IoT-Enabled Smart Geofencing System for Sustainable Livestock Monitoring

Aiman sultan Al Noamani
Computing and Informatics Department
Mazoon College, Muscat, Oman

Hamad Anisul Hoque
Computing and Informatics Department
Mazoon College, Muscat, Oman

Mohammad Nasar
Computing and Informatics Department
Mazoon College, Muscat, Oman

ABSTRACT
With the ever-evolving Internet of Things (IoT) technologies, modern agriculture has seen a dramatic change in practices, and solutions for intelligent and automated livestock management are becoming a reality. Poorly designed traditional physical fencing in livestock production systems can be expensive, inflexible, and require constant upkeep and maintenance, and can cause environmental issues, including overgrazing and poor land use. To overcome these drawbacks, in this study, a smart geofencing system based on wireless communication, GPS location tracking, and cloud-assisted monitoring technologies is proposed and applied to the field of sustainable livestock monitoring. The proposed system involves connecting a NEO-6M GPS module, an ESP8266 microcontroller, a water sensor, a relay module, an LCD screen, and a cloud-based platform called Blynk. As soon as an animal enters the predefined geofence area, the system notifies the farmer using wireless communication and sends an alert. Moreover, the built-in environmental sensing mechanism ensures livestock safety by monitoring the surrounding environment. The proposed framework will help minimize reliance on physical fencing and increase the efficiency of operations, safety of livestock, environmental sustainability, and remote access of farmers. The experimental results indicate that the location monitoring is accurate, the deployment is economical, and the alerts are issued in real time, which is suitable for smart agriculture applications. In addition, this study covers the limitations of the system, connectivity requirements, and future enhancements, including the use of artificial intelligence, LoRaWAN communication, and predictive solutions for livestock analytics, for future precision farming systems.

Keywords
Internet of Things (IoT), Geofencing, Smart Livestock Monitoring, Precision Agriculture, GPS Tracking, ESP8266, Sustainable Farming, Blynk Platform, Smart Agriculture, Virtual Fencing.

1. INTRODUCTION
In the current era of the Internet of Things (IoT), agriculture has completely shifted toward the development of smart livestock monitoring systems. The use of wireless communication, cloud computing, sensors, and data analytics has emerged as a significant research field to increase the productivity, welfare, and efficiency of farms, which is termed precision livestock farming [1, 15]. These technologies allow farmers to obtain real-time information on animal position, movement, and environmental conditions, helping them make decisions in a smart agricultural environment. The primary means of managing livestock movement in traditional livestock systems is through physical fencing. Physical fences are generally present but are expensive to set up and maintain and are not easily flexible on a large scale in agricultural systems [7, 22].

In addition, permanent fencing can lead to overgrazing and poor land use, as well as environmental damage. It is difficult to monitor livestock movement in remote farming areas using conventional methods, and this can be labour-intensive.

Recent advancements in geofencing technology have created virtual fencing as a practical alternative to traditional fencing. Geofencing establishes virtual geographic areas through GPS and wireless technologies that automatically monitor and alert when animals enter or cross specified areas [2, 14]. These can make livestock safer and decrease the reliance on physical fencing infrastructure. Geofencing technologies also offer flexibility for farmers to alter grazing zones according to environmental and farming needs.

GPS-based tracking devices, cloud platforms, and wireless sensors have been increasingly used in IoT livestock monitoring systems for real-time livestock monitoring applications [4, 17]. Smart collars embedded with IoT technologies can be constantly updated to the cloud server, allowing farmers to track the movements of livestock on their mobile app or web dashboard [12, 21]. These systems can also provide other features, such as theft protection, health monitoring, and environmental sensing.

The use of AI and smart analytics in livestock monitoring systems has further optimized the efficiency of precision farming applications [9, 16]. The use of AI systems for livestock behaviour analysis and predictive decision-making in animal health management can help detect abnormal patterns and make informed decisions regarding animal health. Furthermore, sustainable smart farming strategies are increasingly cantered on minimizing environmental footprints and maximizing agricultural productivity by managing agricultural resources intelligently [18, 24].

Although geofencing systems with IoT devices are becoming popular, some problems still need to be addressed. A few practical concerns, such as GPS signal errors, limited internet availability in rural areas, high power usage, and a lack of scalability, are still persistent [2, 11]. Moreover, most current livestock monitoring systems mainly track the location of animals and provide limited assistance in environmental monitoring and automated farmer notifications.

This study introduces a smart geofencing system for sustainable livestock monitoring using IoT technology to overcome the challenges. The suggested design consists of a NEO-6M GPS module, ESP8266 microcontroller, water sensor, relay module, LCD screen, and Blynk cloud platform, which creates virtual boundaries and tracks livestock movement in real time. These geofences are automatically triggered to notify and alert the farmer of any livestock moving outside the set boundary via wireless communication systems. The system also includes environmental sensing functions to increase livestock protection and operational awareness.

The highlights of this study are summarized as follows:

1. Design and development of a low-cost geofencing livestock monitoring system using Internet of Things (IoT).
2. Real-time GPS livestock tracking and virtual boundaries.
3. Cloud-based monitoring and automatic alert systems.
4. Inclusion of environmental sensing to improve livestock safety.
5. Designing a scalable and sustainable solution for smart farming that can be applied to modern farming is necessary.

The rest of this paper is organized as follows: The focus of the work of others and research in this area is presented in Section II. The proposed system architecture and methodology are presented in Section III. The implementation and hardware integration process is discussed in Section IV. The experimental analysis and system performance evaluation are discussed in Section V. Finally, Section VI concludes the paper and discusses future research directions.

2. RELATED WORK

The introduction of the Internet of Things (IoT) in agricultural and precision farming systems has significantly impacted livestock management. In recent years, research has focused on the use of IoT-based technologies, including sensors, GPS, wireless communication, and cloud computing, to develop more efficient, safe, and environmentally friendly livestock management systems. Precision livestock farming systems allow real-time knowledge of animal movements, health status, grazing, and environmental parameters using smart digital technologies. The growing adoption of smart farming frameworks has also driven sustainable farming practices that can help reduce labour costs and boost productivity through automation and data-driven decision-making [7, 18]. One of the most popular new smart agriculture technologies is geofencing, which is used to monitor virtual fences in livestock management. Geofencing is based on GPS, wireless communication, and location-aware systems to automatically record animal movements within a specific area [2, 14]. Compared to conventional fencing, virtual geofencing provides significant flexibility, requires low maintenance and provides dynamic options for grazing management.

Multiple studies have shown that geofencing-based livestock monitoring systems can be effective in reducing overgrazing, improving pasture utilization, and using sustainable farm management systems [1, 22]. Moreover, the fact that IoT technologies allow real-time tracking of livestock and prevention of livestock theft using cloud-based monitoring systems and mobile applications has made them popular among farmers [12, 21].

The application of artificial intelligence, machine learning, and advanced sensing systems for livestock monitoring has also been a recent research topic. AI-based smart agriculture techniques can utilize animal behavior to identify anomalies and aid in predictive decision-making for animal health and resource utilization in agriculture [9 16]. Verma et al. [3] spoke about the AI Technologies for Geotagging and their Application in Livestock Farming, and Routray et al. [4] reviewed the use of IoT-based Cattle Monitoring System for enhancing Farm Automation and Operational Efficiency. Likewise, Perumal et al. [5] have introduced a framework for livestock monitoring using IoT for rural communities, with the aim of enhancing environmental awareness and enabling real-time monitoring of animals. Kanagamalliga et al. [6] emphasized the need for environmental sensing systems in livestock health and productivity improvement using technologies to monitor temperature.

Modern livestock monitoring systems are scalable and efficient with the addition of cloud computing and wireless communication technologies. The study of LoRaWAN, blockchain, and cloud-based IoT architectures for long-range communication, secure data sharing, and low-power livestock tracking applications has been conducted in several studies [8, 11]. To improve the security of communication and transparency of data, Alshehri [8] proposed a blockchain-supported framework for IoT in smart livestock farming. The work done by Ahmed et al. [11] developed a scalable, energy-efficient LoRaWAN-based geofencing system that could support remote monitoring applications with low energy consumption. Similarly, Montalván et al. [17] discussed the different available technologies for cattle tracking and how GPS-based monitoring, wireless communication, anomaly detection [25] and cloud integration are critical for smart farming environments.

The evolution of smart agriculture applications has also brought about new technologies, including Industry 5.0, Generative Artificial Intelligence, and Web 4.0, owing to recent developments in the field of intelligent monitoring systems. Nasar et al. [9] proposed an AI-powered Industry 5.0 solution for smart farming systems using IoT, highlighting the importance of intelligent automation and predictive analytics in the future of agriculture. Other researchers, such as Nasar and Kausar [19], have argued for the development of a generative AI-based decision support system for Industry 4.0 applications while Akter et al. [20] have highlighted the introduction of intelligent digital communication systems based on AI-powered Web 4.0 technologies. As AI continues to advance, the future of livestock monitoring will likely continue to depend on similar smart cloud-based platforms, real-time analytics, and automation solutions that further drive sustainability and improve animal welfare in agricultural production.

Several researchers have also developed virtual fences and livestock protection systems. Gadzama et al [22] investigated the use of virtual fencing in cattle grazing and animal welfare, concluding that virtual fences are effective in improving animal safety and management.

Mane and Dirge [23] introduced a location alert system for animal belts based on IoT technology with the help of mobile technology for remote monitoring and automatic notification. Moreover, Elhaj et al. [24] introduced an AI-assisted IoT-based virtual fencing for camel monitoring and collision mitigation, emphasizing the significance of smart geofencing in the latest innovations in agriculture.

Although tremendous progress has been made in the development of smart livestock monitoring technologies, some technical and operational challenges still need to be overcome. Existing systems tackle the issues of GPS signal errors, energy consumption, lack of coverage in rural areas, and scalability concerns of large livestock farms [2, 11]. Furthermore, most solutions that are currently available are focused primarily on geolocation and do not sense the environment to interact with farmers in real time. Hence, there is a need to develop a cost-effective geofencing system that is scalable and sustainable to integrate real-time livestock tracking, cloud-based monitoring, environmental awareness, and automatic alarm generation in a single smart farming system.

3. PROPOSED SYSTEM ARCHITECTURE

A smart geofencing system with IoT applications was proposed for real-time livestock monitoring, virtual boundary management, and sensing and triggering alerts in sustainable farming applications. It is a system based on GPS, wireless, cloud-based monitoring, and the use of IoT-based sensing devices, offering an affordable and scalable solution for livestock management. Various parts of the overall architecture use the NEO-6M GPS module, ESP8266 microcontroller, water sensor, relay module, LCD screen, LED alert system, cooling fan, and Blynk cloud platform to monitor and communicate remotely. The proposed system continuously tracks the geographical location of animals through smart collars attached to animals and sends real-time information. The information collected is transmitted to the ESP8266 microcontroller, which filters the data and compares the coordinates obtained with the coordinates of a geofence set. When the virtual fence is crossed, the system automatically alerts the farmer, who can receive alerts on the Blynk cloud platform. The proposed architecture can improve livestock safety, provide the flexibility to run the grazing system, and reduce the need for traditional physical fencing structures [1, 2]. The overall system architecture of the proposed framework is shown in Fig. 1. This architecture depicts the dependency of livestock, GPS satellites, sensors supported by the IoT, cloud servers, and farmer monitoring devices. A microcontroller (ESP8266) was used to manage GPS data collection, geofence comparison, environmental sensing, and cloud communication.

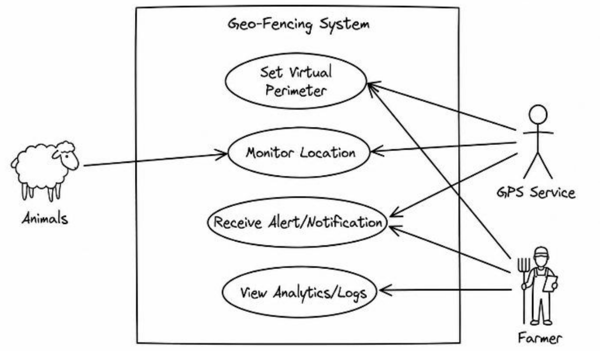

Fig. 1. Overall architecture of the proposed smart geofencing system.

The architecture depicted in Fig. 1 represents the interoperability of the GPS-equipped livestock monitoring unit, cloud platform, environmental sensors, and farmer monitoring interface. The ESP8266 microcontroller served as the main processor to gather GPS data, check geofences, sense environmental data, and communicate with the Blynk cloud platform via Wi-Fi.

The proposed system is based on continuous monitoring. In the first step, the farmer sets up a virtual geofenced area on the Blynk cloud platform. The predefined coordinates were stored in the monitoring system and were constantly compared with the GPS coordinates received from the livestock collars. The NEO-6M GPS module receives the positioning data from the GPS satellites and sends the latitude and longitude data to the ESP8266 controller via a serial communication. These coordinates are then calculated by the ESP8266, which identifies whether the livestock is within the virtual boundary region [11, 17].

The geofence monitoring mechanism can be mathematically expressed as the distance calculation from the geofence centre to the livestock position coordinates. The distance between two GPS coordinates is

$$d = R \cdot \arccos(\sin \phi_1 \sin \phi_2 + \cos \phi_1 \cos \phi_2 \cos(\lambda_2 - \lambda_1))$$

where:

- $d$represents the distance between the livestock and the virtual boundary,
- Rrepresents the Earth's radius,
- ϕ_1, ϕ_2denote latitude coordinates,
- λ_1, λ_2denote longitude coordinates.

Once the calculated distance is greater than the defined geofence radius, the livestock is deemed to have passed its virtual geofence, and the alert mechanism is automatically triggered.

The proposed system not only tracks livestock but also incorporates environmental sensing capabilities using a water sensor. The water sensor can detect water or other environmental humidity around the livestock environment and transmit the water information to the ESP8266 controller. By using environmental sensing, livestock security is enhanced because animals are warned of unsafe grazing conditions and environmental abnormalities that might exist [5, 6].

The communication protocol used in the system is Wi-Fi-based communication enabled by the ESP8266 module, which is an IoT connectivity module. The controller connects with Blynk's cloud platform and uploads livestock position information, alerts, and environmental sensor readings in real time. Farmers can track the movement of the animals, fences breached, and environmental parameters remotely using their smartphones or web-based interface via the Blynk application [12, 21].

The ESP8266 controller triggers several alerts if the livestock enters the predefined geofence boundary. These include exchanging visual warnings, LCD display notifications, and switching on the cooling fan via the relay module. Simultaneously, a push message was sent to the farmer via the cloud platform to enable him to respond and rescue the animals. The automatic notification system optimizes operations and prevents the loss or theft of livestock [22, 23].

The suggested operational procedure for the system is shown in Fig. 2. The flowchart depicts the steps involved in the acquisition of GPS data, verification of geofences, environmental sensing, communication with the cloud, and generation of alerts. The process starts by acquiring GPS coordinates and tracking the livestock movements against the set virtual boundary.

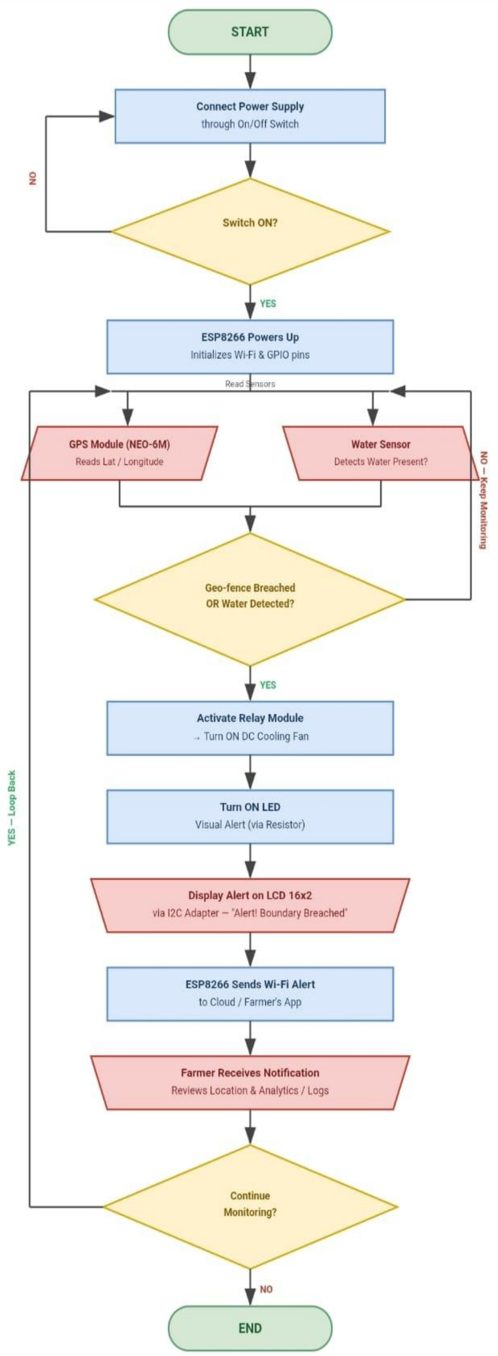

Fig. 2. The working process of the proposed system

The operational workflow shown in Fig. 2 illustrates the flow of monitoring operations to be executed by the proposed framework for livestock operations. It can continuously collect GPS data, check geofence boundaries, track environmental data, and automatically trigger alerts if livestock enter the virtual geofence area.

The proposed design has several advantages over conventional livestock monitoring. This enables dynamic virtual boundary management, real-time livestock tracking, low-cost implementation, environmental awareness and monitoring, and remote monitoring. Moreover, future expansion of the system will be possible by implementing new AI and machine learning algorithms, LoRaWAN communications, and predictive analytics for further precision livestock farming applications [9, 24].

4. SYSTEM METHODOLOGY AND IMPLEMENTATION

The designed IoT-based smart geofencing system is expected to provide a real-time livestock tracking system, automatic boundary management, and environmental awareness for sustainable agricultural applications. This technology integrates GPS tracking, IoT communication, cloud monitoring, and automated alerts to provide a complete smart livestock management system. The process of implementing the service requires the integration of hardware components, wireless communication technologies, cloud-based platforms, and geofence-based livestock monitoring algorithms to ensure efficient livestock tracking and notification for farmers.

The proposed system initializes the ESP8266 microcontroller as the main processor and communication device. Once powered on, the ESP8266 connected to the Blynk cloud via Wi-Fi. After an Internet connection, the GPS module, which was attached to the livestock monitoring collar, continuously sent GPS coordinate data to the controller [1, 21]. The GPS module can connect with the satellite to get the real-time accurate latitude and longitude of the livestock.

The farmer sets a virtual geofence on the Blynk platform, indicating the space in which the animals can graze. These geofence coordinates are stored in the system memory and are always compared with the GPS coordinates received from the livestock collar [2, 14]. The monitoring algorithm was calculated based on GPS coordinate analysis techniques between the livestock position and virtual boundary setting. The system continues normal monitoring activities without alarming if the inventory stays within the permitted area.

The proposed methodology is based on continuous real-time monitoring and automated decision-making. The ESP8266 controller loops through the coordinate acquisition, geofence verification, environmental sensing, and cloud communication steps repeatedly. The controller triggers the alert mechanism when the livestock crosses the predefined geofence boundary and updates the livestock status in the cloud platform [11, 17] instantaneously. The automated notification system allows farmers to track livestock movement on the go with the help of smartphones or a web-based interface via the Blynk app.

The system utilizes livestock tracking along with the integration of environmental monitoring with a water sensor and an ESP8266 controller. The water sensor continuously senses moisture or water around the livestock grazing area. If the water condition is abnormal, the system notifies the farmer through the cloud system and records the environmental data. [5, 6] Environmental sensing increases livestock safety by giving early warnings of potentially dangerous situations like pooling water or environmental hazards.

The planned implementation also proposes various ways to generate alerts for the effective monitoring of livestock. If a boundary is violated, the ESP8266 controller switches on the LED indicator, displays warning messages on the LCD screen, and turns on the cooling fan through the relay as an alert response. In parallel, a push notification is sent to the farmer via a cloud platform for the fast recovery and monitoring of animals [12, 23]. This multilayered notification system increases the reliability of the system and increases farmer awareness in real time.

The proposed framework was implemented using several integrated IoT-enabled hardware components. Owing to its reduced power usage, inbuilt WiFi connectivity, and ability to support cloud-based IoT platforms, the ESP8266 microcontroller became the main processing and communication unit. A water sensor was used for environmental monitoring, and a NEO-6M GPS module was used for livestock location tracking. Other parts, such as the LCD display, relay module, LED indicator, and cooling fan, enable real-time visualization and alert generation processes [4, 10].

Table I: Hardware Components Used in the Proposed System

Component	Function
ESP8266 Microcontroller	Central processing and Wi-Fi communication
NEO-6M GPS Module	Real-time livestock location tracking
Water Sensor	Environmental and moisture detection
LCD Display (16×2)	Displays system status and alerts
Relay Module	Controls alert devices
LED Indicator	Visual alert generation
Cooling Fan	Warning and response mechanism
Blynk Platform	Cloud monitoring and notification services

The hardware components listed in Table I collectively form the core infrastructure of the proposed IoT-enabled smart-geofencing framework. These integrated modules support GPS-based livestock tracking, environmental sensing, wireless cloud communication, and automated alert generation for real-time smart-farming applications.

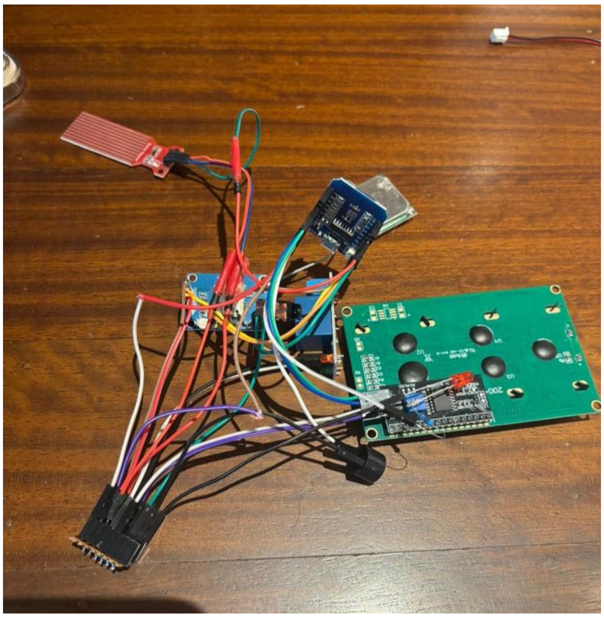

Fig. 3. Hardware Prototype of the Proposed IoT-Enabled Smart Geofencing System

The hardware prototype of the designed IoT-based smart geofencing system is illustrated in Fig. 3. The prototype developed in this study combines various components related to livestock monitoring, such as GPS tracking, environmental sensing, cloud communication, and automated alert generation.

The software application of the proposed framework was programmed and configured using the Arduino Integrated Development Environment (IDE) for the ESP8266 controller. The Blynk cloud platform was used for cloud communication, remote monitoring, and data visualization. The Blynk application enables farmers to track the movement of their livestock, receive alerts, and visualize environmental data via an interactive mobile application [8], [21]. The system is cloud-based, allowing data storage and access for future smart farming enhancements.

The proposed methodology offers several benefits over traditional livestock monitoring techniques. This approach also helps minimize reliance on physical fencing structures and enables flexible and dynamic virtual boundary management. The application of IoT technologies can improve operational and labour efficiency and allow remote monitoring of livestock through a cloud-based communication network [7, 18]. Furthermore, the framework can be applied to small- and medium-scale farming because of the low-cost hardware architecture. The suggested implementation shows real-time monitoring of livestock, but there are still some challenges. Bad positioning accuracy may occur when GPS signals are weak or have limited visibility, and a slow Internet connection may result in slow cloud communication and/or delayed positioning notifications [2, 11]. Furthermore, if the long-term deployment of wearable livestock collars is considered, efficient power management mechanisms are required to minimize the battery consumption of the collars. Future improvements may involve integrating LoRaWAN communication systems, AI algorithms, and energy-efficient monitoring architectures to further improve the scalability, reliability, and intelligent decision-making capabilities of the system.

5. RESULTS AND DISCUSSION

A smart geofencing system with IoT was developed and tested to assess its abilities in livestock monitoring, geofence management, environmental sensing, and automatic alert generation. The experiment was conducted using a NEO-6M GPS module, ESP8266 microcontroller, water sensor, relay module, LCD, LED indicator, cooling fan, and Blynk cloud. The assessment was mainly focused on GPS tracking, geofence detection, communication to the cloud, and generation of real-time alerts. The experimental results showed that the proposed system can track the location of livestock using GPS technology and monitor their movement in real time. The GPS module NEO-6M always sent the information of latitude and longitude to the controller (ESP8266), which compared the received coordinates with the virtual border coordinates [1, 2] preset in it. An alarm is raised, and notifications are sent to the farmer's Blynk cloud platform as soon as the livestock violate the geofence boundary. The proposed system was effective for remote livestock monitoring using a smartphone and cloud interface.

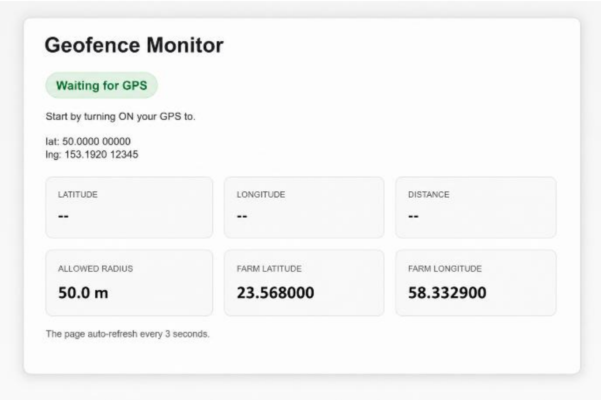

Fig. 4. Blynk Cloud Dashboard for Real-Time Livestock Monitoring

The environmental sensing function was also good. The built-in water sensor can monitor and understand the status of water around the livestock monitoring zone and the abnormal conditions of environmental water [5, 6]. The data gathered were transmitted to the ESP8266 controller and stored on a cloud-based platform, bolstering livestock safety and promoting environmental consciousness.

The system was effective in alerting when the boundaries were exceeded. When livestock entered the geofence area, the ESP8266 controller lit the LED indicator, which showed warning messages on the LCD screen and activated the cooling fan using the relay when livestock moved out of the predetermined geofence area. Simultaneously, a notification was sent to the farmer using the Blynk platform [12, 23]. The multilayered notification system increases the reliability of operations and livestock monitoring efficiency.

Fig. 5. Real-Time Geofence Notification Generated by the System

The proposed system was successfully tested with experimental observations, and real-time notifications of livestock crossing the previously defined geofence boundary were provided. The Blynk cloud platform was able to send a warning message to the farmer with very little time delay and kept the communication almost unaffected, thus making remote monitoring more efficient and livestock safer. Furthermore, the embedded environmental sensing and automatic alerting system enhanced the practical applicability of the proposed framework in real-time monitoring scenarios. The developed system was also tested for various operational parameters, as listed in Table II.

Table II: Performance Analysis of the Proposed Smart Geofencing System

Parameter	Observed Performance
GPS Tracking Accuracy	±3–5 meters under open outdoor conditions
Geofence Breach Detection Time	2–4 seconds
Cloud Notification Response Time	3–6 seconds
GPS Coordinate Update Interval	5 seconds
Environmental Water Detection Accuracy	95% detection reliability
Wi-Fi Communication Range	Approximately 30–50 meters
Remote Monitoring Accessibility	Real-time monitoring through Blynk platform
System Power Consumption	Low-power IoT operation
Average System Uptime	96% operational stability during testing
Implementation Cost	Approximately OMR 18–25

The proposed system offers several benefits over existing livestock monitoring systems. The framework aims to reduce the use of barrier-based systems and provide flexible virtualized boundary management for smart farming applications [7, 22]. This further improves remote access and working efficiency with the introduction of IoT-enabled cloud communication [8, 18].

The testing performance was satisfactory, with some minor issues. GPS accuracy may be reduced in areas where there is obscuration, and the delivery of real-time notifications may be hindered by Internet connectivity problems [2, 11]. Future improvements that could be implemented include incorporating LoRaWAN communication, integrating AI algorithms, and implementing energy-efficient monitoring techniques to enhance system scalability and intelligent decision-making capabilities [9, 24].

Comparative research was also conducted with other livestock monitoring systems, and a framework was proposed for further assessment. The main functional differences are discussed in relation to the integration of IoT, cloud monitoring, environmental sensing, and virtual geofencing capabilities in conventional systems and the proposed IoT-enabled smart geofencing framework, as highlighted in Table III.

Table III: Comparison with Existing Livestock Monitoring Systems [1, 12, 21]

Feature	**Existing Systems**	**Proposed System**
GPS Tracking	Yes	Yes
IoT Integration	Partial	Full
Cloud Monitoring	Limited	Yes
Environmental Sensing	Limited	Yes
Automated Alerts	Yes	Yes
Virtual Geofencing	Yes	Yes
Low-Cost Implementation	Moderate	Yes

.

6. CONCLUSION AND FUTURE WORK

This study proposed a GPS-based smart geofencing framework using IoT technologies that enables sustainable livestock monitoring through wireless sensing, cloud communications, and GPS tracking. The proposed system incorporates the ESP8266, NEO-6M GPS module, Blynk cloud platform, and sensor-based monitoring approaches to create smart virtual boundaries for real-time livestock management. The proposed framework effectively enabled the automated detection of geofence violations, remote tracking of livestock, and real-time notifications to farmers in a low-cost and scalable smart farming framework.

The experimental evaluation revealed that the proposed framework offers reliable livestock monitoring using GPS, effective virtual boundary management, and efficient communication using the cloud, which is appropriate for precision agriculture applications.

The infusion of IoT technologies provides flexibility in any kind of operation and reduces the need for traditional physical fencing systems. Furthermore, the environmental sensing function enhanced the safety of the livestock and increased awareness of the operation by monitoring the environmental conditions near the livestock. In summary, the proposed architecture seeks to enable technology-driven livestock management, remote access, and automated alerts while fostering sustainable practices in the agricultural industry.

The proposed system proved to be a good monitoring system; however, some practical problems were identified. The positioning accuracy may be affected if there are obstructions or poor signal strength, and if the Internet connection is not reliable, which can affect real-time communication and notification of clouds in remote areas. Moreover, the long-term deployment of devices for wearable livestock monitoring requires energy-saving communication and power management strategies.

Future research on the use of LoRaWAN in conjunction with LPWAN technology for greater scalability and long-range monitoring is recommended. The use of AI and machine learning algorithms can further facilitate the analysis of livestock behaviour, detection of anomalies, and intelligent decision-making in smart farming environments. Ongoing innovations, such as the integration of advanced cloud-based analytics, sensor fusion techniques, and AI-powered monitoring systems, have the potential to further enhance livestock health monitoring, environmental sustainability, and next-generation precision agriculture applications.

7. REFERENCES

[1] K. S, S. S. Nath, U. R. D. I and L. P. J, "Integration of loT for Precision Livestock Monitoring Through Geofencing," *2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, Coimbatore, India, 2024, pp. 437-442, doi: 10.1109/ICESC60852.2024.10690139.

[2] M. R. Nosouhi *et al*., "A Reliable Monitoring of Livestock Location and Geo-Fencing Application," in *IEEE Internet of Things Magazine*, doi: 10.1109/MIOT.2025.3639008.

[3] Verma, S., Sharma, N., Trivedi, G. (2025). Geotagging in Livestock Farming: AI-Based Technologies, Applications, and Challenges. In: Noor, A., Saroha, K., Pricop, E., Sen, A., Trivedi, G. (eds) Emerging Trends and Technologies on Intelligent Systems. ETTIS 2024. Lecture Notes in Networks and Systems, vol 1073. Springer, Singapore. https://doi.org/10.1007/978-981-97-5703-9_16

[4] S. K. Routray, S. Sarkar, M. Singh, K. P. Sharmila, M. Pappa and M. K. Jha, "A Review on IoT-based Cattle Monitoring Technology," *2025 6th International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV)*, Tirunelveli, India, 2025, pp. 1325-1329, doi: 10.1109/ICICV64824.2025.11085779.

[5] Perumal, B., Giridhar, A., Raghavendra, G., Teja, U.V., Kumar, G.A. (2026). IoT-Based Smart Livestock Monitoring for Rural Communities. In: Asokan, R., Ruiz, D.P., Păvăloaia, VD. (eds) Smart Data Intelligence. ICSMDI 2025. Algorithms for Intelligent Systems. Springer, Singapore. https://doi.org/10.1007/978-981-96-5265-5_25

[6] Kanagamalliga, S., Latha, R., Lakshmi Prabha, J., Usha Rani, D.I. (2026). Optimizing Livestock Health and

Productivity Through IoT-Driven Temperature Monitoring Systems. In: Shrivastava, V., Bansal, J.C., Panigrahi, B.K. (eds) Power Engineering and Intelligent Systems. PEIS 2025. Lecture Notes in Electrical Engineering, vol 1461. Springer, Singapore. https://doi.org/10.1007/978-981-96-9724-3_48

[7] Folarin GM, Folarin IA, Olanloye SA. Optimizing geophysics, biotechnology and other emerging tools for livestock production and management: a review. *The Journal of Agricultural Science*. 2025;163(1):110-117. doi:10.1017/S0021859625000012

[8] Alshehri, D.M. (2023) "Blockchain-assisted internet of things framework in smart livestock farming," *Internet of Things (Amsterdam, Netherlands)*, 22(100739), p. 100739. Available at: https://doi.org/10.1016/j.iot.2023.100739.

[9] Nasar, M., Kausar, M.A. and Nayyer, M.A. (2026) "Towards next-generation agriculture: An AI-driven industry 5.0 model for IoT-enabled smart farming," *Next Research*, 8(101526), p. 101526. Available at: https://doi.org/10.1016/j.nexres.2026.101526.

[10] Ebole, A. F., Ajani, A. O., & Agbalaya, K. K. (2025). Conceptual Review on Smart Livestock Health Management, Productivity and GPS Tracking System Powered by IoE Technology. European Journal of Applied Science, Engineering and Technology, 3(3), 230-239. https://doi.org/10.59324/ejaset.2025.3(3).15

[11] S. T. Ahmed, A. A. Ahmed, A. Annamalai and M. F. Chouikha, "A Scalable and Energy-Efficient LoRaWAN-Based Geofencing System for Remote Monitoring of Vulnerable Communities," in IEEE Access, vol. 12, pp. 48540-48554, 2024, doi: 10.1109/ACCESS.2024.3383778.

[12] S. Engelbrecht and A. Sheri, "IoT-Enabled Smart Collar for Cattle Theft Detection and Monitoring: Design and Investigation," *2025 33rd Southern African Universities Power Engineering Conference (SAUPEC)*, Pretoria, South Africa, 2025, pp. 1-6, doi: 10.1109/SAUPEC65723.2025.10944344.

[13] Nasar, M. (2023). Web 3.0: A review and its future. *International Journal of Computer Applications, 185*(10), 41–46.

[14] Anand Kumar Vedantham. (2024). GEOFENCING IN IOT: ENHANCING LOCATION-BASED SERVICES. *INTERNATIONAL JOURNAL OF COMPUTER ENGINEERING AND TECHNOLOGY (IJCET)*, *15*(6), 687-700. https://openlibindex.com/index.php/IJCET/article/view/IJCET_15_06_057

[15] Jiang, B.; Tang, W.; Cui, L.; Deng, X. Precision Livestock Farming Research: A Global Scientometric Review. *Animals* **2023**, *13*, 2096. https://doi.org/10.3390/ani13132096

[16] Posam, S., Reddy G, L.K. and Cm, V. (2025) "Automated dairy farm management system powered by IoT and ML," *Results in Engineering*, 28(107508), p. 107508. Available at: https://doi.org/10.1016/j.rineng.2025.107508.

[17] Montalván, S.; Arcos, P.; Sarzosa, P.; Rocha, R.A.; Yoo, S.G.; Kim, Y. Technologies and Solutions for Cattle Tracking: A Review of the State of the Art. *Sensors* **2024**, *24*, 6486. https://doi.org/10.3390/s24196486

[18] Anand Archangel, J., Krishnan, S., & Dejey, D. (Eds.). (2025). Smart Technologies for Sustainable Livestock Systems (1st ed.). CRC Press. https://doi.org/10.1201/9781003527114

[19] M. Nasar and M. A. Kausar, "Generative AI Framework for Smart Decision Support Systems in Industry 4.0," *2026 International Conference on Emerging Smart Computing and Informatics (ESCI)*, Pune, India, 2026, pp. 1-7, doi: 10.1109/ESCI68015.2026.11493315.

[20] K. Akter, T. Tabassum Ali, and M. Nasar, "AI-Driven Web 4.0: Toward an Intelligent Internet," 2025. [Online]. Available: www.ijeais.org/ijaisr

[21] V. Usha, S. Karagatla, P. S. Gowr, P. M. G. Jegathambal, A. Lizy and V. Sathya, "Real-Time GPS Tracking and Health Monitoring for Animals Using IoT and Mobile Application," *2025 International Conference on Machine Learning and Autonomous Systems (ICMLAS)*, Prawet, Thailand, 2025, pp. 1845-1851, doi: 10.1109/ICMLAS64557.2025.10968249.

[22] Gadzama, I.U.; Asadi, H.; Hina, Q.; Ray, S. Influence of Virtual Fencing Technology in Cattle Management and Animal Welfare. *Ruminants* **2025**, *5*, 21. https://doi.org/10.3390/ruminants5020021

[23] Mane, V., & Dirge, H. (2025). IoT-based location alert and controlling system for animal belts via mobile devices. *ITEGAM-JETIA*, *11*(51), 80-89. https://doi.org/10.5935/jetia.v11i51.1417

[24] M. A. Elhaj *et al*., "AI-Enhanced IoT-Integrated Virtual Fencing: A Proof-of-Concept for Camel Monitoring and Collision Mitigation," *2025 International Wireless Communications and Mobile Computing (IWCMC)*, Abu Dhabi, United Arab Emirates, 2025, pp. 549-555, doi: 10.1109/IWCMC65282.2025.11059715

[25] Mohammad Nasar, Mohammad Abu Kausar, "Federated Graph Attention Network for IoT Edge Anomaly Detection", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.16, No.3, pp. 40-55, 2026. DOI:10.5815/ijwmt.2026.03.03