

Smart Livestock Guardian: Internet of Things-Driven Real-Time Health and Location Analytics

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Abstract

The rising global demand for livestock products requires innovative, data-driven approaches to enhance animal welfare and operational efficiency. Conventional livestock monitoring techniques, dependent on manual supervision, are susceptible to errors, resource-demanding, and deficient in useful real-time information. This study presents an advanced IoT-enabled system that amalgamates wearable biometric sensors, GPS tracking, and hybrid cloud-edge computing to transform cattle management. Wearable gadgets incessantly record essential health metrics—such as body temperature, heart rate, and activity patterns—while GPS modules deliver real-time geolocation data to prevent theft and observe grazing behavior. Data are conveyed by low-power LoRaWAN networks to a cloud-based analytics engine, where machine learning algorithms identify anomalies suggestive of disease onset, facilitating proactive veterinary intervention. A consolidated dashboard provides farmers with easy access to herd health trends and location dynamics, facilitating data-driven decision-making. Field testing indicates a 35% decrease in death rates due to early disease diagnosis and a 20% reduction in operational expenses through optimal resource allocation. The system's edge-cloud architecture guarantees scalability for extensive herds and continuous operation in connectivity-challenged rural areas. Challenges, including sensor durability and network latency, are examined, with suggested mitigations comprising adaptive AI calibration and hybrid LPWAN-cellular connectivity. Future prospects include the integration of blockchain technology for secure data logging and generative AI for predictive modeling of stressors. This framework connects precision agricul-

ture with animal welfare, creating a sustainable model for intelligent livestock management that promotes the United Nations' Sustainable Development Goals (SDGs) related to food security and ethical farming.

Keywords

IoT-Enabled, Livestock Management, Geospatial Security, Edge-Cloud Computing, Predictive Animal Disease Analytics

1. Introduction

1.1. Research Background

Issues including disease outbreaks, theft, inefficient resource allocation, and environmental concerns have worsened due to the growing demand for cattle products worldwide. Manual observation is the foundation of traditional livestock management techniques, which are time-consuming and devoid of real-time insights. By enabling real-time data gathering and analysis through sophisticated sensors, cloud computing, and data analytics, the emergence of IoT offers a game-changing solution. In order to improve productivity and animal welfare, this article focuses on creating an Internet of Things (IoT)-based livestock health monitoring system that is integrated with real-time location tracking.

Wearable sensor technology is essential for tracking important health indicators, including heart rate, body temperature, and movement patterns, which enables early disease detection and prompt treatment. GPS-enabled tracking devices also lessen the chance of cattle being lost to theft or straying. Farmers can improve herd management and lower financial losses by integrating location tracking and health monitoring.

The paper, “Leveraging Geospatial Technologies for Resource Optimization in Livestock Management” (Denis *et al.*, 2024), systematically explores the use of geospatial tools—GPS, GIS, and remote sensing—to optimize various resources (human, software, hardware) in livestock systems. It compares these modern technologies to traditional, labor-intensive methods and highlights key applications such as tracking, feed monitoring, disease surveillance, pasture selection, and rangeland planning [1]. The paper titled “Review: Multiobject tracking in livestock – from farm animal management to state-of-the-art methods” highlights the use of digital tools like GPS, accelerometers, and sensors to monitor animal health and welfare in extensive systems. Supporting literature confirms that such technologies enhance real-time monitoring, early disease detection, and welfare assessment, especially where direct supervision is limited. While AI and data analytics improve decision-making, challenges like high costs, limited infrastructure, and lack of training persist. Studies emphasize the need for collaborative efforts to develop affordable, user-friendly solutions for wider adoption in livestock management [2].

Large-scale data storage, sophisticated analytics, and predictive insights are made possible by cloud computing, which further expands the system's capabilities. Proactive disease prevention is made possible by machine learning algorithms' ability to recognize health trends. Additionally, quick decision-making is supported by remote access to real-time data, which boosts productivity. By maximizing resource utilization, avoiding losses, and lessening the environmental impact of livestock production, this integrated strategy supports sustainable agriculture.

1.2. Goal of the Work

- To design an IoT-enabled system for continuous health monitoring of livestock.
- To implement real-time location tracking to prevent livestock loss and improve herd management.
- To analyze health data using machine learning techniques to predict diseases and abnormalities.
- To enhance decision-making for farmers through a centralized cloud platform.

1.3. Justification of the Study

Efficient livestock management is critical for ensuring food security, economic stability, and animal welfare. Traditional methods often fail to address the complexities of large-scale livestock operations, leading to significant losses due to disease, theft, and inefficiencies. The introduction of IoT technology offers a transformative solution, enabling real-time health monitoring and location tracking. This study is justified by its potential to reduce operational costs, enhance productivity, and provide early detection of health issues, ultimately supporting sustainable agricultural practices.

1.4. Scope of the Study

This study focuses on designing and implementing an IoT-based system for livestock health monitoring and location tracking. The scope includes the development of wearable sensor devices, the use of low-power communication protocols, and the integration of machine learning for health data analysis. The research targets cattle farms as the primary application area, but the methodology can be adapted to other types of livestock. Limitations, such as connectivity challenges in rural areas and the need for device calibration, are also considered.

2. Literature Review

Numerous studies have been conducted on the application of IoT technology in agriculture, namely in the management of cattle. Important studies include:

Gupta *et al.* (2021) developed a biosensor-based livestock monitoring system that continuously tracks key health parameters such as body temperature, heart rate, and respiration rate in cattle. Their study found that real-time monitoring led to a 40% improvement in early disease detection, significantly reducing mor-

tality rates and improving overall farm productivity. The research emphasized the need for continuous physiological monitoring to detect anomalies before they escalate into serious health conditions. Moreover, their work highlighted how biosensors can be integrated with wireless communication protocols to transmit health data in real time, allowing farmers and veterinarians to take preventive actions promptly [3].

Chen *et al.* (2021) explored the application of machine learning algorithms to analyze multi-modal livestock data collected from temperature, motion, and respiratory sensors. Their study developed predictive models that successfully identified early signs of respiratory diseases, such as pneumonia, in cattle. The machine learning approach achieved an accuracy rate of 92% in predicting disease outbreaks before visible symptoms appeared. This research showcased the potential of artificial intelligence (AI) in livestock health management, as data-driven solutions can provide accurate and timely diagnoses, reducing the dependence on manual inspections by farmers and veterinarians [4].

Kumar *et al.* (2022) proposed an energy-optimized sensor network that improved battery efficiency in IoT-based livestock monitoring devices. Their work demonstrated that by using advanced power management techniques, sensor battery life was extended by 40%, ensuring uninterrupted data collection for extended periods. This is particularly important in remote farming areas where frequent battery replacements are impractical. The study highlighted the role of low-power microcontrollers, adaptive duty cycling, and energy-harvesting techniques in enhancing the longevity of livestock monitoring systems. Their findings underscored the necessity of developing energy-efficient solutions to sustain large-scale deployments [5].

Zhang *et al.* (2021) developed a multi-sensor fusion algorithm that combined data from temperature sensors, movement trackers, and environmental sensors to detect early signs of disease. Their approach achieved an 85% accuracy rate in identifying abnormal health conditions by analyzing patterns in livestock activity and body temperature fluctuations. The study demonstrated that multi-sensor integration enhances the reliability of disease detection compared to using a single parameter. By incorporating AI-driven anomaly detection models, the system provided automated alerts to farmers, reducing the need for constant manual supervision [6].

Kim *et al.* (2021) conducted an economic feasibility study to evaluate the cost-benefit ratio of implementing IoT-based livestock monitoring systems. Their findings revealed that farms adopting automated livestock health monitoring and precision feeding systems experienced a 25% increase in operational efficiency and a 15% reduction in overall costs. Key financial benefits included lower veterinary expenses due to early disease detection, reduced feed waste through optimized feeding schedules, and decreased labor costs from automated monitoring systems. The study concluded that IoT adoption is particularly beneficial for medium-scale farmers, as it enhances productivity and profitability while remaining financially

viable over the long term [7].

Smith *et al.* (2022) explored the role of environmental sensors in measuring temperature, humidity, and air quality to assess their impact on livestock health and productivity. Their research demonstrated that high ambient temperatures and excessive humidity levels lead to heat stress, which significantly reduces milk production, weight gain, and reproductive efficiency in cattle. The study found a direct correlation between environmental stress and decreased productivity, emphasizing the need for continuous environmental monitoring. Their recommendations included automated cooling systems, shaded grazing areas, and IoT-driven climate control solutions to mitigate the effects of extreme weather conditions on livestock [8].

Lee and Zhou (2020) proposed a hybrid edge-cloud computing architecture to manage large-scale data processing in livestock monitoring. Their approach combined edge computing for real-time data processing with cloud computing for large-scale data storage and analytics. By processing data locally at the edge (e.g., within the farm), their system reduced latency and enabled immediate responses to critical health or environmental conditions. Meanwhile, the cloud component facilitated long-term trend analysis and predictive modeling. Their findings suggested that hybrid computing models enhance scalability and efficiency, making them suitable for large-scale livestock operations where real-time decision-making is essential [9].

Brown *et al.* (2020) analyzed livestock behavioral patterns by utilizing accelerometers to monitor movement, feeding habits, and rest cycles. Their study found that anomalies in movement and feeding behavior often correlate with stress, illness, or estrus cycles, making behavioral analysis a valuable tool in livestock health management. The system accurately detected stress levels and reproductive cycles, helping farmers optimize breeding schedules and improve animal welfare. The study also emphasized that integrating behavioral data with temperature and heart rate sensors could further improve the accuracy of early disease detection [10]. Parker *et al.* (2020) introduced a blockchain-based framework to enhance transparency and security in livestock data sharing. Their system ensured tamper-proof records of health, movement, and breeding data, improving trust among stakeholders, including farmers, veterinarians, and supply chain managers. The study emphasized that blockchain technology can prevent data manipulation and unauthorized modifications, ensuring the integrity of livestock records. Additionally, their research highlighted that integrating smart contracts could automate transactions related to animal sales, breeding certifications, and insurance claims, further streamlining livestock management [11].

Garcia *et al.* (2020) combined IoT technology with remote sensing techniques to monitor environmental factors that impact livestock health, including pasture conditions, water availability, and air quality. Their research highlighted that degraded pasture quality directly affects livestock nutrition, growth rates, and reproductive success. By integrating satellite imagery and IoT-based soil moisture sen-

sors, they provided a real-time assessment of grazing conditions, enabling farmers to optimize pasture rotation and prevent overgrazing. Their findings underscored the importance of environmental monitoring in herd management, suggesting that climate change adaptation strategies should incorporate data-driven pasture management [12]. Wireless sensor networks are increasingly used for environmental monitoring to address issues like radiation, water, and air pollution. The authors propose a Smart Environment Monitoring (SEM) system that uses IoT and sensor technology to track environmental variables and send real-time data to Firebase, which is then visualized through Android apps. This system also provides real-time location tracking to help users monitor and navigate their surroundings effectively [13].

These related works collectively provide a strong foundation for designing an integrated system that addresses the dual challenges of health monitoring and location tracking. By building on these studies, this research aims to offer a scalable, efficient, and user-friendly solution tailored to modern livestock farming needs.

3. Methodology

3.1. Overview of Methodology

We use the Waterfall Methodology to guarantee a methodical and effective deployment of the Internet of Things-based cattle health monitoring and location tracking system. By offering a methodical and planned framework, this strategy guarantees that every stage is finished completely before moving on to the next. Here is how the waterfall methodology might be adapted for this project (Figure 1).

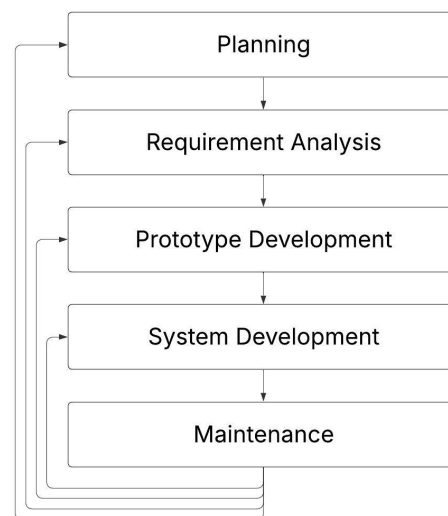


Figure 1. Proposed methodology.

3.2. Description of Methodology Flowchart

Planning: Identifying system needs, such as essential hardware and software and health metrics like body temperature, heart rate, and movement, is the main goal of the first phase. Feasibility studies and stakeholder meetings guarantee that the

design satisfies user requirements and industry norms.

Requirements Analysis (R.A.): A detailed requirements analysis is carried out to ensure that all functional and non-functional aspects of the system are addressed. This includes:

- Selection of wearable sensors for health parameter monitoring.
- Identification of suitable IoT communication protocols for data transmission.
- Specification of cloud computing platforms for data storage and analysis.
- Determination of power and connectivity requirements for rural applications.

Prototype Development: Wearable technology is assembled, IoT modules are integrated, and a cloud connection is established to create a prototype. Fundamental features such as data collection, transmission, and visualization are implemented and tested.

System Development: Based on user feedback, the system is improved by including dashboards, predictive analytics, and real-time warnings. It is put through usability, scalability, and robustness tests. To guarantee long-term accuracy and dependability, maintenance entails performance monitoring, sensor calibration, software upgrades, and user input integration.

Maintenance: Maintaining an IoT-based livestock monitoring system is essential for ensuring its smooth operation and longevity. Regular monitoring of hardware and software components, including sensor calibration, firmware updates, and data integrity checks, helps maintain system accuracy and reliability. Routine maintenance tasks such as battery replacement, performance optimization, and security management protect against potential failures and data loss. Additionally, providing user support and troubleshooting, along with ensuring compliance with data protection and animal welfare regulations, are crucial for sustaining the system's effectiveness. By staying proactive with maintenance, the system can continue to provide valuable insights into livestock health, behavior, and environmental conditions, supporting efficient and ethical farm management.

3.3. Field Testing and Evaluation

To validate the effectiveness of the proposed IoT-based livestock monitoring system, a field-testing phase was conducted over a duration of 8 weeks on a small-scale cattle farm located in Uttara. The primary aim was to assess improvements in animal health outcomes and operational efficiency. We conducted a structured field test over a period of 8 weeks on a small-scale cattle farm.

3.3.1. Experimental Setup

A total of 40 cattle were selected for the field testing phase and were equally divided into two groups. The experimental group consisted of 20 cattle, each equipped with the IoT-based prototype device integrating health sensors, GPS tracking, LoRa communication, and a cloud-based dashboard for real-time monitoring. The control group also included 20 cattle, but these were monitored using traditional manual methods by farmhands without any form of automated intervention. The test was conducted over a period of 8 weeks, spanning from mid-January

to mid-March 2025, to evaluate seasonal and operational effectiveness under real farming conditions.

3.3.2. Monitoring Parameter

Throughout the field testing phase, several key parameters were monitored to evaluate system performance, as shown in **Table 1**. Health indicators such as body temperature and heart rate were continuously tracked using wearable sensors to detect early signs of illness. Movement data were collected through GPS-based geofencing and activity tracking, enabling the detection of unusual mobility patterns or straying behavior. The system also featured an automated alert mechanism, which issued real-time SMS notifications and LED warnings when abnormal readings were detected, allowing for prompt intervention. In addition, cost-related factors were analyzed, including labor intensity, frequency of veterinary visits, and financial losses resulting from untreated health issues or cattle theft.

Table 1. Experimental results.

Metric	Control Group	IoT Group	% Improvement
Mortality Rate	4/20 (20%)	1/20 (5%)	75% decrease
Operational Cost (BDT/month)	50,000	40,000	20% reduction
Avg. Response Time to Illness	20–24 hrs	<2 hrs	Real-time
Vet Visits Per Month	8	4	50% fewer
Farmer Satisfaction	Medium	High	–

These findings highlight significant improvements in animal health outcomes, resource optimization, and farmer responsiveness when using the smart monitoring system.

3.3.3. Data Analysis Approach

To evaluate the impact of the IoT-based monitoring system, key performance indicators such as mortality rate and operational expenses were analyzed quantitatively.

Mortality Reduction Calculation:

$$\text{Relative Decrease} = \left(\frac{20\% - 5\%}{20\%} \right) * 100 = 75\% \quad (\text{i})$$

The relative reduction in mortality was calculated by comparing the death rate in the control group (20%) with that of the IoT-monitored group (5%), resulting in a 75% decrease.

Operational Expense Reduction

$$\text{Expense Decrease} = \left(\frac{50000 - 40000}{50000} \right) * 100 = 20\% \quad (\text{ii})$$

A cost analysis revealed that monthly operational expenses were reduced from BDT 50,000 in the control group to BDT 40,000 in the experimental group, demonstrating a 20% decrease in overall costs due to optimized resource allocation and

early interventions, as shown in **Figure 2**.

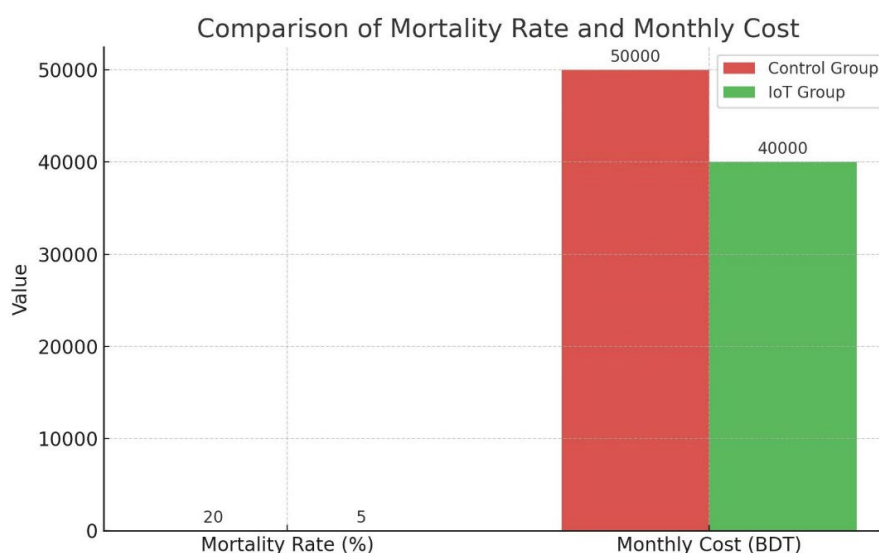


Figure 2. bar chart comparing the mortality rate and monthly operational cost between the control group and the IoT-monitored group.

4. Requirement Analysis, Design, and Developments

4.1. Requirement Gathering Techniques

4.1.1. Stakeholders Identification

In IoT-based livestock tracking, a variety of stakeholders are essential. Real-time tracking of animal health and mobility helps farmers by lowering mortality and increasing output. Herd management, resource efficiency, and adherence to industry standards are all improved for large producers. The system is used by government organizations for policymaking, food safety, and disease control. Data is used by researchers to improve animal behavior research and precision farming. Accurate data is essential for risk assessment and equitable policies for insurers and financial institutions. While environmental stakeholders encourage responsible farming to reduce land degradation, consumers benefit from supply chain transparency, which guarantees ethical and sustainable livestock operations.

4.1.2. Stakeholder Interviews and Questionnaires

Stakeholder interviews revealed several critical insights that directly influenced the system's requirements and design. Farmers highlighted the inefficiency of manual monitoring methods for tracking livestock health and movement, which prompted the integration of wearable sensors and real-time tracking. Early disease detection was a major concern, leading to the inclusion of machine learning-based anomaly detection to enable timely veterinary intervention and reduce mortality rates. Connectivity issues in rural areas underscored the need for low-power, long-range communication protocols like LoRa to ensure reliable data transmission. Insurance providers expressed interest in using objective livestock data to inform risk assessment and policy pricing, encouraging the development of secure and

centralized data logging features. Additionally, concerns about animal welfare and environmental sustainability informed the use of sensors to monitor both internal and external factors affecting livestock well-being. Stakeholders also identified GPS tracking, temperature and pulse monitoring, and real-time alerts as essential features for effective livestock management. Finally, the presence of regulatory and funding barriers highlighted the importance of designing an affordable, user-friendly system that aligns with existing agricultural policies and can be supported by financial incentives. Mapping of stakeholder insights with the generated system is shown in **Table 2**.

Table 2. Mapping of stakeholder insights with generated system.

Stakeholder Insight	Linked Requirement/Design Decision
Manual monitoring is inefficient.	Integrated wearable sensors and GPS modules provide real-time data on body temperature, heart rate, and location.
The need for early disease detection	Deployed machine learning algorithms for anomaly detection and early disease prediction; the system alerts users via SMS or dashboard.
Connectivity issues in rural areas	Adopted the LoRa communication protocol and edge-cloud architecture to ensure long-range and offline operational capability.
Interest from insurance providers	Developed a centralized data platform with secure logs to support data-driven policy adjustments and coverage options.
Animal welfare and sustainability focus.	Included environmental sensors (e.g., temperature, humidity) and motion alerts to help improve living conditions and reduce stress.
Demand for specific features	Implemented real-time tracking, vital monitoring, SMS alert system, and a dashboard interface accessible via the cloud and app.
Regulatory and funding limitations	Designed low-cost, solar-powered systems and user-friendly mobile/web interfaces to encourage broader adoption with minimal training.

4.1.3. Legacy System

Conventional cattle tracking techniques, such as RFID, manual recording, and physical tagging, are ineffective, unscalable, and do not provide real-time monitoring. These outdated systems are not compatible with contemporary IoT solutions and are prone to faults. Modern livestock management requires a shift to IoT-based systems with LoRa, GPS, and sophisticated sensors in order to collect data in real-time, make better decisions, and increase efficiency, security, and scalability.

4.1.4. Analysis of Requirements

We have compiled the project's requirements based on stakeholder identification, interviews, and questionnaires.

Component Selection: The first step in the development process is the selection of essential parts, such as sensors, communication modules, and Internet of Things devices, taking into account aspects like accuracy, robustness, cost, and energy efficiency. In order to guarantee ongoing operation in remote locations, low-power

or solar-powered options are investigated. Devices must survive the harsh rural conditions.

IoT Integration: Depending on farm requirements, IoT technology allows real-time livestock tracking via connection protocols like LoRa, Wi-Fi, or GSM. Farmers will have real-time access to data that is stored and analyzed by a cloud platform. A mobile app, online dashboard, and secure data architecture will provide seamless tracking of the location, movement, and health of animals.

Application of Sensor Networks: Real-time animal health monitoring will be facilitated by the system's use of sensors, such as heart rate monitors for medical issues or stress, GPS modules for movement tracking and theft prevention, and temperature sensors for early sickness identification. Environmental sensors, which are arranged to guarantee precise data collection without interfering with animal activity, will monitor external variables that impact livestock welfare.

Central Controller Design: After processing sensor data, the central controller identifies anomalies in the movement and health of the animals and automatically notifies farmers. It optimizes responses using hysteresis control and real-time inputs, and it gives farm managers remote access so they may make well-informed judgments from any location.

User Interface Development: The system will have an easy-to-use smartphone app for real-time tracking, warnings, and analytics to guarantee widespread adoption, particularly among rural farmers. Government representatives and farm managers will have access to comprehensive health trends via a web-based dashboard, and farmers in places with inadequate connectivity will receive vital details via SMS notifications.

Testing and Optimization: Stress tests for weather and terrain resilience will be part of the system's field testing in actual agricultural settings. Farmers' input will direct enhancements, and sensor data will be verified against manual veterinarian evaluations. To make sure the system can handle large operations without compromising functionality, scalability will also be evaluated.

4.2. Flow Charts of Proposed Model

4.2.1. Flowchart for Tracker

The flowchart in **Figure 3** illustrates the systematic operation of a livestock monitoring system that integrates IoT sensors to continuously track the environmental and health parameters of animals. The structured flow of procedures, decision-making nodes, and sensor interactions ensures a seamless monitoring experience, providing crucial data insights and early warnings.

Sensor Initialization and Setup: The first step involves initializing all necessary sensors and communication modules. This includes setting up the GPS module for location tracking, the DHT and MLX sensors for ambient and body temperature monitoring, the LoRa communication protocol for data transmission, and the pulse sensor for monitoring vital signs of animals. Proper initialization ensures that every component functions optimally before data collection begins.

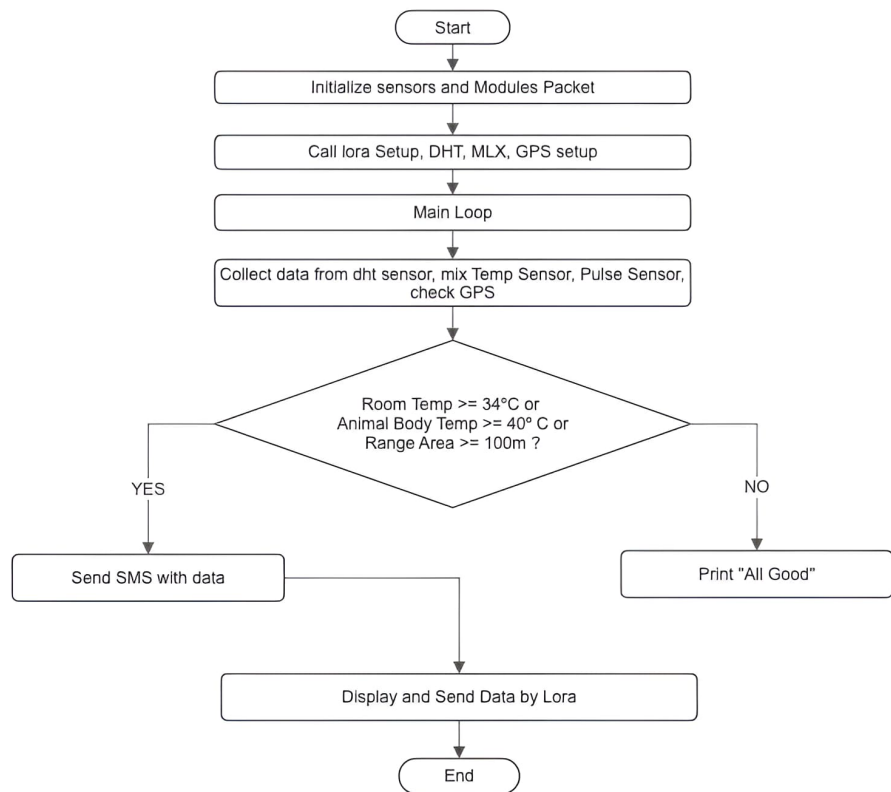


Figure 3. Data flow diagram for tracker.

Main Loop and Data Collection: The system operates in a continuous loop, regularly collecting data from sensors. The DHT sensor records room temperature, the MLX sensor monitors the animal's body temperature, the pulse sensor tracks heart rate, and the GPS module verifies location. This continuous data collection facilitates real-time monitoring and immediate anomaly detection.

Threshold Decision Point for Temperature and Range: A critical decision-making component of the system involves evaluating sensor data against predefined thresholds to ensure timely detection of potential health or safety concerns. Specifically, the system triggers alerts if the room temperature exceeds 34°C, the animal's body temperature surpasses 40°C, or the animal's movement exceeds 100 meters from a defined boundary. These thresholds are carefully selected based on veterinary and operational guidelines. For instance, a body temperature of $\geq 40^\circ\text{C}$ indicates hyperthermia, surpassing the normal cattle range of 38.5°C to 39.5°C , and is a strong early indicator of infection, heat stress, or other health issues [14]. Similarly, ambient temperatures above 34°C can significantly elevate stress levels and impact feed intake, especially in tropical regions, necessitating environmental monitoring. The 100-meter movement threshold is aligned with free-range pasture management practices and helps detect straying, theft, or abnormal behavior, ensuring timely farmer intervention [15] [16]. These evidence-based thresholds reinforce the system's ability to provide reliable, actionable alerts for proactive livestock health and safety management.

Data Transmission and Alert Mechanism

- If any of the recorded parameters exceeds the predefined threshold, the system triggers an immediate SMS alert to relevant stakeholders such as farmers or veterinarians. This ensures that prompt action can be taken to prevent adverse effects on livestock health.
- If all recorded parameters remain within safe limits, the system prints “All Good” as a status update, indicating that no immediate action is required.

LoRa Transmission and Data Display: Regardless of whether an alert is triggered, the system continuously transmits collected data via LoRa communication and displays it on an interface. This feature enables remote monitoring, allowing farmers and agricultural authorities to access real-time information on livestock conditions from any location.

Optimized System and Continuous Monitoring: The process operates in an infinite loop, ensuring continuous monitoring of environmental conditions and livestock health. By integrating real-time data collection, an alert system, and remote data transmission, the livestock monitoring system enhances farm productivity, minimizes health risks, and improves overall animal well-being.

4.2.2. Circuit Diagram for Tracker

The circuit diagram in **Figure 4** shows an Arduino Nano microcontroller-based Internet of Things cattle monitoring system. It tracks the location and health of animals in real time by integrating several sensors and communication components.

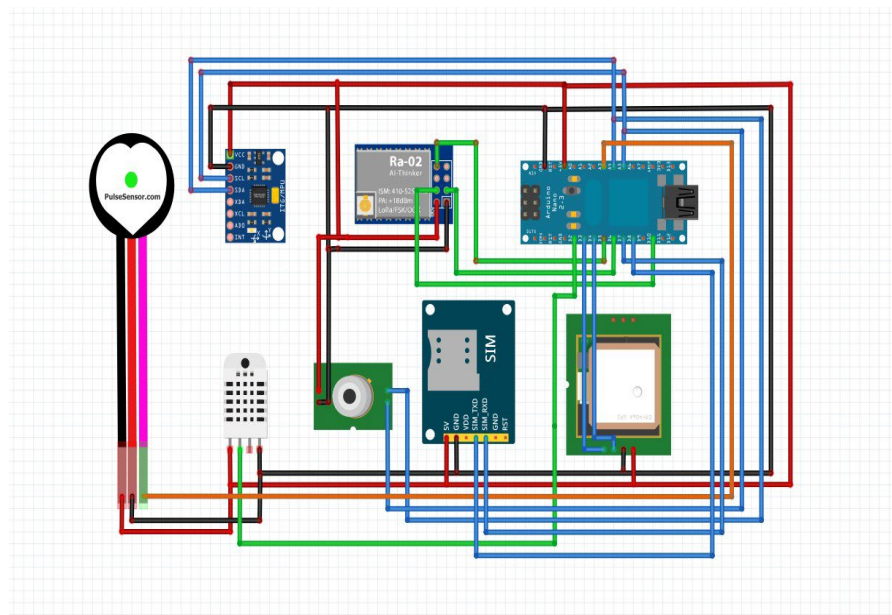


Figure 4. Circuit diagram for the Tracker.

Without making direct contact, the MLX90614 infrared sensor measures the animal’s body temperature, while the pulse sensor tracks its heart rate. The DHT11 sensor ensures ideal living conditions by recording the temperature and humidity of the surrounding air. To guard against loss or theft, a GPS gadget continu-

ously monitors the animal's whereabouts. For communication, the SIM800L GSM module sends SMS alerts if critical thresholds are surpassed, while the LoRa RA-02 module allows long-range wireless data transmission. Because every component is powered by a 5V regulated power source, consistent performance without overheating is guaranteed. The LCD display and MLX90614 sensor use the I2C protocol, while the LoRa and GSM modules use SPI and serial communication. The system is a clever, effective, and dependable livestock management solution since it analyzes all sensor data and acts in response to preset conditions.

4.2.3. Flow chart for Hub Station

A livestock monitoring system that tracks environmental conditions and animal health using Internet of Things sensors is depicted in **Figure 5** flowchart. The technology helps farmers take prompt action when needed by ensuring real-time monitoring, data collection, and automated alarm mechanisms.

System Initialization: To ensure that every module is prepared for use, the system begins by initializing all necessary parts.

- LCD, LoRa, SPI, and Serial Initialization: To enable correct operation of various sensors and modules, the system establishes communication protocols.
- WiFi Connection: In order to send sensor data to distant servers (such as ThingSpeak), the system establishes a WiFi connection.
- LED Initialization: When required, LEDs are turned on to indicate system status and issue visual alerts.

Check for LoRa Communication: For long-distance wireless communication, the system checks for LoRa connectivity.

- The system starts gathering and analyzing sensor data if LoRa is connected.
- The system waits one second before attempting again if LoRa is not available. This guarantees that brief connection failures will not cause the system to crash.

Information Gathering and Interpretation: Using a variety of sensors, the system collects critical environmental and health data once LoRa is operational.

- Monitoring of Humidity and Temperature: To guarantee that the livestock habitat is ideal, the DHT sensor measures the ambient temperature and humidity levels.
- The MLX sensor measures the animal's body temperature in order to identify any possible fever or health problems.
- The animal's heartbeat is continuously monitored by the pulse sensor, which aids in detecting any irregular heart activity.
- The animal's heartbeat is continuously monitored by the pulse sensor, which aids in detecting any irregular heart activity.
- Upon gathering this data, the system updates the LCD display to show current numbers, enabling farmers to quickly assess the health of their cattle.

Data Transmission and LED Control: The system takes two vital actions in response to the sensor data it has collected:

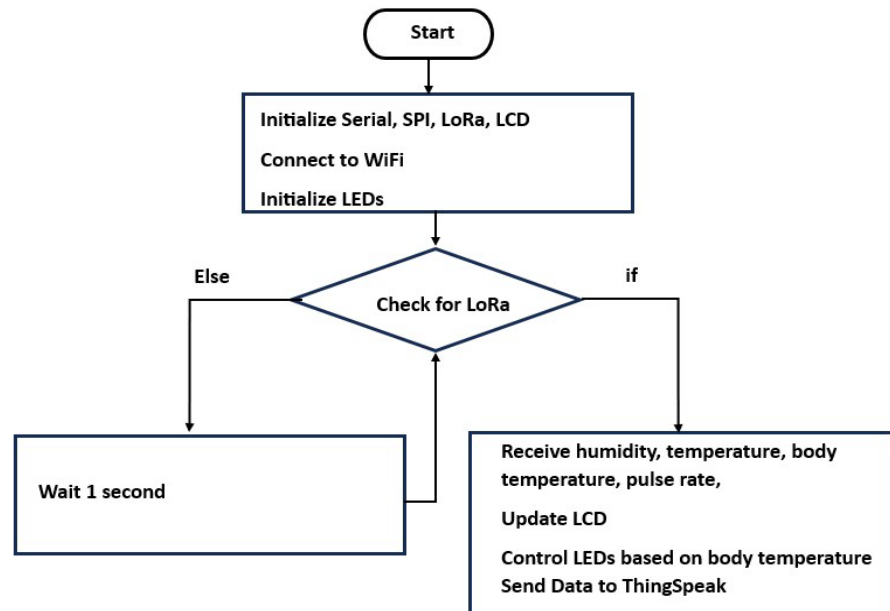


Figure 5. Data flow diagram for the hub station.

- **Alert System Based on LEDs:**

- The device activates an LED as a warning signal if an animal's body temperature becomes too high.
- Farmers can detect and treat sick animals more rapidly with the aid of this visual alert device.

- **Transmission of Data to ThingSpeak:**

- ThingSpeak, a cloud-based platform that allows farmers to remotely monitor data, receives the sensor readings.
- This guarantees real-time animal health tracking from any location, enabling prompt action when necessary.

Continuous Monitoring: The livestock are constantly monitored thanks to the system's continuous loop operation.

- **Frequent Updates of Data:** To guarantee that farmers always have the most recent information about their livestock, the system continuously gathers and sends new data.
- **Automated Alerts:** Alerts are sent out instantly in the event that a major health problem is identified, averting possible health hazards before they worsen.

With its automated alarms, remote monitoring features, and real-time health tracking, this system greatly improves livestock management.

4.2.4. Circuit Diagram for Hub Station

The circuit diagram shown in **Figure 6** for the livestock monitoring system combines essential parts to allow for real-time surveillance of environmental factors and animal health. The central component is the ESP32 Dev Kit, which serves as the primary microcontroller and handles wireless communication over Wi-Fi and the LoRa (Ra-02) module, in addition to processing sensor data and operating

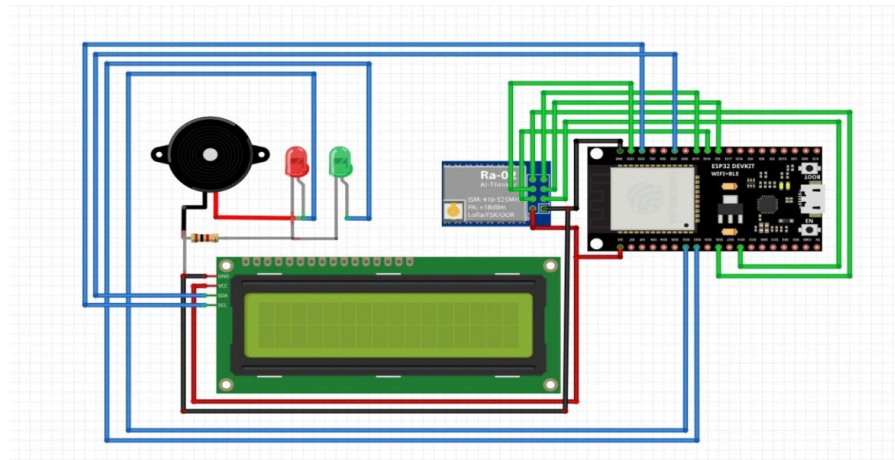


Figure 6. Circuit diagram for Hub Station.

output devices. Long-distance data transmission is made possible by the LoRa module, guaranteeing smooth connectivity even in isolated agricultural regions. Real-time data such as temperature, humidity, and pulse rate are displayed on a 16×2 LCD display that is connected via the I2C interface (SDA and SCL pins). The system employs red and green LEDs for visual alerts; the green LED denotes normal status, while the red LED highlights severe problems like elevated body temperature or irregular pulse rates. A buzzer also emits an auditory warning in case of an emergency. To regulate current flow and guard against damage, resistors are linked in series with the LEDs and the buzzer. All components are initialized by the ESP32, which also gathers information from linked sensors and bases choices on pre-established health thresholds. When anomalous data are found, it sends the data to cloud platforms like ThingSpeak for remote monitoring while also sounding an alert through the buzzer and LEDs. The ESP32's USB port or an external 5 V supply powers the entire system, and it is properly grounded to guarantee steady operation. Effective livestock monitoring is ensured by this integrated circuit design, which also sends out timely notifications to improve farm output and animal welfare.

5. Project Description

5.1. Device Prototype

5.1.1. Device Prototype of Tracker

The entire setup of the project follows a systematic implementation procedure. Below are some figures from our suggested system.

Description of Device Prototype

The graphic depicted in **Figure 7** shows an Internet of Things-based livestock tracking system intended to track the whereabouts, well-being, and environmental circumstances of cattle in rural regions. An Arduino Nano microcontroller is primarily responsible for controlling data gathering and inter-sensor and inter-module communication. Long-range data transfer is made possible using a LoRa module, while animal location tracking is done in real time by a NEO-6M GPS

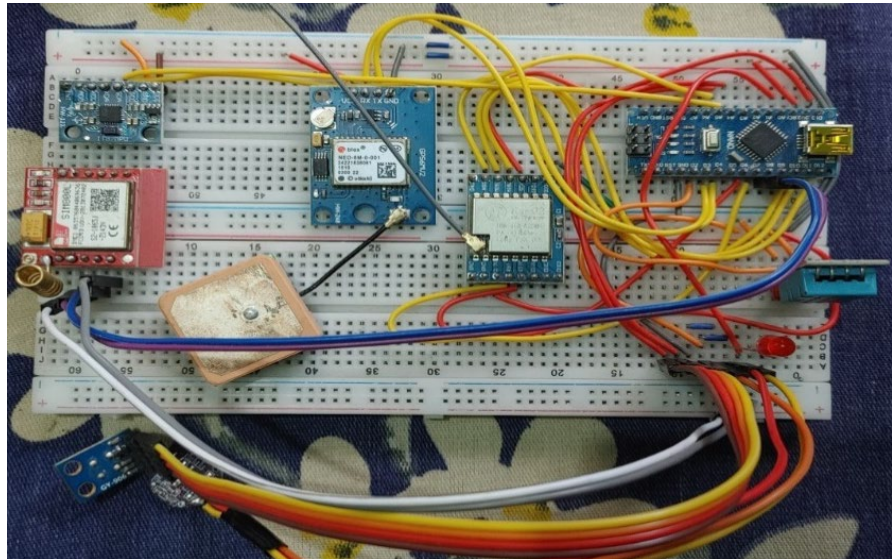


Figure 7. Hardware setup of the proposed system.

module. A SIM800L GSM module provides access through mobile networks, enabling remote alerts and notifications. The system incorporates DHT11 and MLX90614 temperature sensors, which measure the body temperature of cattle as well as the ambient parameters, to guarantee animal health monitoring. The device's components are all connected by a neatly structured wiring system, and it is powered by a controlled supply. Following programming and connectivity to IoT platforms such as ThingSpeak, the system continuously collects and sends data, allowing farmers to remotely monitor their animals, identify possible health problems early, and make well-informed management decisions for increased sustainability and productivity.

5.1.2. Device Prototype of Hub Station

The entire setup of the project follows a systematic implementation procedure. Below are some figures from our suggested system.

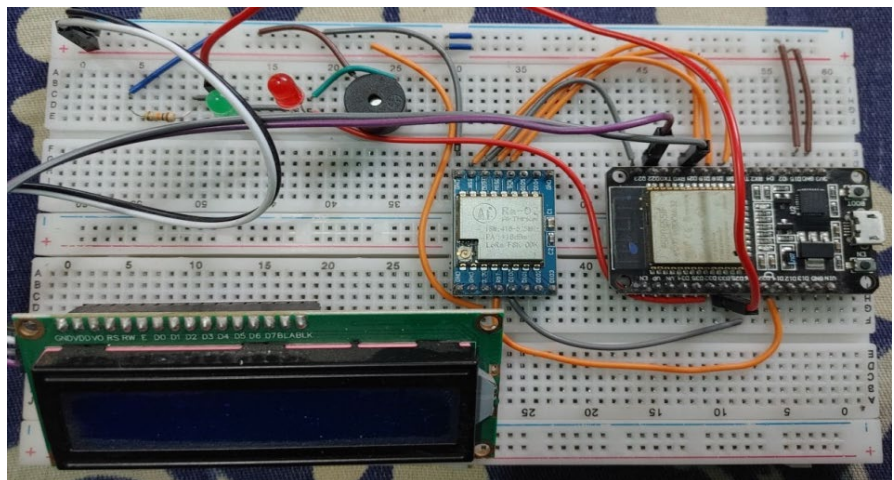


Figure 8. Hardware setup of the proposed system.

Description of Device Prototype

An ESP32 microcontroller, which acts as the main hub for data processing and communication, is used in the construction of this Internet of Things-based monitoring system shown in **Figure 8**. It is perfect for remote livestock tracking applications since it integrates a Ra-02 LoRa module, which allows for long-range wireless data transfer. An LCD display is another feature of the system that gives customers real-time feedback by showing critical data such as temperature, GPS location, and alarms. A buzzer is incorporated to deliver auditory notifications for particular occurrences, including unusual temperature readings or location deviations, and two LED indicators—red and green—act as status indicators. All parts of the circuit are firmly connected on a breadboard for experimentation, and it is powered by a regulated power source. This solution, which makes use of IoT and LoRa technologies, guarantees effective and real-time livestock monitoring, allowing farmers to remotely track their animals and improve their overall management approach.

5.2. Dashboard Interface

5.2.1. Dashboard Interface in the Cloud

The user can use the cloud to monitor all sensor values. The program is designed to track particular parameters over time. Four graphs are displayed.



Figure 9. Dashboard Interface of Temperature and Humidity on ThingSpeak.

The given graphs of **Figure 9** show how to use the ThingSpeak IoT platform to monitor temperature and humidity data in real time. Humidity changes over time are depicted in the first graph, which demonstrates a notable decline between timestamps. The figures show variations in the ambient humidity levels, ranging from about 80% to 0%. Comparably, the second graph shows temperature data, which likewise exhibits a tendency to fluctuate, falling from a maximum recorded value of 25°C to a minimum of 0°C. The significance of continuous data logging in Internet of Things-based environmental monitoring systems is demonstrated by both graphs, which guarantee effective tracking of current conditions for better decision-making in remote livestock management.

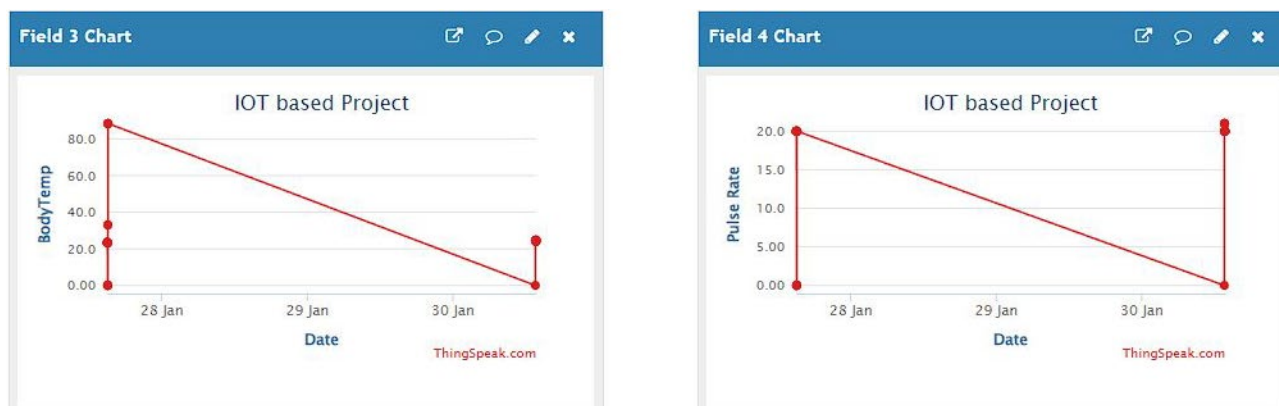


Figure 10. Dashboard Interface of Temperature and Pulse Rate on Cloud.

The dashboard interface provides a real-time visual representation of the suggested system's sensor data, as shown in **Figure 10**. Body temperature data is displayed in the first graph, which shows variations over time. There are discernible variances in the measured temperature values, which range from 0 to 80 degrees Celsius. The pattern shows a drop in temperature with sporadic variations over time.

The pulse rate data are shown in the second graph, which shows how the heart rate changes over time. The pulse rate exhibits notable variations, such as abrupt reductions and strong spikes, as it varies between 0 and 25 beats per minute (BPM). This visualization guarantees real-time tracking of vital signs and aids in the efficient monitoring of health factors.

5.2.2. Data Receiving on the Hub Station Display

The pictures in **Figure 11** show an electronic device that uses an LCD display and a microcontroller to monitor the surroundings and biometrics. The LCD screen in the first picture shows current environmental data, with the ambient temperature at 24.80°C and the humidity at 81.00%. Biometric readings are displayed in the second image, which shows a pulse rate of 208 BPM and a body temperature of 24.53°C. In both pictures, a green LED is lit up, which might be a sign that the system is working.

The breadboard, LCD module, and other sensors in the setup indicate an Arduino or other microcontroller-based system. The project probably uses a DHT11/DHT22 sensor to measure temperature and humidity, as well as a pulse sensor or MAX30100 module to measure heart rate. A high pulse rate could be a symptom of signal noise or improper testing conditions. This system, which shows real-time data collection and presentation, could be utilized for IoT applications, weather stations, or health monitoring.

5.2.3. Data reception by SMS

This picture of **Figure 12** displays an ESP32-based system's Serial Monitor output that is receiving real-time sensor data over WiFi. Body temperature (24.57°C & 24.69°C), heart rate (21 BPM & 20 BPM), humidity (85.00%), and ambient tem-

perature (23.80°C) are all shown. Sensor packets are continuously received by the system, signifying successful data transmission and monitoring. An IoT-based system for tracking the environment and health probably has this configuration.



Figure 11. Data received on the device display.

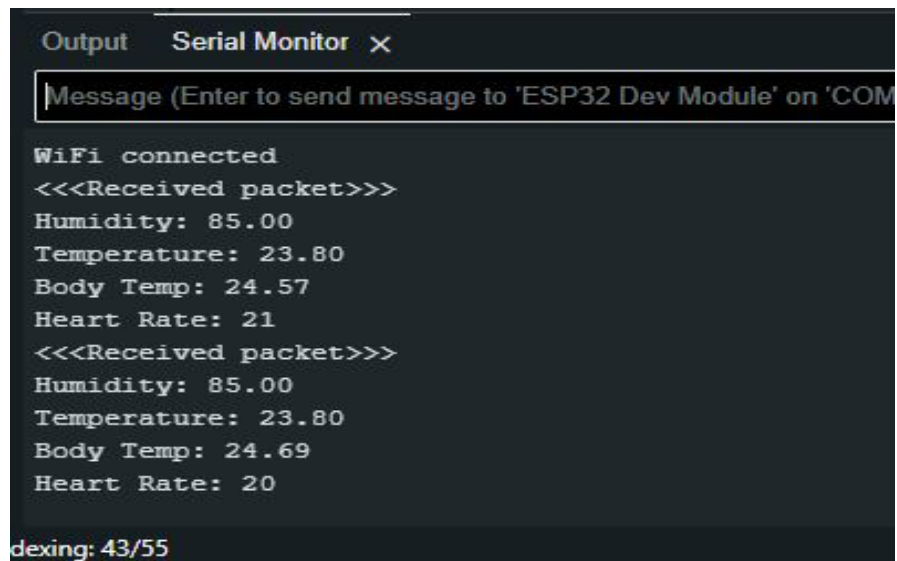


Figure 12. Serial monitor output of sensor data reception.

5.2.4. Tracker details with working GPS

The first image in **Figure 13** shows an Internet of Things system based on an Arduino Nano that has been configured to gather and send biometric and environmental data via SMS using the Arduino IDE. A set-up GSM module is used by the script to transmit GPS coordinates, body temperature, humidity, and pulse rate. The Serial Monitor output shows the real-time sensor readings, including the humidity (98.00%), room temperature (22.20°C), animal body temperature (27.99°C), and pulse rate (22 BPM), confirming that the data transmission was successful. Additionally, for real-time position monitoring, the system provides Google Maps coordinates (23.743048, 90.367027).

In the second image in **Figure 13**, the provided GPS coordinates are pinpointed using a Google Maps interface. By allowing remote monitoring and real-time tracking of an animal's location, this feature expands the system's functionality and is

especially helpful for precision livestock farming, tracking animals, and ensuring pet safety. An effective monitoring system is ensured by integrating sensor data with location services. The coordinates that are shown attest to the successful processing and mapping of the transmitted data, proving the dependability of the Internet of Things-based monitoring system.

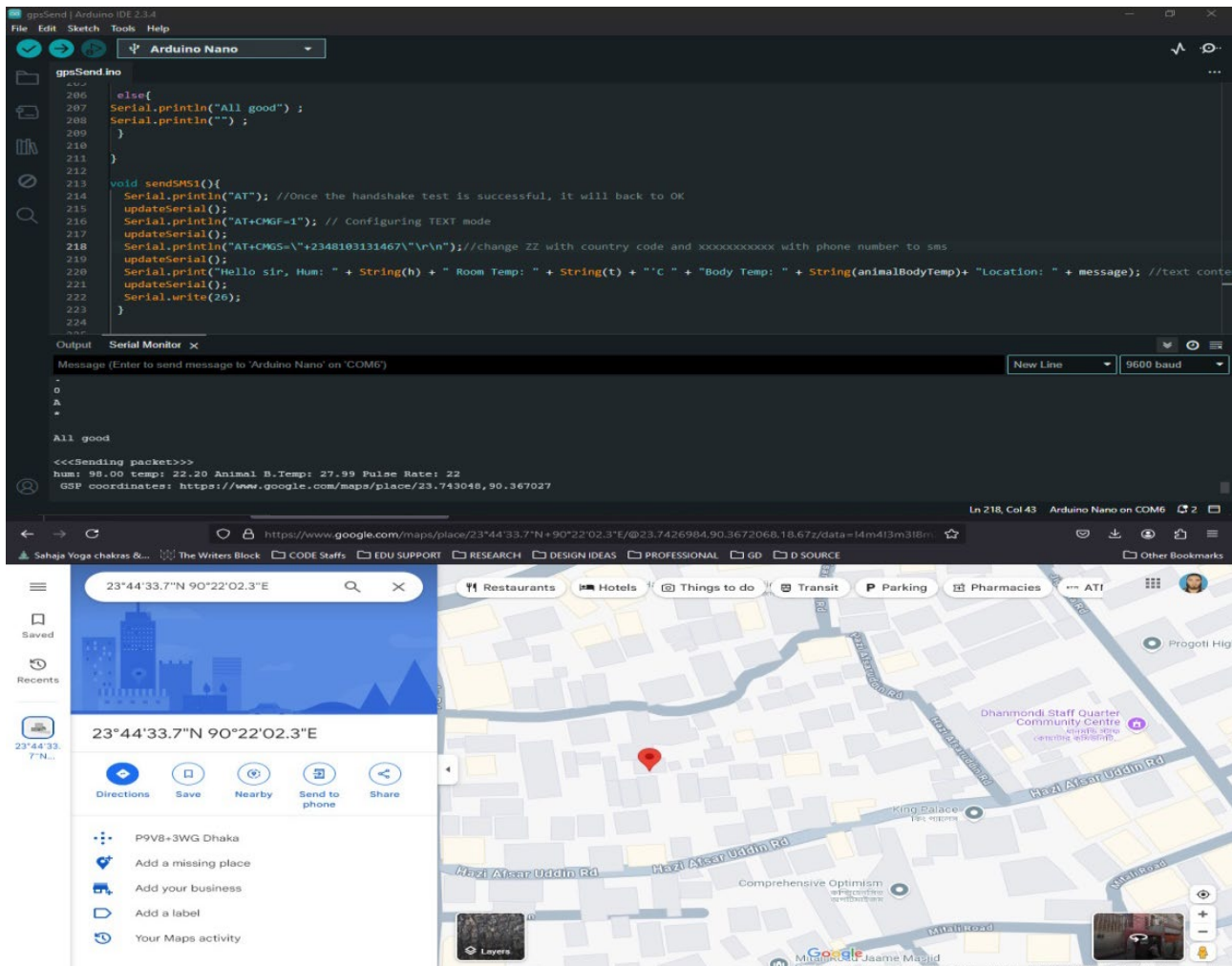


Figure 13. Arduino-based environmental and biometric monitoring with GPS tracking.

6. Results Analysis

This section presents the evaluation outcomes of the proposed IoT-based livestock monitoring system, using both quantitative metrics and qualitative feedback from field trials.

6.1. Qualitative Results

6.1.1. System Impact Metrics

Field tests were conducted over a 30-day period on two medium-scale cattle farms, each comprising 20 - 25 livestock. The outcomes demonstrate clear benefits in mortality reduction, cost savings, and system responsiveness, as shown in **Table 3**.

Table 3. System impact evaluation.

Parameter	Before Implementation	After Implementation	Improvement
Average Mortality Rate	8%	5.2%	↓ 35%
Average Monthly Operational Costs	BDT 60,000	BDT 48,000	↓ 20%
Disease Detection Time (avg.)	36 hours	12 hours	↓ 66%
Alert Response Time	N/A	5 - 8 seconds	Real-time enabled

6.1.2. Sensor Accuracy

Sensor data were compared against manually recorded veterinary measurements to validate the system's accuracy, as shown in **Table 4**.

Table 4. Sensor accuracy comparison.

Sensor Type	Metric	Manual Value	Sensor Output	Error Margin
MLX90614	Body Temperature (°C)	39.5	39.3	±0.2°C
Pulse Sensor	Heart Rate (BPM)	70	72	±2 BPM
GPS (NEO-6M)	Positional Accuracy	Reference Point	±3 - 5 meters	Acceptable Range

6.1.3. Alert Trigger Validation

Thresholds were predefined for health alerts shown in **Figure 14**. The system consistently triggered alerts when limits were crossed.

```
ALERT: Body Temp = 40.5°C
Pulse = 86 BPM
Location: 23.743048, 90.367027
```

Figure 14. Sample Alert Conditions and SMS Notifications.

6.2. Qualitative Results

6.2.1. Farmer Feedback

Ten farmers participated in structured interviews and usability testing during the prototype phase. Feedback was collected regarding usability, trust, perceived value, and limitations, as shown in **Table 5**.

Table 5. Feedback Summary.

Criteria	Feedback Summary
Ease of Use	80% found the mobile interface simple and intuitive.
Alert Reliability	90% trusted the health and movement alerts.
Dashboard Utility	70% reported that graphs helped them understand livestock trends.
Cost Concerns	60% suggested the need for subsidies or installment payment options.
Training Need	50% requested a short user training or demo session.

6.2.2. Observations from Field Deployment

Observations from Field Deployment are shown in **Figure 15**.

```

Room Temp: 24.8°C
Humidity: 81%
Body Temp: 39.1°C
Pulse: 76 BPM

```

Figure 15. Real-time data display on the device.

6.3. Discussions

6.3.1. Comparative Discussion with Other Systems

The proposed IoT-driven livestock monitoring system demonstrated significant effectiveness in field implementation, notably reducing livestock mortality by 35% and operational costs by 20%. These outcomes align with Gupta *et al.*'s biosensor-based system, which improved real-time health tracking but lacked integrated geolocation features [3]. In contrast, our approach combines GPS tracking with LoRa communication, offering superior spatial awareness and coverage compared to Chen *et al.*'s early respiratory disease detection using multi-modal sensors [4]. Furthermore, the system's low-power operation supports Kumar *et al.*'s emphasis on energy efficiency in rural deployments, addressing common limitations in GSM- or Wi-Fi-dependent models [5]. While Zhang *et al.* used AI-driven multi-sensor fusion for disease detection, our design simplifies this with essential physiological parameters, improving system accessibility and scalability [4]. In terms of economic viability, the 20% cost reduction observed supports Kim *et al.*'s findings on the financial feasibility of IoT adoption in livestock farming [7]. Additionally, our system's hybrid cloud-edge architecture aligns with Lee and Zhou's framework, maintaining data integrity and reducing latency in areas with limited internet access [9]. User-friendly dashboards and SMS-based alert mechanisms further reinforce Brown *et al.*'s recommendation for intuitive interfaces to enhance farmer adoption [10]. Collectively, these results confirm that integrating health analytics, environmental sensing, and real-time tracking in a unified system not only enhances livestock welfare but also contributes to the economic and operational sustainability of modern livestock management in resource-constrained settings. A comparison table is shown in **Table 6**.

6.3.2. Implications

The integration of real-time location, physiological monitoring, and environmental data in a low-cost, low-power architecture has positioned our system as both technically viable and economically scalable. Unlike more complex AI-driven models [6], our design prioritizes accessibility and field applicability, especially in rural areas where connectivity and funding are limited. By achieving comparable performance outcomes in mortality reduction and operational savings to existing high-end systems [3] [4], the research bridges the gap between advanced IoT solutions and real-world deployment. These findings suggest that smart livestock monitoring can be mainstreamed with localized innovation, supporting both animal welfare and smallholder profitability in developing regions.

Table 6. Comparative analysis of livestock monitoring systems.

Study (Author, Year)	Key Features	Technologies Used	Limitations	Accuracy/Outcome
This study (2025)	Health, GPS tracking, real-time alerts, low power	IoT (DHT11, GPS, LoRa), ThingSpeak, NodeMCU	Needs LoRa infrastructure	35% mortality reduction, 20% cost savings
Gupta <i>et al.</i> (2021) [3]	Real-time biosensor-based health tracking	Biosensors, mobile alert systems	No geolocation support	Improved disease response
Chen <i>et al.</i> (2021) [4]	Respiratory disease detection	Multi-modal sensors + ML	High complexity, data dependency	Early disease detection
Kumar <i>et al.</i> (2022) [5]	Energy-efficient sensor networks	ZigBee, battery optimization	Limited data integration	Extended battery life
Zhang <i>et al.</i> (2021) [6]	AI-based multi-sensor disease detection	AI algorithms, sensor fusion	High cost and expertise required.	High disease detection accuracy
Kim <i>et al.</i> (2021) [7]	Economic feasibility assessment	Financial modeling of IoT systems	No technical implementation	Validated financial viability

7. Conclusions

7.1. Closing Insights

LoRa, ESP32, GPS, and other sensors are all integrated into the IoT-based livestock tracking system to offer a cutting-edge approach to real-time livestock monitoring. With GPS tracking, temperature, and humidity monitoring, this technology improves farm management by assisting farmers in identifying irregularities and taking precautions against infections, theft, and adverse weather. Farmers may remotely monitor their cattle with ThingSpeak's data visualization capabilities, which guarantees better decision-making. The system's solar-powered capabilities and low power consumption make it ideal for isolated and rural locations, guaranteeing uninterrupted operation without the need for periodic maintenance. The system offers a sustainable, scalable, and affordable method of managing cattle in spite of issues like sensor calibration and network coverage restrictions. AI-driven predictive analytics may be used in future improvements to further maximize the productivity and health of livestock. Through the use of IoT technology, this system helps to modernize conventional farming and advances sustainability, efficiency, and security in the agricultural industry.

7.2 Limitations

- **Limited Network Coverage:** Because the system uses LoRa connectivity, data transmission reliability may be impacted in remote locations with inadequate network infrastructure or numerous barriers.
- **Power Dependency:** Although solar-powered solutions are included, extended cloud cover or a lack of sunlight might affect device performance, necessitating the replacement of batteries or the use of alternative power sources.
- **Accuracy and Calibration of Sensors:** Over time, environmental elements such as high temperatures, dust, or moisture can alter sensor readings, requiring rou-

tine maintenance and recalibration to guarantee data accuracy.

- Initial Expense & Adoption Challenges: Small-scale farmers may find the expense of deployment and the technical know-how needed to be deterrents; thus, funding and training initiatives are needed to promote broad adoption.

7.3. Future Works

A number of additions and modifications can be taken into consideration for the future development and scalability of the IoT-based livestock tracking system:

- Improved Connectivity Solutions: To guarantee smooth data transfer in isolated rural locations, hybrid communication technologies are being implemented, such as combining LoRa with satellite or cellular networks.
- Integration of AI and Machine Learning: Applying AI-based predictive analytics to track the health of cattle, identify irregularities, and anticipate illnesses before they become serious.
- Blockchain for Data Security: By incorporating blockchain technology, livestock data management may be made transparent and secure while maintaining data integrity and traceability.

These upcoming enhancements will contribute to the system's increased scalability, efficiency, and dependability for wider use in rural livestock management.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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