometers during testing. This allowed for a continuous flow of information without data loss. Implementing a solution of this type allows for immediate decisions to be made in the face of potential health risks, unusual movements, and even unsafe situations, demonstrating that technology can be adapted to the needs of the livestock environment, promoting its sustainable development.

This study confirms the relevance of monitoring body temperature and geolocation through LoRa-based communication, validating global findings reported by (Navia et al., 2024). Unlike more complex systems, the proposed simplified solution demonstrates practical value and feasibility under the technological and economic constraints of rural Ecuador. Future developments of this research may include the integration of additional physiological parameters, such as heart rate or respiration, to provide a more comprehensive view of cattle health. Likewise, incorporating renewable energy sources, such as solar panels, could improve device autonomy and reduce maintenance needs. Finally, the integration of advanced data analytics or machine learning techniques could enhance anomaly detection and decision-making, further strengthening the role of IoT in sustainable livestock management

Contributions ot the Authors

Walter Armando Orozco Iguasnia: Conceptualization, Methodology, Writing-revision and editing paper. **Juleidy Jailin Tigrero Muñoz:** Research, Data curation, Formal analysis and Software. **Santiago Andrés Orozco Villarroel:** Original draft paper.

Conflict of interest

The authors declare that they have no conflict of interest.

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