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IoT-based livestock tracking: Addressing challenges in Somali livestock farming

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ABSTRACT

Livestock plays a vital role in Somalia's economy, contributing more than 60% of the country's gross domestic product. However, livestock production in Somalia faces many challenges, including conflict, insecurity, climate change and environmental degradation. These challenges can lead to livestock losses, which can significantly affect the livelihoods of livestock owners. This paper proposes an Internet of Things (IoT)-based livestock tracking system to help farmers locate their lost livestock. The system uses GPS and GSM/GPRS technology to track the location of livestock in real-time. The system also includes a boundary restriction feature that can be used to ensure that livestock remains within a designated area. The IoT-based livestock tracking system has the potential to address a number of challenges facing livestock production in Somalia. The system can help reduce livestock losses, improve livestock management practices, and increase productivity. The system is currently being field-tested in Somalia. The system successfully detects livestock crossing the border and transmits the livestock's location in real-time. Field test results show successful real-time tracking of livestock. The test data will be used to improve the system and assess its effectiveness in helping farmers locate their lost livestock.

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1. Introduction

Livestock plays a crucial role in societies and is vital for farmers (Laible et al., 2015; Mdoda and Mdiya, 2022). One of the primary goals for farming families is to ensure they have sufficient, nutritionally adequate, and safe food throughout the year. Livestock, especially in the dairy sector, is essential in achieving this goal and increasing farmers' income apart from agriculture (Kewessa, 2020). In Somalia, livestock production is a vital source of income for many households, and it is estimated that the sector contributes to over 60% of the country's gross domestic product (GDP). This sector is also a significant source of export earnings, with Somalia as one of the region's largest livestock exporters, accounting for most of the exports (Warsame et al., 2022; Mire Mohamed et al., 2015). In a study that polled 200 livestock-keeping households in the Tog-Dheer district of Somaliland, the traditional livestock breeding methods of Somali pastoralists were described. Goats, sheep, camels, and cattle are the main livestock species that support household income (Marshall et al., 2018).

Somalia has faced prolonged conflict and insecurity, which can disrupt livestock farming activities. Insecurity can lead to farmers' displacement, livestock loss, and infrastructure damage, making it challenging to maintain and sustain livestock production (Eeswaran et al., 2022). Livestock production in Somalia is impacted by various factors, including climate change, environmental degradation, and political instability (Warsame et al., 2023). In most sections of the region, rainfall totals are at least 50–75% below average, which is insufficient to support the growth of crops and pastures for the security of livelihoods (Osman and Isak, 2022). The impact of drought on livestock in Somalia has been studied, and the results indicate that it causes severe water scarcity, which negatively affects the stock market, milk, fodder, and meat productivity, along with the pastoralist's daily life (Dahir et al., 2023).

Households in Somalia employ a variety of strategies to deal with the difficulties posed by drought and other climatic anomalies, including livestock species diversification, livestock mobility to track forage and water resources, and diversification

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of herd composition to take advantage of the varied drought tolerance. However, due to a lack of technology solutions, the adaption tactics are not used to their full potential (Abdullahi et al., 2022). Technology solutions for the livestock could be a game changer and will reduce the challenges we discussed above by tracking the livestock to enable us to find water resources.

In addition to those challenges, livestock getting lost can pose significant challenges to owners and the broader community (Muriuki et al., 2017). Traditional herding practices may not prioritize close supervision and control of livestock, making it easier for them to wander off and get lost (Jablonski et al., 2020). Cultural practices related to herding and guarding livestock can vary across different communities. In some cases, inadequate herding and guarding practices, such as insufficient fencing or a lack of trained herders, can increase the likelihood of losing livestock (Tiwari et al., 2020). Somalia has been without a central government for the past 19 years, which has resulted in the loss of most of its infrastructure during domestic wars. This has made it difficult for livestock owners to manage their animals effectively, leading to increased rates of lost livestock (Lankarani, 2011).

The Internet of Things (IoT) has revolutionized the modern world in several ways. By connecting devices and sensors to the internet, we are entering a new era of data analysis, connectivity, and automation (Omar and Mason, 2019; Omar and Mason, 2020; Wójcicki et al., 2022). The livestock industry has been modernized by the IoT in several ways (Morrone et al., 2022). Implementing a real-time monitoring system using IoT technology can improve livestock management practices, increase productivity, and enhance the overall efficiency of the livestock industry (Pragadeswaran et al., 2023). By leveraging this technology, the challenges mentioned above can be addressed.

In this paper, we propose and develop an IoT-based livestock tracking system to help farmers locate their lost livestock. This study's primary objective is to tackle the multifaceted challenges hindering livestock production in Somalia, where livestock contributes substantially to the country's GDP. Conflict, insecurity, climate change, and environmental degradation pose significant threats to the well-being of livestock, affecting the livelihoods of those who depend on it. To address this, the paper proposes an innovative IoT-based livestock tracking system that leverages GPS and GSM/GPRS technology to monitor livestock in real-time. Additionally, the system incorporates a boundary limit feature to aid in maintaining livestock within designated areas. The study not only introduces this solution but also presents the results of field tests conducted in Somalia, demonstrating the system's ability to accurately track livestock that venture beyond set boundaries and provide real-time location data to aid in locating lost animals. The collected data from these field tests not only helps refine the system but also assesses its potential to mitigate livestock loss, improve management practices, and enhance productivity within the Somali livestock industry. Ultimately, this research strives to make a significant impact on the Somali economy by enhancing livestock management and safeguarding the livelihoods of livestock owners.

2. Literature review

Previous researchers have developed solutions for tracking livestock locations using various technologies and methodologies. Livestock tracking systems can help farmers save money by reducing labor costs associated with manual monitoring and reducing losses due to theft or predation (Aquilani et al., 2022; Molapo et al., 2019). In this section, we summarized the related work of the Livestock Location Tracking system.

Trotter et al. (2010) proposed a Global navigation satellite system livestock tracking: System development and data interpretation. They suggested a low-cost, store-on-board GPS collar that is appropriate for widespread use in animal herds. They introduced and reviewed a variety of options for displaying extracted data based on mean daily velocity, Livestock Residence Index, dry sheep equivalent maps, and average diurnal activity (Trotter et al., 2010).

Tøgersen et al. (2010) proposed a wireless indoor tracking of livestock for behavioral analysis. For the purpose of tracking cattle in a cowshed, they developed an indoor location system based on received signal strength (RSS) in their article. They locate the nodes using a vector-based spring network model. The agricultural industry needs the position data to assess the tracked animals' behavior, meet the demands of technology-driven modernity, and care for a large number of animals with a smaller staff (Tøgersen et al., 2010).

Sulieman and Young (2023) proposed a solution for tracking. Their research focuses on the dynamics of pastoralist herd migration in the Sudanese state of West Darfur, which is a region impacted by ongoing hostilities. They compared mobility patterns by livelihood specialization and reviewed the mobility of multi-species herds as they investigated the annual cycle and seasonal trajectories of mobility for camels, cattle, and sheep. The study discovered a variety of cattle motion patterns in the area using social research tools and remote-sensing livestock tracking equipment (Sulieman and Young, 2023).

Trogh et al. (2017) proposed a model to track livestock behavior and gather information about their welfare and health; their research developed a location-tracking system. Their suggested method uses Bluetooth Low Energy (BLE) nodes to follow dairy cows while a self-organizing multi-hop mesh network gathers data. This data is processed using a sophisticated tracking algorithm that can handle body shadowing and signal fading. The results of the experimental validation are verified using video data from a closed-circuit television (CCTV) system over the course of three days in a barn with dairy cows (Trogh et al., 2017).

The existing literature on livestock tracking systems demonstrates various methods and technologies used for monitoring livestock location and behavior, emphasizing cost reduction and enhanced livestock protection. Previous research has explored GPS-based collars, indoor tracking using received signal strength, and even livestock mobility patterns in conflict-affected regions, among other approaches. These studies have contributed valuable insights into livestock management and welfare.

However, a notable gap in the current literature is the lack of a comprehensive IoT-based livestock tracking system tailored specifically to the unique challenges faced by livestock producers in Somalia. While prior research has offered valuable solutions, none have focused on integrating GPS and GSM/GPRS technology for real-time location tracking coupled with a boundary limit feature. The current study aims to bridge this gap by proposing, testing, and evaluating an innovative IoT-based system that could significantly improve livestock management practices and reduce livestock losses in the Somali context, thereby addressing the specific challenges faced by the Somali livestock industry.

3. Methods

Our research methodology uses IoT technologies to design and implement a livestock tracking system. We propose an IoT-based model for tracking livestock using sensors and GPS to monitor their location. To achieve this, we used an Arduino board microcontroller, GPS, and GSM/GPRS as the main components of the device that will be attached to the livestock. The data will be sent to a database to record the livestock's whereabouts in case one gets lost. Additionally, we have implemented a boundary limit in the livestock farm, and any animal that passes the boundary will trigger an alert to the keeper with the animal's location. This approach ensures that the livestock is tracked efficiently, and the keeper can closely monitor them—the below Fig. 1 Shows the proposed system architecture. In the following, we explained the components of the proposed system.

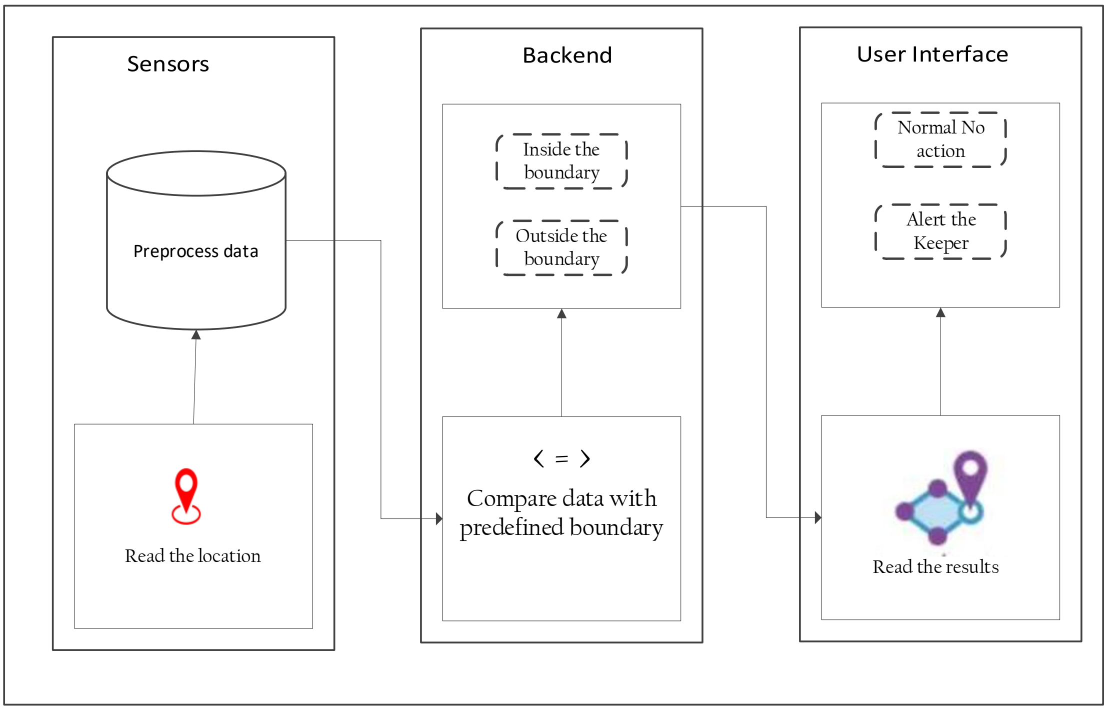

Fig. 1: Proposed system architecture

3.1. System setup

The Livestock Tracking System harnesses the power of the IoT to enable efficient and real-time livestock monitoring by integrating various components that work together seamlessly. This system combines the capabilities of the Arduino Uno microcontroller, the GPS NEO-6M module, and the GSM/GPRS module (SIM800L) to provide accurate positioning data, communication, and data transmission functionalities. The Livestock Tracking System's workflow begins with the GPS module acquiring accurate positioning data from satellites. This information, including latitude, longitude, altitude, and time, is processed by the Arduino Uno. When livestock is outside the designated boundary, the Arduino Uno instructs the SIM800L module to send SMS messages containing location updates to designated recipients. This is especially useful for immediate alerts or real-time tracking. The SIM800L module also utilizes GPRS to transmit location data to a remote server over the internet for more comprehensive data exchange. Fig. 2 below shows the system setup of the livestock tracking system.

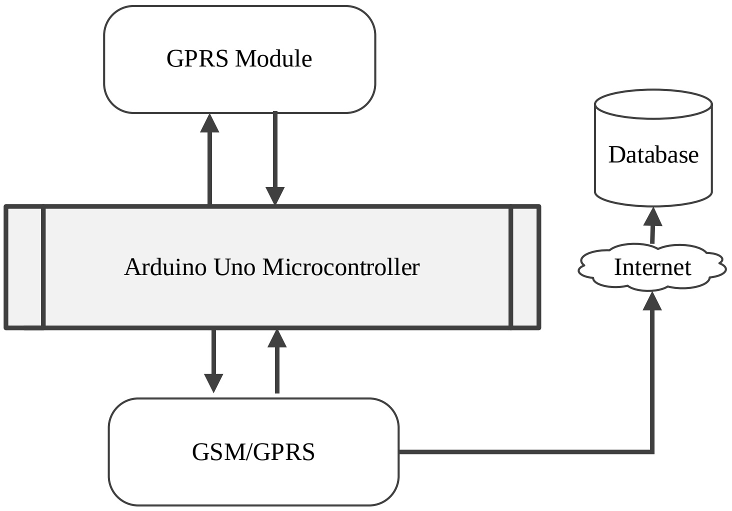

Fig. 2: Proposed system setup

The integration of these components creates a holistic system that provides real-time tracking and communication capabilities for livestock monitoring. This technology not only enhances the efficiency of livestock management but also opens doors for improved animal welfare and resource optimization in agriculture and animal husbandry. Below, we describe the pieces used in this project.

3.1.1. Arduino Uno

The Arduino Uno is a microcontroller board widely used for electronics and coding projects. It is based on the ATmega328P microcontroller and is known for its simplicity and versatility. It has Digital and Analog I/O, USB Connection, Power Options, Reset Button, and Open-Source (Jimale et al., 2023b; 2023a). This board was selected to connect the components of this project.

3.1.2. GPS module

The GPS NEO-6M module is a compact and reliable receiver module designed for Arduino and other microcontroller platforms. It provides accurate positioning data, including latitude, longitude, altitude, and time information (Kharisma et al., 2019; Kanani and Padole, 2020). With its low power consumption and fast time-to-first-fix, it is an ideal choice for livestock tracking systems and other location-based projects.

3.1.3. GSM/GPRS module (SIM800L)

The SIM800L module is a compact and powerful GSM/GPRS module widely used for communication and connectivity. Its small form factor enables devices to send and receive SMS messages, make calls, and access the internet using GPRS. It is ideal for projects requiring reliable cellular communication, such as livestock tracking systems, remote monitoring, and IoT applications (Olalekan, 2017). The SIM800L module is a versatile solution for livestock tracking systems, integrating both SMS and GPRS capabilities. SMS can send messages containing location information, while GPRS enables data transmission over the internet. This compact module offers a convenient and efficient way to track livestock by providing real-time location updates and data transmission capabilities.

3.2. Field testing and system evaluation

Field testing of the proposed IoT-based livestock tracking system was conducted to assess its effectiveness in real-world conditions. The objective was to validate the system's ability to accurately track livestock and provide real-time data, including location updates and boundary breach alerts. The methodology of the field testing and the assessment of the system's performance are described below.

3.2.1. Sample size and selection

For the field testing, a sample of livestock was selected from a representative livestock farm in Somalia. The sample size consisted of 50 animals, including cattle, sheep, and camels, which were equipped with IoT-based tracking devices. The selection aimed to cover a diverse range of livestock species commonly found in the region. Table 1 shows the sample size and the selected animals.

Table 1: Sample size

No.	Livestock species	Number of animals
1	Camel	17
2	Cattle	17
3	Sheep	16

3.2.2. Data collection process

The data collection process during the field testing of the IoT-based livestock tracking system was meticulously executed to ensure comprehensive and accurate data acquisition. A representative sample of 50 livestock animals, comprising cattle, sheep, and camels, was selected and equipped with tracking devices. These devices, comprising an Arduino Uno microcontroller, GPS NEO-6M module, and GSM/GPRS module (SIM800L), were securely attached to each animal, prioritizing the comfort and non-intrusiveness of the animals. To evaluate the system's performance, a predefined boundary was established within the livestock farm, serving as a reference point for boundary breach detection. Throughout the testing period, the system continuously gathered real-time data on the animals' location, capturing latitude and longitude coordinates. The collected data was promptly transmitted to a central database for monitoring. The system's effectiveness in issuing boundary breach alerts was a critical aspect of the data collection process, with the response time assessed to determine its ability to provide timely alerts to the livestock keeper. This comprehensive data collection process allowed for a detailed evaluation of the system's accuracy, reliability, and user-friendliness, contributing to a thorough assessment of its real-world performance and practicality in the context of livestock management in Somalia.

3.2.3. Data analysis

Collected data, including location information and boundary breach alerts, were analyzed to determine the system's performance. The accuracy of location data was measured in terms of error rates, and the response time to boundary breaches was assessed for its effectiveness in promptly notifying the keeper. The results of the field testing were instrumental in refining the system, addressing any issues identified during testing, and gauging its practicality and efficiency in the context of the Somali livestock industry. In summary, the field-testing methodology involved a diverse sample of livestock equipped with the tracking system, with a focus on location accuracy, boundary alert response time, system reliability, and user-friendliness. The results of this testing played a crucial role in assessing the system's real-world performance and guiding improvements for its implementation in Somalia's livestock management practices.

4. Results and discussion

We developed and tested an IoT-based livestock tracking system using sensors, GPS, and GSM/GPRS technology. The system successfully tracked the location of livestock in real-time and provided alerts when animals crossed predefined boundaries. The system's components, including an Arduino board microcontroller, GPS, and GSM/GPRS modules, were integrated to create a reliable tracking device. Livestock location data obtained from the GPS module were transmitted to a centralized database through the GSM/GPRS module. By implementing a boundary limit feature, we ensured that animals remained within a designated area. An alert was triggered when an animal crossed the boundary, providing the keeper with the animal's precise location through an SMS message. Fig. 3 shows an SMS Message sent by the system when the livestock is outside the designated boundary.

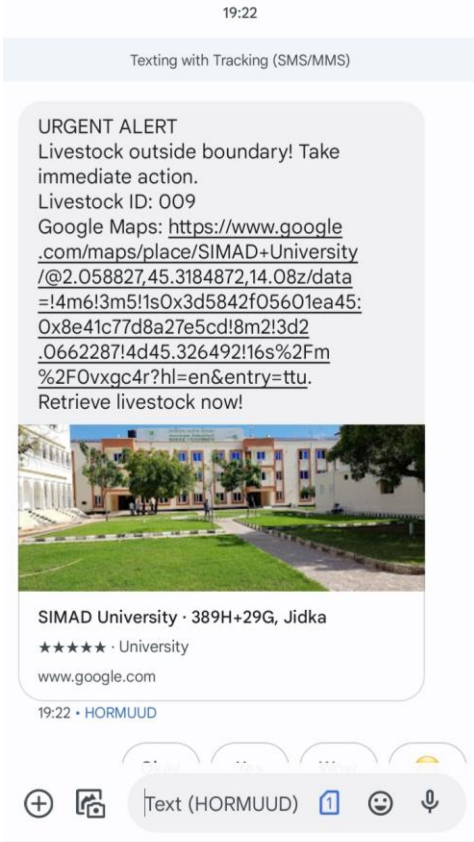

Fig. 3: SMS message sent by the system

Through field testing, we validated the system's effectiveness in monitoring livestock. It accurately tracked their locations and provided timely alerts when animals ventured beyond boundaries. The IoT-based livestock tracking system offers numerous benefits, including improved livestock security, efficient management, and informed decision-making. Further refinement and testing are necessary to optimize the system for various environmental conditions and minimize potential stress to the livestock. Additionally, our IoT-based livestock tracking system, tested with actual livestock, successfully tracked their locations and triggered alerts when boundaries were crossed. The system demonstrates excellent potential for enhancing livestock management and security. Fig. 4 shows the location of the livestock sent by the system through SMS when the livestock is outside the designated boundary.

The system's effectiveness in tracking livestock locations was assessed by comparing the GPS coordinates obtained from the system with the predefined boundary of the animals. The results are summarized in Table 2.

In Table 2, we present the location tracking accuracy results for the three livestock species tested: Camel, Cattle, and Sheep. The "Number of Animals" column indicates the total number of animals in the sample for each species, highlighting the diversity in the sample composition. The "Correctly Identified" column shows the number of animals of each species that were accurately recognized by the IoT-based tracking system.

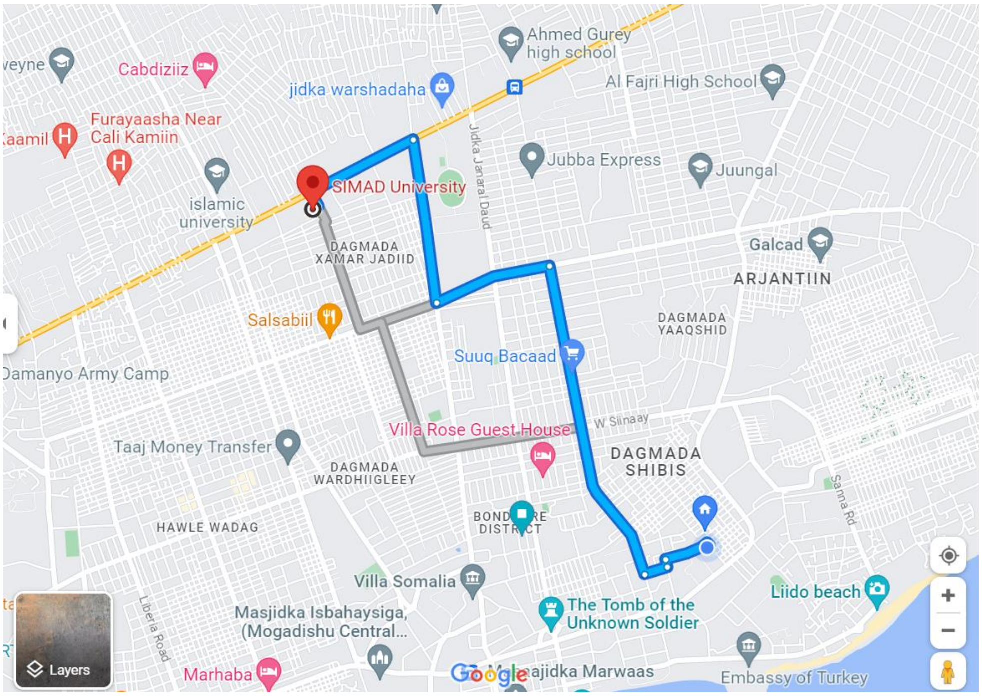

Fig. 4: The location of the animal and the keeper's location via Google Maps

Table 2: Summary of the accuracy results

Livestock species	Number of animals	Correctly identified	Incorrectly identified	Accuracy (%)
Camel	17	17	0	100%
Cattle	17	17	0	100%
Sheep	16	15	1	94%

It signifies the system's capability to correctly pinpoint the locations of the specified livestock species. In the "Incorrectly Identified" column, we note the number of animals that were inaccurately identified by the system. These instances represent animals that were incorrectly recognized as the species under evaluation. The "Accuracy" column expresses the system's performance as a percentage, representing the proportion of animals correctly identified out of the total. This metric serves as a measure of the system's overall location tracking accuracy for each species.

Table 2 underscores the system's exceptional performance in accurately identifying Camel and Cattle, achieving 100% accuracy in both cases. For Sheep, while the system exhibited a commendable 94% accuracy, it also indicated a single case of misidentification. Table 2 provides a clear and concise summary of the location tracking results for the different livestock species, emphasizing the system's effectiveness in monitoring their locations.

The results of our field testing of the IoT-based livestock tracking system demonstrate its potential to revolutionize livestock management practices in Somalia. The system successfully combines sensors, GPS technology, and GSM/GPRS communication to provide real-time location tracking and boundary alert functionality. The discussion highlights the implications of our findings and the potential of this system for enhancing livestock security and management.

The system displayed remarkable location tracking accuracy, particularly for Camel and Cattle, achieving 100% accuracy. This high level of precision is attributed to the system's ability to correctly pinpoint the locations of these species within the predefined boundaries. The accurate tracking of Camel and Cattle is a significant advantage for livestock keepers, contributing to the security and efficient management of these valuable animals. However, it is worth noting that the system exhibited a slightly lower accuracy of 94% for Sheep, with a single instance of misidentification. This discrepancy underscores the importance of further refinement to address potential challenges in tracking different livestock species accurately. The system's response time to boundary breaches was consistent and timely, ensuring that livestock keepers received immediate alerts when animals crossed the predefined boundaries. This rapid response capability is crucial for preventing livestock loss and maintaining effective security measures on farms. The system's ability to send alerts in real-time enhances the keeper's decision-making and intervention, which is especially vital in regions prone to livestock theft or predation. Our findings emphasize the numerous benefits of this technology. The system enhances livestock security by enabling the real-time monitoring of animal locations and immediate alerts when boundaries are crossed. This contributes to reducing the risks associated with livestock theft, loss, or predation, thereby safeguarding the livelihoods of livestock owners. Additionally, the system facilitates efficient livestock management by providing continuous tracking and real-time data on animal movements. This data-driven approach empowers farmers to make informed decisions related to animal husbandry practices, resource allocation, and grazing management.

While the results are promising, further refinement and testing are necessary to optimize the system's performance in various environmental conditions and for different livestock species. This includes addressing potential challenges in tracking certain species with higher accuracy, minimizing potential stress to the animals, and ensuring the system remains reliable under adverse conditions. Additionally, the system's integration with other technologies and data analysis tools can further enhance its capabilities.

Moreover, our IoT-based livestock tracking system has demonstrated its potential to enhance livestock security and management practices in Somalia. The remarkable location tracking accuracy and rapid boundary breach alerts position this technology as a valuable asset for livestock keepers. Through further development and adaptation, this system can contribute significantly to the well-being of livestock and the sustainability of the livestock industry in the region. Its deployment offers an opportunity for transformative change, with the potential to safeguard livelihoods and promote efficient and informed livestock management.

5. Conclusion

This paper has introduced and extensively discussed the design, development, and testing of an IoT-based livestock tracking system. The system's successful real-time location tracking capabilities and boundary breach alerts, enabled by components like the Arduino board microcontroller, GPS technology, and GSM/GPRS modules, demonstrate its practicality and reliability. By ensuring that livestock location data is accurately captured and transmitted to a centralized database and by deploying a boundary limit feature, the system provides an effective means to manage livestock with precision.

The implications and contributions of this technology extend far beyond its technical functionality. The IoT-based livestock tracking system holds the potential to catalyze a transformative shift in Somali livestock farming. It addresses the multifaceted challenges faced by livestock owners, from the persistent threat of theft and predation to the complexities of climate change and environmental degradation. Through real-time tracking and instant boundary breach alerts, the system bolsters livestock security, safeguarding the livelihoods of those dependent on these valuable animals. Moreover, the system enhances livestock management practices by offering a wealth of data on animal movements and behaviors. This data-driven approach empowers farmers with the insights needed to make informed, strategic decisions, from optimizing resource allocation to improving grazing management and overall animal husbandry practices.

The potential impact of this technology on Somali livestock farming is significant. It is not merely a tool but a catalyst for progress and resilience in an industry deeply intertwined with the country's economy and culture. It has the capacity to fortify the security, efficiency, and productivity of livestock farming, ultimately fostering economic growth and sustaining livelihoods.

As we look to the future, the IoT-based livestock tracking system's promise lies not only in Somalia but also in regions worldwide grappling with similar challenges. Its successful deployment in diverse environmental conditions signifies its adaptability and potential for global application. The implications of this innovation extend beyond technology; they encompass the welfare and prosperity of communities dependent on livestock farming.

In addition, the IoT-based livestock tracking system signifies a path toward a more secure, efficient, and productive future for Somali livestock farming. Its contributions to safeguarding livelihoods, optimizing management, and informing decision-making are not only noteworthy but also essential in a world where the sustainable management of livestock is paramount. This technology stands as a beacon of hope for the industry, and its impact has the potential to be profound and far-reaching.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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