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Automated monitoring system for estrus signs in cattle using precision livestock farming with IoT technology in the Peruvian Amazon

Sistema automatizado de monitoreo de signos de celo en bovinos mediante ganadería de precisión con tecnología IoT en la Amazonía peruana

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ABSTRACT

Estrus detection is key to optimizing conception in cows and improving livestock reproductive efficiency. The conventional method requires continuous observation, demanding labor and time. We developed an IoT-based system that automates estrus monitoring using a multisensor device mounted on the cow's neck. It collects data and transmits it via LoRaWAN to a Gateway, which forwards it to The Things Stack and then to TagoIO for visualization and storage. In field tests, after synchronizing estrus in a cow in the Peruvian Amazon, data was collected and analyzed. The system recorded physiological and behavioral information, showing that within 72 hours, movement and body temperature increased, indicating estrus.

Keywords: Estrus detection; precision livestock farming; Internet of Things; LoRa; LoRaWAN

RESUMEN

La detección del estro es clave para optimizar la concepción en vacas y la eficiencia reproductiva del ganado. El método convencional requiere observación continua, demandando mano de obra y tiempo. Desarrollamos un sistema basado en IoT que automatiza el monitoreo del estro mediante un dispositivo multisensor montado en el cuello de la vaca. Este recopila datos y los transmite vía LoRaWAN a un Gateway, que los envía a The Things Stack y luego a TagoIO para visualización y almacenamiento. En pruebas de campo, tras sincronizar el estro de una vaca en la Amazonía peruana, se recolectaron datos y se analizó su variación. El sistema registró información fisiológica y de comportamiento, evidenciando que en 72 horas aumentaron el desplazamiento y la temperatura corporal, indicando el estro.

Palabras clave: detección del celo; ganadería de precisión; Internet de las cosas; LoRa; LoRaWAN

1. INTRODUCTION

The global population reached 8 billion in 2022 and is estimated to grow to 9.7 billion by 2050 (United Nations Organization, 2023). This increase will significantly drive food demand, necessitating a 60% to 70% rise in production to meet this need (Food and Agriculture Organization, 2016). Similarly, global consumption of meat and other animal-based products is expected to grow progressively, driven by rising urbanization rates (Milford et al., 2019).

In this context, the need for efficient cattle management becomes evident, aiming to produce a higher volume of livestock with limited natural resources, such as land and water (Dineva & Atanasova, 2021; Gargiulo et al., 2018; Sharma et al., 2021). This reality presents significant challenges for the livestock industry to improve animal production in terms of productivity, efficiency, and environmental sustainability (Araújo et al., 2021). Therefore, solutions tailored to the sector are needed to enhance livestock management, improve animal welfare, and address growing challenges (Chaudhry et al., 2020; Shabani et al., 2022).

A key factor in achieving reproductive efficiency in cattle is the accurate and positive detection of estrus, which is essential to maximize conception opportunities in cows. Effective estrus detection must consider several factors: the cow must exhibit estrus, and the farmer must detect it. Low detection rates result in reduced fertility, prolonged calving intervals, and intensive heifer replacement, leading to economic losses (Nebel et al., 2011).

The estrus or heat period is an external behavioral sign in cattle, during which females are most fertile and receptive to mating with males. However, its duration is very short, lasting between 10 to 18 hours per month; thus, effective detection is crucial to ensure pregnancy and reduce calving intervals (Pohler et al., 2020; Remnant et al., 2018). Estrus signs are associated with behavioral changes due to increased hormonal levels preceding ovulation. The primary and most pronounced sign is standing to be mounted, indicating that the female is ready for mating. Secondary signs include mounting or attempting to mount other cows, increased locomotion, reduced feed and water intake, sniffing other cows' genitalia, increased vocalization, and more aggressive and agonistic interactions (López-Gatius, 2022; Reith & Hoy, 2018; Röttgen et al., 2018).

The traditional method of estrus detection is visual and continuous observation of cow behavior, an activity that is highly labor and time intensive. As herd sizes increase, this method becomes inefficient, requiring more time from farm personnel. Additionally, it must be noted that mounting receptivity is typically expressed during nighttime (6:00 pm–6:00 am) (Wangler et al., 2005), which often results in estrus going unnoticed. Consequently, fewer calves are born, leading to economic losses (Jónsson et al., 2011; Kaya et al., 2018; Koçyiğit et al., 2021). This technique has an efficiency rate of less than 50% in herds (Van Eerdenburg et al., 2002).

Precision livestock farming encompasses the application of smart technologies, such as the Internet of Things (IoT), for monitoring livestock behavior to manage production, health, reproduction, animal welfare, and environmental impact. This approach has the potential to improve decision making for farmers, reduce workload, and increase profitability (Astill et al., 2020; Kraft et al., 2022; Monteiro et al., 2021; Morrone et al., 2022; Odintsov Vaintrub et al., 2021; Papakonstantinou et al., 2024). The development of these technologies for automated estrus detection has improved livestock reproductive indices while requiring less labor (Benjamin & Yik, 2019).

Automatic monitoring of animal variables generally involves placing an electronic device equipped with sensors (Eckelkamp, 2019; Niloofar et al., 2021). One of the earliest technologies applied were pedometers, which are attached to cows' legs to record the number of steps per unit of time. This count indicates increased locomotion associated with estrus (Gündüz & Başçiftçi, 2023; Yildiz & Özgüven, 2022), achieving detection rates of 80–90%, although with a high incidence of false positive estrus alerts (Firk et al., 2002). Another commonly used technology in livestock is accelerometers, encapsulated in collars and placed on cows' necks. These devices identify upward head and neck movements during walking and mounting activities, generating time series data to determine estrus (Rahman et al., 2018).

For its part, the technique that uses image acquisition cameras requires a computer to analyze estrous behavior in the recorded videos (Lodkaew et al., 2023). This approach is combined with machine learning and computer vision to detect estrus in cows; however, it only considers primary signs and disregards secondary estrus signs (Heo et al., 2019; Noe et al., 2021).

Similarly, locators that assist in navigating to a specific location using satellite signals, such as the Global Positioning System (GPS), are used to accurately determine the geolocation of animals. This reduces the time and effort required for tracking and grouping, particularly on large-scale farms (Hassan-Vásquez et al., 2022; Vidal-Cardos et al., 2024). GPS trackers have also been combined with accelerometers to obtain multimodal information and classify animal behavior (Arablouei et al., 2023).

Recently, infrared thermography has emerged as a non-invasive and user-friendly technique capable of generating estrus alerts by detecting changes in the animal's body surface temperature. This method does not rely on monitoring physical activity, requires less handling, and causes minimal stress to the cattle (Perez Marquez et al., 2019; Riaz et al., 2023; Singh Rajput et al., 2022; Tiwari et al., 2021; Wang et al., 2023).

In Peru, the potential of natural resources offered by each region determines the type of livestock production system. Combined with modern techniques, these systems ensure competitive livestock farming to maintain, exploit, and develop production and the domestic market. The national livestock population is 27.9 million livestock units, of which 5.8 million are cattle. Of this population, 60% is located in the highlands, 26% on the coast, and 14% in the rainforest. The department of Madre de Dios, located in the southeastern part of Peru, has 64,923 cattle with an annual growth rate of 1.9% from 2007 to 2023. Over 50,000 hectares of its area are allocated to extensive livestock farming (Ministerio de Desarrollo Agrario y Riego, 2024).

Extensive livestock farming provides benefits that promote animal welfare, offering free access to their natural environment where they can exhibit innate behaviors such as grazing and exploration. Additionally, it contributes to landscape protection and carbon sequestration (Scoones, 2023). Extensive farmers prioritize feeding livestock with local pastures (Wróbel et al., 2023) due to their low financial investment and relative ease of management. However, controlling the livestock becomes more challenging due to infrastructure limitations and communication options (Morgan-Davies et al., 2018). These limitations are driving the increasing adoption of precision livestock farming in extensive cattle grazing systems on pastures (Aquilani et al., 2022).

In this context, the present study proposes the design and implementation of an IoT-based system to monitor and collect real-time data on multiple parameters associated with changes occurring during the estrus cycle of female cattle, including body temperature, physical movement, and locomotion. Unlike existing studies, this research introduces a combined analysis of explanatory variables of estrus, focusing on the physiological variable of temperature and physical activity to improve detection rates, taking into account that the intensity and duration of estrus are unique to each animal.

2. MATERIALS AND METHODS

2.1. Experimental Site

The data was collected at the facilities of the Jorge Basadre Grohmann Higher Technological Institute, located in Madre de Dios, Peru (12°35′32″ S latitude, 69°11′39″ W longitude, and an altitude of 183 meters). The institute covers an area of 14.3 hectares and operates an extensive production system where cattle graze on natural pastures.

2.2. IoT System Design and Development

The architecture of the estrus monitoring system based on IoT technology followed the three-layer model: perception, network, and application (Al-Fuqaha et al., 2015; Al-Gumaei et al., 2018; Domínguez-Bolaño et al., 2022), as illustrated in Figure 1.

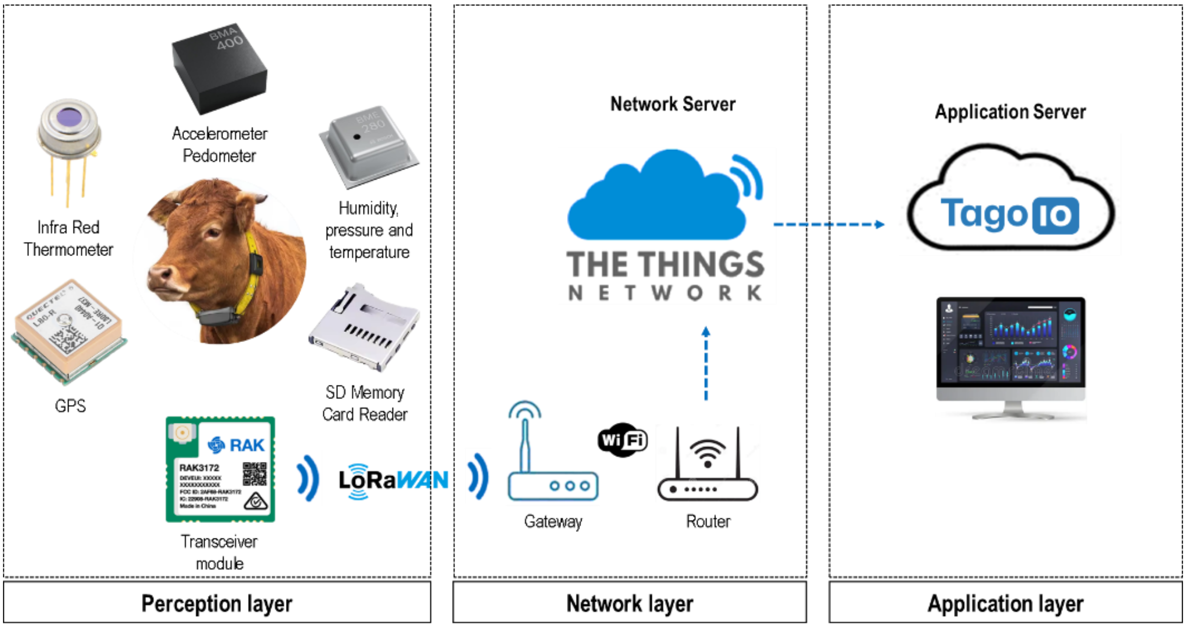


Figure 1. IoT system architecture for monitoring estrus signs in cattle

2.2.1. Perception Layer

An electronic device was designed and manufactured, consisting of a compact printed circuit board (PCB) that integrates sensors to record parameters such as movement, locomotion activity, geolocation, and the animal's body temperature, as well as the ambient temperature. The board includes a microcontroller, sensors, a long-range wireless communication module, and a socket for adding external memory. A rechargeable 3.7V 3000mAh Li-Ion battery was incorporated to provide autonomy to the device. The PCB design was created using the open-source software tool KiCad 8.0 (Kanagachidambaresan, 2021; X. Zhao et al., 2024).

Figure 2 shows the PCB design created with KiCad software. The board was housed in a 3D-printed case made of carbon fiber material. The physical dimensions of the electronic board were 6.26 cm × 5.08 cm (L × W).

(a) (b) (c)

Figure 2. Device design and assembly: (a) PCB design; (b) Electronic board with soldered components; (c) Top view of the PCB encapsulated in a housing

The electronic device is centered around the RAK3172 module, which integrates the STM32WLE5CCU microcontroller from the STM32 family by STMicroelectronics. Its features allow it to function both as a control unit and for long-range wireless communication. This microcontroller features a high-performance 32-bit Arm Cortex-M4 RISC core, with an operating frequency of up to 48 MHz. It incorporates 256 KB of flash memory, 64 KB of SRAM, and supports UART (Universal Synchronous Asynchronous Receiver Transmitter), I2C (Inter-Integrated Circuit), and SPI (Serial Peripheral Interface) interfaces (Kustov et al., 2023; STMicroelectronics, 2024). The electronic board includes three sensors and a satellite positioning module (GPS), detailed as follows:

(i) Bosch BMA400 triaxial acceleration sensor with pedometer: Used to record data on head and neck movements, as well as the number of steps taken by the cattle during locomotion activities. This sensor features ultra-low power consumption, extending battery life.

(ii) Melexis MLX90614 non-contact infrared temperature sensor: Designed to measure the body temperature of the cattle. This sensor has a fine membrane sensitive to infrared radiation emitted by a distant object, with an operating range from -70°C to 380°C and an accuracy of 0.5°C.

(iii) Quectel L80-R GPS Receiver: Equipped with an integrated patch antenna and a low-noise amplifier, it was used to record the cow's position. This tracker offers high sensitivity, precision, and navigation performance with minimal energy consumption. It can acquire and track satellites quickly, even indoors.

(iv) Bosch BME280 atmospheric pressure, temperature, and relative humidity sensor: Used to measure environmental conditions in the cow’s surroundings. This low-power sensor has a pressure range of 300 to 1100 hPa, a temperature range of -40°C to 85°C, and a humidity range of 0 to 100%.

(v) MicroSD Memory Slot: Allowed local storage of data collected by the sensors.

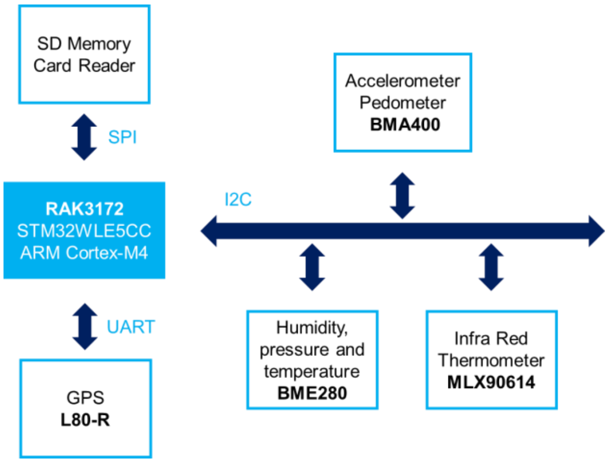


Figure 3. Presents a schematic of the asynchronous and synchronous communication protocols used for data transmission from each sensor to the microcontroller

The STM32CubeMX graphical interface was used to assign the pins of the STM32WLE5CCU microcontroller and generate the C code. The initial configuration is shown in Figure 4. The following is a list of hardware initialization steps for the microcontroller:

1. Middleware initialization to transmit data received from the sensors using the LoRa module via the LoRaWAN protocol.

2. GPIO input and output pin configuration.

3. Communication interfaces: UART, I2C, SPI.

4. Sub-GHz network mode configured to operate in the 915 MHz frequency band.

5. Timer initialization in RTC mode to activate the calendar and configure the 48 MHz clock source.

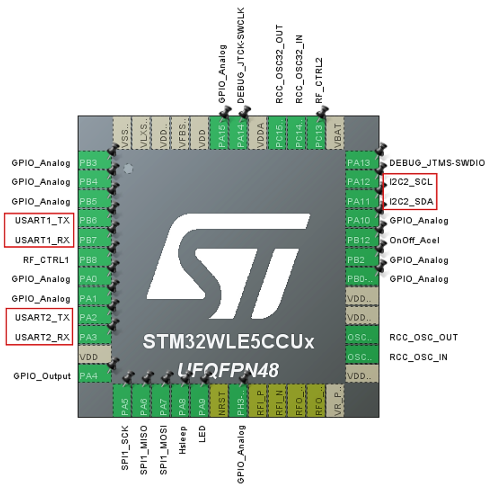


Figure 4. STM32CubeMX interface for pin assignment of the STM32WLE5CCU microcontroller

The STM32CubeIDE platform (version 1.16.1) was used to configure peripherals and generate, compile, and debug the project code. First, specific libraries (files with the `.h` extension) were created to manage each of the sensors: BMA400, BME280, MLX90614, and L80-R. Next, individual programs (files with the `.c` extension) were developed to perform the reading, calibration, and storage of data collected by each sensor. These programs referenced the previously created libraries. We present the algorithm that implements the library for managing the BME280 sensor in Annexes A.1 and the algorithm for reading temperature, pressure, and humidity from the BME280 sensor in Annexes A.2

2.2.2. Network Layer

The data collected by the sensors in the perception layer was transferred using LoRa (Long Range) (Gkotsiopoulos et al., 2021; Sun et al., 2022) and LoRaWAN (Long Range Wide Area Network) (Al-Samman et al., 2022; Jouhari et al., 2023) technology. The RAK3172 transceiver module for LoRa and LoRaWAN applications was configured to operate in the 915 MHz frequency band, creating a long-distance communication link through radiofrequency modulation.

The binary data from the LoRa frame was received by the RAK7249 Gateway at 915 MHz and subsequently transmitted to the network server The Things Stack via WiFi. There, the data was decoded using a JavaScript program into a human-readable format, as shown in Figure 5.

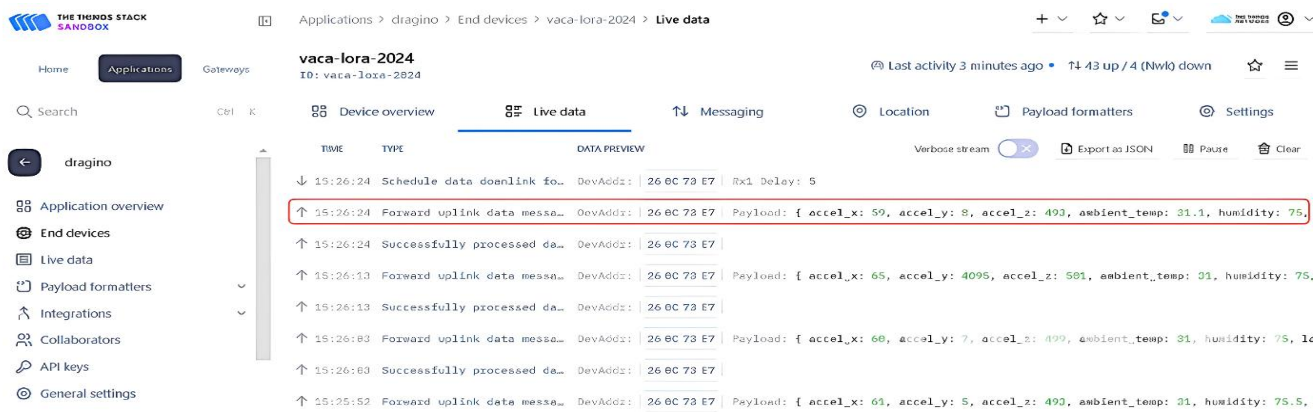


Figure 5. Data uploaded to The Things Stack network server

2.2.3. Application Layer

The Things Stack uses webhooks to send data to various cloud-based IoT platforms via the HTTP protocol, providing multiple webhook templates to facilitate these integrations and enable data transmission to third-party services. We integrated the system with the TagoIO platform, so whenever The Things Stack receives data, it sends a webhook to access TagoIO's HTTP endpoint and transmits it in JSON format. This data is stored and visualized in a dashboard, as shown in Figure 6.

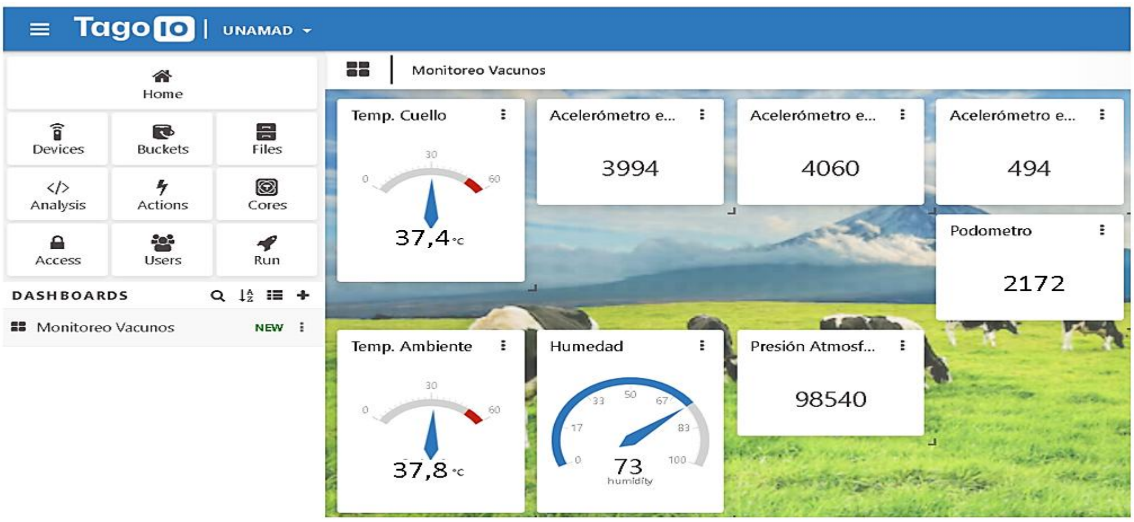


Figure 6. Monitoring measurements on the TagoIO platform dashboard

2.3. Field implementation in animals

2.3.1. Animal Selection

A mature Holstein cow in its reproductive stage, weighing approximately 350 kg, clinically and physiologically healthy, and in its second calving, was selected.

2.3.2. Gynecological Diagnosis

A gynecological ultrasound was performed on the selected cow to confirm its non-pregnant reproductive status. Additionally, its ovarian structure was evaluated to identify the presence of a corpus luteum or dominant follicles.

2.3.3. Hormonal estrus synchronization

Estrus synchronization refers to manipulating the estrous cycle or inducing estrus to bring the female into estrus in less than 21 days (Arya et al., 2023). The hormone used for estrus synchronization was prostaglandin F2α (PGF2α).

2.3.4. Animal testing

Field experiments were conducted from November 1 to November 4, 2024, with each day labeled as day 1, day 2, day 3, and day 4 of the trial. The device, housed in a casing, was fixed around the cow’s neck using a strap, as shown in Figure 7. The sensors were programmed to record body surface temperature, step count, and body movement every 5 minutes, and the animal's geolocation every minute.

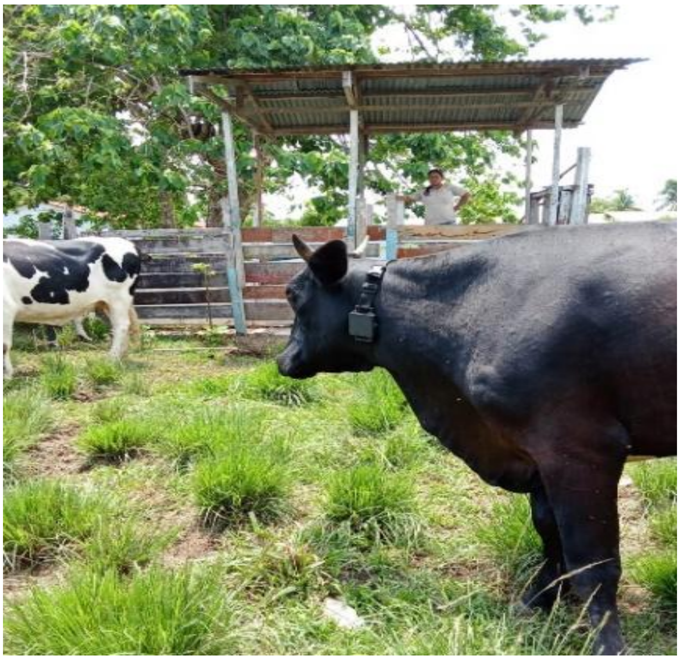


Figure 7. Cattle with electronic device during data collection experiment

3. RESULTS

Physiological and behavioral data from the cattle were collected for analysis and pattern recognition associated with the phases of the estrous cycle to verify the occurrence of estrus in the cow. Since the hormonal treatment to induce estrus was applied at noon on October 31, 2024, the theoretical estrus response was expected to occur 72 hours later, during day 3 of the experiment.

3.1. Cow step count

Figure 8 plots the step count separated by day of the experiment and according to the corresponding data collection time. During days 1, 2, and 4 of the study, the female cow exhibited similar locomotor activity. In the early hours of the day, between 6:00 and 8:00 a.m., the cow increased its steps while searching for high-quality food. This was followed by a decrease in activity over the next two hours as the cow continued feeding and ruminating. Between 11:00 a.m. and 12:30 p.m., the highest step count was observed as the cow moved in search of shade due to higher heat incidence, followed by a resting period of approximately an hour and a half. From 3:00 p.m. onward, as the heat sensation decreased, the cow resumed continuous movement, although at lower levels compared to earlier, and continued feeding and drinking water to support its digestive function.

On day 3 of the experiment, the cow increased its movement, with very short periods of inactivity followed by an abrupt increase in steps at midday, despite the high sun exposure. In the afternoon, the cow exhibited its highest locomotor activity, with a step count exceeding that of the previous days. This pattern of translational movement indicates the appearance of estrus signs, coinciding with the onset of estrus 72 hours after the application of hormonal treatment.

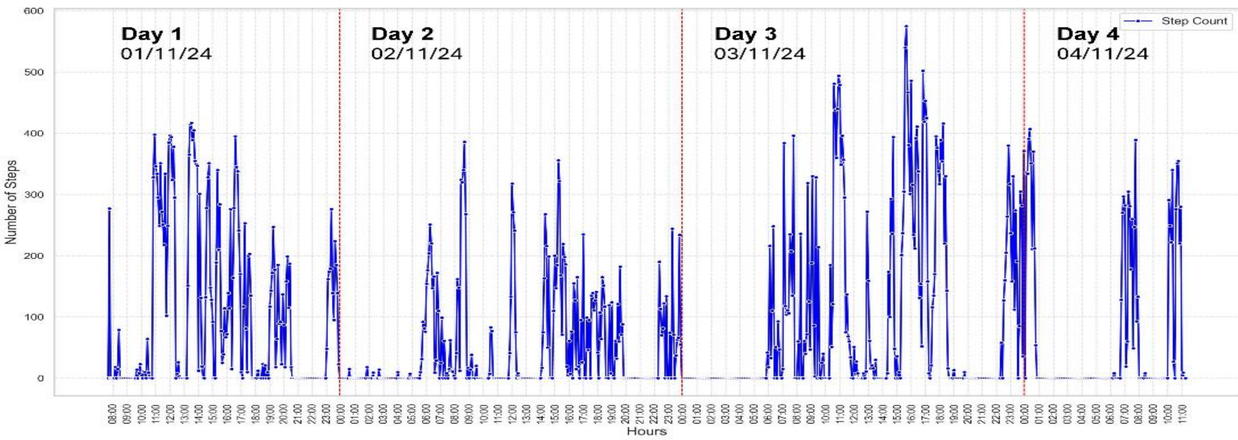
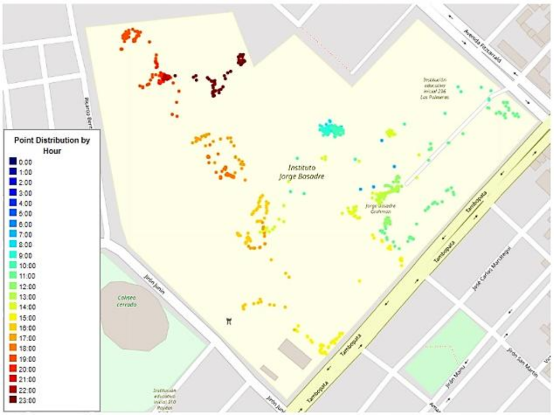


Figure 8. Number of steps recorded by the cow using the pedometer

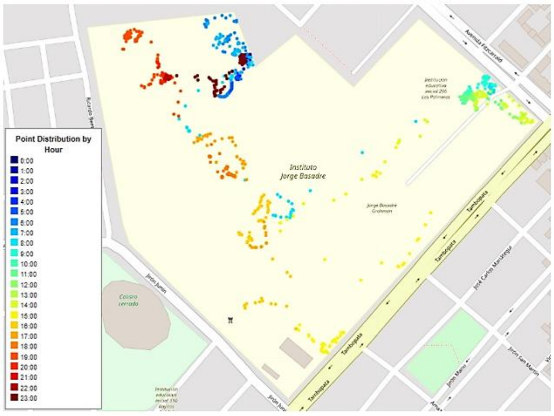
3.2. Cow geolocation

Figure 9 shows the GPS-estimated positions (longitude and latitude coordinates) of all points collected by the device. The estimated positions were plotted separately for each day and color-coded according to the time of data collection. Figure 9 (c) depicts the animal's location on day 3, between 6:00 and 8:00 a.m. (light blue tones). The dense points indicate minimal translational movement. It is observed that in the following hours, the cow covered greater distances in grazing areas, searching for food and water, coinciding with the increased step count recorded during those hours.

At midday, the concentrated points (cyan tones) denote minimal translational movement, as the animal remained under the trees to protect itself from the sun's heat. Around 4:00 p.m., the focused points represent the cow's movement within a small area. However, the higher step count during this period further supports the hypothesis of behavioral changes in the cow during estrus.



(**a**)



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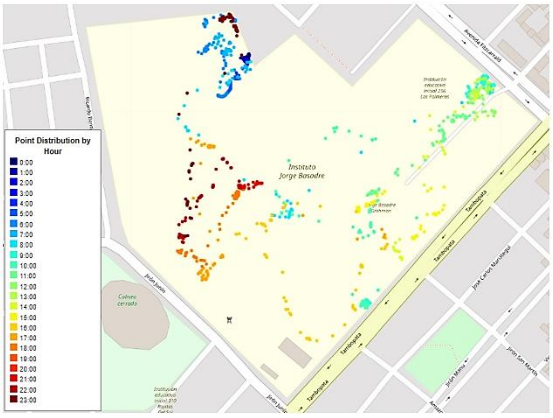
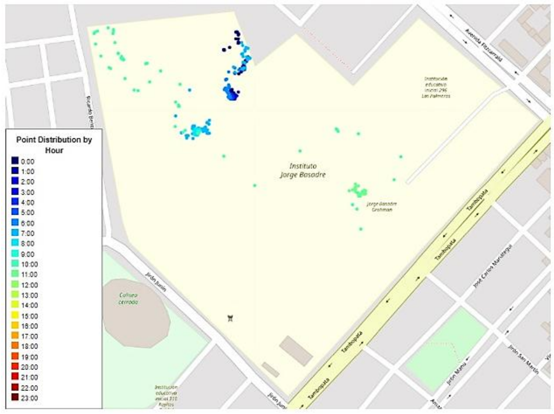


(**c**)



(**d**)

Figure 9. GPS-estimated position coordinates for each test day, with points colored by hour of data collection: (a) Day 1; (b) Day 2; (c) Day 3; (d) Day 4

3.3. Cow Body Temperature

Figure 10 shows the temperature values recorded by the infrared sensor, separated by day and hour of data collection. It is observed that around 3:00 p.m. on day 3 of the experiment, the animal's body temperature reached its highest level. This variation coincides with the increased step count and the greater movement range of the cow.

This temperature information, on its own, demonstrates a change in the cow's non-pathological physiological state, which aligns with the onset of estrus following the hormonal application to induce the estrous cycle.

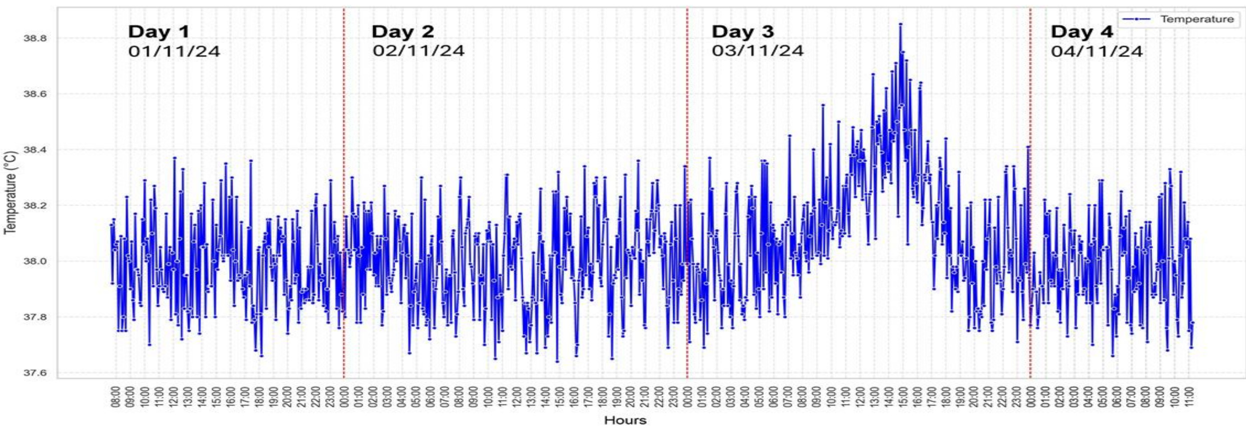


Figure 10. Cow body temperature recorded using the infrared sensor

In recent years, several authors have highlighted the need for a deeper under-standing of the behavioral and physiological changes in females during their estrous cycle to achieve efficient estrus detection and high reproductive performance in herds. This is particularly important given the decreasing expression of estrus and the existing limitations in identifying cows in estrus. Recent technological developments have emerged as alternatives to visual estrus detection or manual body temperature measurement methods, which can cause stress in animals and negatively impact reproductive outcomes. One such alternative is auto-mated estrus detection through the monitoring of the animal's physical activity.

This study proposes the development of an IoT system to monitor estrous physiological and behavioral variables using a non-invasive device placed on the animal's neck to collect data related to step count, geolocation, and body temperature. Unlike previous studies that monitored only a single parameter, this research employs multiple sensors, including a pedometer, GPS receiver, and body temperature sensor, enabling the combination of information for improved accuracy in identifying the estrous period in cows. During system testing, a hormonal synchronization protocol was used to induce estrus exhibition in the cow approximately 72 hours after treatment application.

The study found that female cattle exhibit more active behavior near the estrous period and during estrus compared to normal days. Consequently, the cow's daily step count increases. On day 3 of the trial, following the 72-hour post-treatment period, the cow reached a peak of 575 steps, compared to peaks of 417, 386, and 407 steps recorded on days 1, 2, and 4, respectively. Additionally, on the same day, around 4:00 p.m., changes in the animal's location were observed, concentrated in small areas. Despite the higher step count, these movements likely correspond to secondary estrous behavioral signs, such as initiated and received mounts, trailing, rubbing, anogenital sniffing, and aggressive behavior.

Moreover, a sustained increase in body temperature was observed, peaking at 38.85°C on day 3 starting at 7:00 a.m. This value exceeds the peaks of 38.37°C, 38.36°C, and 38.33°C recorded on days 1, 2, and 4, respectively. These findings align with, who reported that the animal's body temperature temporarily decreases a few days before estrus, followed by a sudden rise during estrus. This temperature in-crease is associated with the rise in preovulatory luteinizing hormone. Additionally, Gündüz & Başçiftçi (2023) state that body temperature generally ranges between 38.5°C and 38.6°C under healthy conditions, and during estrus, ap-proximately 84% of animals show a temperature increase between 0.1°C and 0.5°C, which is consistent with our findings.

In summary, since cows exhibit distinct behavior during the estrous phase, estrus detection was determined to coincide with periods of heightened focused physical activity and increased body temperature before returning to baseline.

CONCLUSIONS

We developed an Internet of Things (IoT)-based system to automate the monitor-ing of estrus signs, aiming to assist farmers in detecting cows during the estrous period. The system consists of an electronic device capable of long-distance data transmission using LoRa/LoRaWAN technology, with data sent to the TagoIO web platform for storage and visualization. The device was placed on a cow from the herd at the Jorge Basadre Grohman Higher Technological Institute, located in the Peruvian Amazon, to collect parameters such as step count, geolocation, and body surface temperature. Data analysis confirmed that when the animal exhibits induced estrus, its behavior changes, with increased physical activity and body temperature. The adoption of innovative technologies for cattle monitoring not only promotes efficiency and productivity but also provides other key benefits, such as traceability and food safety, environmental sustainability, automation, data-driven decision-making, and reduced operational costs. This study represents a significant step toward consolidating precision livestock farming in extensive grazing systems, where technology and science are integrated to ensure more sustainable, profitable, and animal welfare-oriented management.

ACKNOWLEDGMENTS

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FINANCING

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to the development of the study.

AVAILABILITY OF DEPOSITED DATA

The datasets collected during this study and supporting the findings of the study are available at: https://github.com/luisholgado/cow_data_set

AUTHORSHIP CONTRIBUTION

Conceptualization: Prieto-Luna, J. C., Alarcón-Sucasaca, A., Turpo-Galeano, Y. H., Delgado-Berrocal, Y. R., and Fernández-Romero, V. Data Curation: Prieto-Luna, J. C., Turpo-Galeano, Y. H., Delgado-Berrocal, Y. R., and Holgado-Apaza, L. A. Formal Analysis: Prieto-Luna, J. C., Alarcón-Sucasaca, A., Fernández-Romero, V., and Holgado-Apaza, L. A. Research: Prieto-Luna, J. C., Alarcón-Sucasaca, A., Turpo-Galeano, Y. H., Delgado-Berrocal, Y. R., and Fernández-Romero, V. Methodology: Prieto-Luna, J. C. and Fernández-Romero, V. Project Administration: Prieto-Luna, J. C. and Alarcón-Sucasaca, A. Software: Prieto-Luna, J. C. Validation: Prieto-Luna, J. C. and Fernández-Romero, V. Writing - Original Draft: Prieto-Luna, J. C., Alarcón-Sucasaca, A., Fernández-Romero, V., and Holgado-Apaza, L. A. Writing - Review and Editing: Prieto-Luna, J. C. and Holgado-Apaza, L. A.

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Annexes

Annexe A.1

Algorithm 1: Definition of the library for managing the BME280 sensor

```
START
1. DEFINE A CONSTANT TO PREVENT MULTIPLE INCLUSIONS:
    if not defined BME280_H then
        define BME280_H
    end if
2. INCLUDE NECESSARY HEADERS:
    Include the HAL library for STM32:
    Include the standard integer library:
```

3. DEFINE THE BME280 SENSOR ADDRESS:
BME280_ADDRESS ← 0x76 shifted 1 bit to the left
4. DEFINE THE ADDRESSES OF IMPORTANT REGISTERS:
ID REGISTER ← 0xD0
HUMIDITY CONTROL REGISTER ← 0xF2
MEASUREMENT CONTROL REGISTER ← 0xF4
CONFIGURATION REGISTER ← 0xF5
REGISTERS FOR PRESSURE, TEMPERATURE, AND HUMIDITY DATA
5. DEFINE A STRUCTURE FOR CALIBRATION DATA:
Fields to store the calibration values provided by the sensor:
Temperature calibration parameters (dig T1, dig T2, dig T3)
Pressure calibration parameters (dig P1 a dig P9)
Humidity calibration parameters (dig H1 a dig H6)
6. DEFINE A STRUCTURE FOR SENSOR MANAGEMENT:
hi2c: Pointer to the I2C controller to be used for communication with the sensor
calib data: Sensor calibration data
t fine: Auxiliary value for temperature calculations
7. DECLARE FUNCTIONS TO INTERACT WITH THE SENSOR:
BME280 Init: Initialize the sensor
BME280 ReadID: Read the unique identifier of the sensor
BME280 ReadTemperature: Read and calculate temperature
BME280 ReadPressure: Read and calculate pressure
BME280 ReadHumidity: Read and calculate humidity
END

Annexe A.2

Algorithm 2: Read temperature, pressure, and humidity from the BME280 sensor

START
1. DECLARE AUXILIARY FUNCTIONS:
BME280_ReadReg: Read data from a register
BME280_WriteReg: Write data to a register
2. DECLARE FUNCTION TO READ CALIBRATION DATA:
BME280_ReadCalibrationData: Read calibration registers from the BME280, extract and store calibration values to correct subsequent measurements.
3. DECLARE FUNCTION TO INITIALIZE THE SENSOR:
BME280_Init: Call the calibration reading function and configure the sampling type, delay time, and filter.
4. DECLARE FUNCTION TO READ SENSOR ID:
BME280_ReadID: Read the device identifier from a specific register.
5. DECLARE FUNCTION TO READ TEMPERATURE DATA:
BME280_ReadTemperature: Read temperature data from the sensor, apply calibration adjustments, and obtain the measurement in °C.
6. DECLARE FUNCTION TO READ PRESSURE DATA:
BME280_ReadPressure: Read atmospheric pressure data from the sensor, apply calibration adjustments, and obtain the measurement in pascals.
7. DECLARE FUNCTION TO READ HUMIDITY DATA:
BME280_ReadHumidity: Read humidity data from the sensor, apply calibration adjustments, and obtain the measurement in %.
END