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Monitoring of Livestock on Large-Scale Areas using Aerospace Data and IoT Technologies

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Abstract: ***This article explores innovative solutions for developing a remote-control system to monitor cattle in vast, remote areas that are inaccessible to humans. The system, utilizing Internet of Things and geofencing technologies, enables farmers to reduce manual labor, track lost livestock, and effectively utilize pasture resources. Advanced technologies, including GPS, ultrasonic sensors, databases, antennas, and Arduino microcontrollers, were utilised in this system. Additionally, methods for assessing vegetation cover in pastures and their nutritional productivity using vegetation indices, such as NDVI, were also analysed. The research results show that the proposed solution enables increased efficiency in livestock management, as well as optimisation of energy and time costs. This, along with creating conveniences for farmers, will serve to improve the health and productivity of livestock.***

Keywords: Monitoring, Geofencing, IoT, GPS, NDVI, Farming System, Productivity, Satellite, Aerospace Data.

Abbreviations:
NIR: Near-Infrared
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
RS: Remote Sensing
IoT: Internet of Things

I. INTRODUCTION

In modern livestock farming, animal management and tracking technologies are crucial for enhancing labour productivity, optimising resource utilisation, ensuring safety, and maximising economic benefits. Traditional methods of manual livestock tracking require a significant amount of labour, time, and resources, and result in considerable uncertainty.

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In these conditions, the implementation of automated monitoring and control systems based on remote sensing (RS), the Global Positioning System (GPS), geofencing (virtual geographic barriers), and the Internet of Things (IoT) technologies is becoming increasingly relevant. Especially on large-area pastures, real-time monitoring of herd placement, movement, grazing dynamics, and safety zones is one of the most critical problems today.

The development and implementation of an innovative system for applying digital aerospace technologies in animal husbandry enables the prediction of soil fertility, as well as the amount of grass and water in pastures. Complete application of the necessary algorithms for monitoring the state of forage plants in pastures based on remote sensing technologies is required. These algorithms are fully functional only if an electronic digital map of the pasture area is compiled. In this approach, the area is divided into elementary parts based on surface spatial discreteness. In the development of a modern and innovative livestock system, information support is crucial for making informed management decisions, mitigating moderate risks, and enhancing labour productivity in agriculture. In this scientific work, the concept of an intelligent monitoring and management system was developed, aimed at ensuring the safe movement of livestock within a designated zone using real-time geofencing technology, automatic tracking of their location and activity through external monitoring, and creating convenient management opportunities for farmers.

Effective management of the spatial distribution of grazing requires an understanding of the factors that influence how animals respond to their environment. These influencing factors include the position of water sources, the size and shape of the pastureland, environmental elements such as terrain slope, soil conditions, and weather variations (wind, temperature, and atmospheric pressure), as well as the physiological condition of the animals and the social dynamics within the herd. Therefore, analyzing the spatial distribution of grazing livestock must take into account the environment, the animals, and their interactions to ensure informed decision-making in both spatial and temporal grazing management [1].

II. USE OF SATELLITE SYSTEMS FOR DETERMINING FEED CONSUMPTION FOR REMOTE SENSING

Grazing herds in large areas requires considerable labour, unless the amount of grass and water is determined in advance. Since the late 2010s, with the emergence of applications for the Global Navigation Satellite System (GNSS) in animal monitoring, the demand for it has also begun to grow. In smart livestock farming, the use of GPS devices to control and protect herds, as well as virtual boundary demarcation, is becoming increasingly popular as an alternative to traditional livestock practices that are declining. Several studies have been conducted in this area, including J.Plaza and C.Palacios, who used two prototype devices, including a GPS sensor, a data storage unit, a GPSR SIM card, and a long-term battery (one week) to track the feeding behavior of herbivorous animals with free distribution of pasture location data [2]. Additionally, they installed an antenna for receiving satellite and phone signals. Most of the device's elements are housed within a hermetically sealed, rigid plastic enclosure, which protects them from impact and moisture. The receiving antenna is mounted on a collar, protected by an insulating material. In another study, S. Oleynik and V. Skripkin demonstrated a positive correlation between remote sensing of NDVI (Normalised Difference Vegetation Index) and feed nutritional value during remote monitoring in animal husbandry [3]. In this work, the NDVI, which is a standardised index indicating the presence and condition of green plants (relative biomass), was studied. This index uses the difference between the red and near-infrared (NIR) wavelength ranges in multispectral raster images: the red wave is strongly absorbed by the chlorophyll pigment, while the NIR is highly reflected by vegetation.

The formula determines NDVI:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad \dots \quad (1)$$

To determine moisture content, the normalised moisture difference index (NDMI), which is sensitive to the moisture content of plants, was used. This index, used to track the amount of fuel in arid and fire-prone areas, utilises the NIR and SWIR ranges to obtain a ratio designed to mitigate the impact of lighting and atmospheric effects.

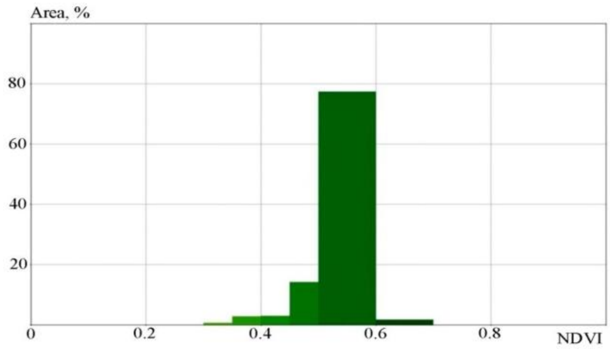
The formula determines NDMI:

$$NDVI = \frac{NIR - SWIR1}{NIR + SWIR1} \quad \dots \quad (2)$$

Additionally, when examining the SAVI (Soil-Adjusted Vegetation Index), the index employs a correction factor to mitigate the impact of soil on the vegetation index. It is typically used in desert areas with low vegetation cover, and its values range from −1.0 to 1.0. The following formula determines this index:

$$SAVI = \left(\frac{NIR - RED}{NIR + RED + L}\right) * (1 + L) \quad \dots \quad (3)$$

To determine pasture areas with high and low vegetation cover, a surface based on NDVI was constructed using a multispectral camera. Areas with the lowest NDVI indicator indicate plant growth retardation or leaf damage (Fig. 1).

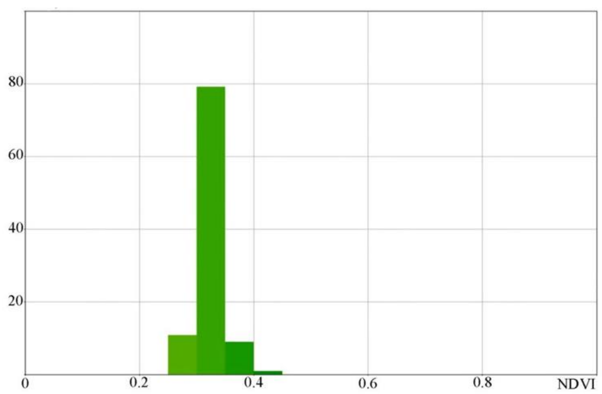


[Fig.1: Distribution of Vegetation According to NDVI in Pasture No. 1]

In areas with low vegetation, NDVI indicators are low. The obtained data were used to construct a histogram showing the distribution of plants depending on the NDVI value, which is necessary to determine the area of pastures suitable for grazing livestock [4]. In large and remote pastures, especially in semi-arid regions, due to the difficulty of determining biomass from the earth's surface, the use of spectral indices based on remote sensing is becoming increasingly important as an economical and effective method. Currently, the most widely used index among ecologists and agricultural specialists is the NDVI [5].

The conducted studies confirm a positive correlation between the vegetation index obtained remotely and the nutritional value of feed. Optimization of the selection of pasture areas ensured an additional increase in the live weight of young merino sheep by 11.06% ($p<0.05$), as a result of which the use of remote monitoring based on satellite services increases the possibility of more efficient use of agricultural pastures.

Water is the most critical food source for grazing livestock in arid and semi-arid pastures [6]. The study shows a positive correlation between remote sensing of NDVI and feed nutrition. If cattle are left without water in the summer, they can lose about 7 percent of their body weight per day and die in a 5-day drought and high temperatures [7]. Therefore, farmers regularly check the water availability of livestock, usually every 1-3 days, taking into account weather conditions and available water reserves.



[Fig.2: Distribution of Vegetation According to NDVI in Pasture No. 2]

In real-time, GPS monitoring and other sensors enable the remote monitoring

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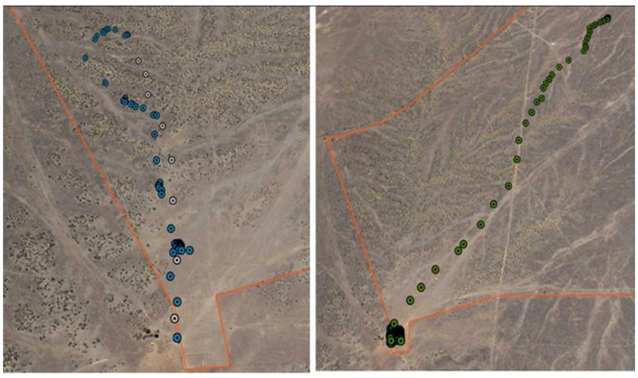
of water presence in pastures. When sensors are used to monitor water levels in drinkers and water containers, the data is transmitted directly or via the internet to the farm using mobile phone or satellite technologies [8]. The conducted research shows that sensors on animals and GPS observations can detect malfunctions in water systems. Usually, cattle do not stay near the water body after drinking, and they typically rest more than 100 meters from the water body. During the simulated water deficit, cattle remained at a distance of 100 m from the tank and were more active than with normal irrigation measures (Fig. 3). Typically, after drinking water, cows moved at least 250 m away from the water source. Cows and other livestock raised for meat are typically managed under different grazing regimes, particularly on expansive pastures and uneven terrain. Bailey et al. noted that cows using steeper slopes (mountaineers) spent twice as much time on steep slopes (44-57% slope) as cows using softer terrain [9]. Mountaineering cows were also 46 meters higher on average than cows living below. Several researchers have suggested that livestock can be divided into two groups: cows that prefer soft land near water in the pasture, and cows that use steep terrain and areas far from water [10]. The selection of cows that use several uneven terrains (mountaineers) and the combination of cows that prefer soft lands near water (lower ones) make it possible to increase the uniformity of pastures [11]. Two studies have shown that cattle feeding characteristics (land use characteristics) are associated with genetic markers of single-nucleotide polymorphism (SNP) [12]. The candidate genes for pasture traits were also associated with other cattle traits, such as heat stress, oxygen homeostasis, feed efficiency, and growth. Two studies in Montana found no negative phenotypic correlation between land use characteristics and cows' work capacity characteristics [13]. The correlations between the peculiarities of terrain use (use of slopes, distance travelled vertically and horizontally from water) and indicators of the cow's body position, calf's weaning weight, calving date, and thigh height were usually low (between -0.2 and 0.2) and uneven over the years.



[Fig.3: On the Graph on the Left, the White Dots Indicate that the Cow is Going into the water, and the Blue Dots Indicate that the Cow is Coming Out of the water. On the Map on the Right, the Green Dots Indicate that the Cow Comes into the Water and Remains in the Water During the Simulation of a Malfunction in the Water System. Both Maps include an Observation that begins 30 Minutes before the Cow Enters the Water Tank, followed by an Additional Hour of Observation (Simulated Water Deficit)]

III. MONITORING OF ANIMALS AT LONG DISTANCES USING NAVIGATION DEVICES

Traditional control of animals for feeding in large-scale livestock farming zones is quite labour-intensive. In the research conducted by Derek W. Bailey and his team, horse observers were used to record the location of cattle during grazing [14]. It took several observers up to 180 cows to locate in 1.5-2.5 hours on pastures of 100-350 hectares. Modern information and measurement systems for monitoring pastures in aerospace require further improvement of predictive mathematical models to enhance the quality of animal productivity. There are several types of satellite navigation systems used for determining the condition of livestock, including the Global Positioning System (GPS) by the United States, Galileo by the European Union, the Global Navigation Satellite System (GLONASS) by Russia, and the BeiDou system by China. An artificial satellite navigation device is attached to the monitored livestock, which allows real-time monitoring of the livestock's condition. In addition to this navigation, the installation of a special geofence device will significantly aid in determining its closed shape, which refers to a geographical area on Earth. The location detector triggers alerts when an object enters or exits a geo-barrier-marked area. In this regard, I. K. Mudassar and A. Muneer proposed a system that allows remote monitoring of various livestock animals using GPS [15]. In this study, an improved management system is proposed that will enable farmers to determine a geographically safe zone for their livestock. The system notifies farmers when livestock attempts to exceed the designated area. Additionally, navigation and communication are automatically controlled based on the genetic diversity of different animals. Figure 3 shows a general overview of the conceptual framework of the proposed system. The red ellipse represents a geographically safe zone for livestock. Ultrasonic sensors, installed at the elliptical boundary of the safe zone, detect the movements of cattle. The propagation of ultrasonic waves detects the presence of livestock and calculates its distance. If the cattle's distance exceeds the established safety distance limit, the communication navigator will activate.

The algorithm for implementing the proposed structure, as described in Fig. 4, is illustrated in Fig. 5. This figure shows different stages based on the sensing location coordinates and communication with the system when observing either the entire herd or a specific cow within the herd. The developed presentation is presented in the following algorithm:

1. The H herd includes a variety of livestock, the number of which can be arbitrary depending on the local conditions available for keeping and managing the animals. At the same time, we assume

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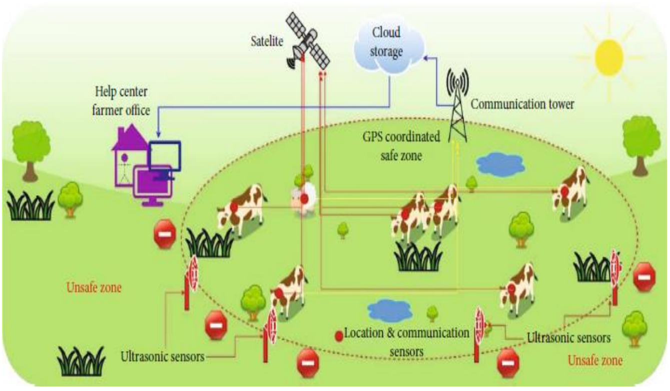
that a typical herd can have three, f N anials, where capwh$H = H_1, H_2, H_3 \ldots H_i, i \leq$

2. Since the proposed system currently tracks the location of animals in the H herd, GPS is necessary to connect individual cattle to the satellite to obtain the location coordinates of each animal. Additionally, since the system needs to analyze the final distance of animals from the designated safe zone, we need to transmit these location coordinates to the system via the communication channel. For this, we need to equip H_i animals with N_i and C_i navigation and communication sensors, where $i < N$
3. First of all, since the system provides for keeping animals in a designated safe zone, to maximize their safety, grazing, and rest periods, we denote the safe zone S with geographic coordinate points $S = S_1, S_2, S_3 \ldots S_j$.

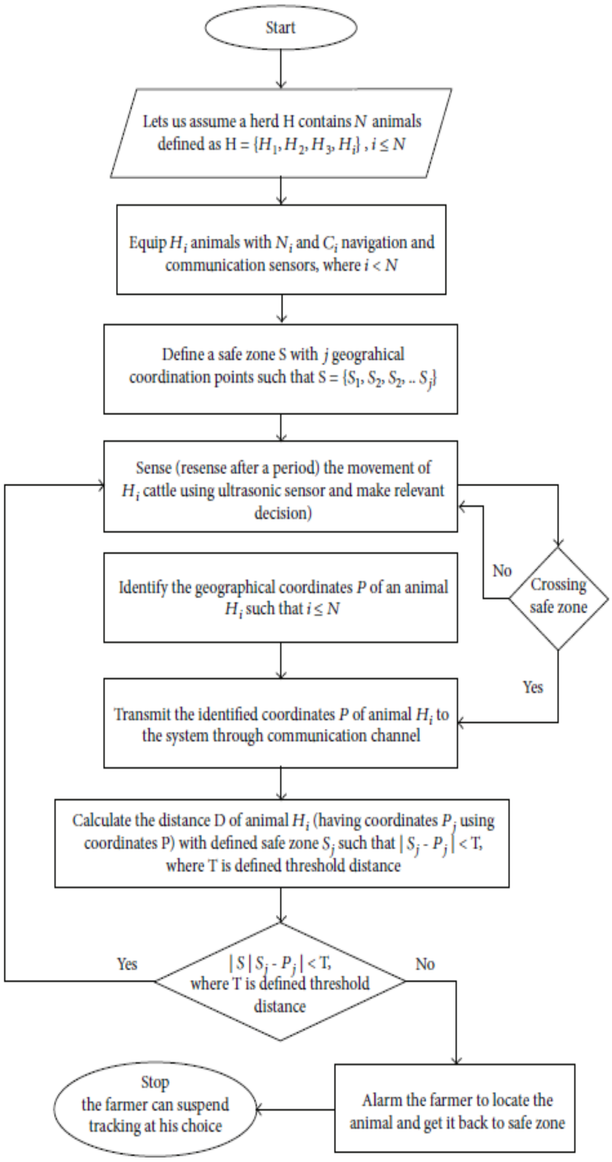


[Fig.4: Conceptual Foundations of the Proposed System]

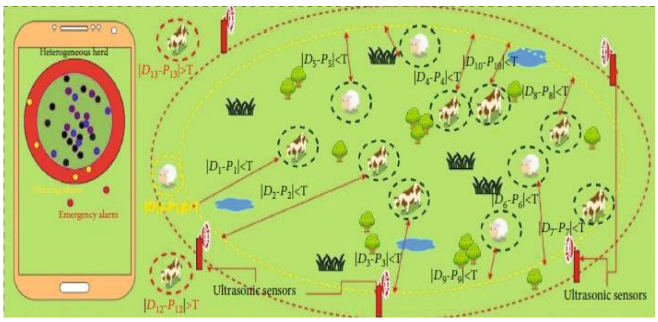
4. Ultrasonic sensors detect high cattle passing through the safe zone S and signal a GPS sensor to start detecting H_i's location
5. Installed geographic sensors to calculate the coordinates of livestock through satellite communication. We define the geographical coordinates P of the animal H_i so that $i \leq N$.
6. For a comprehensive and timely analysis of the calculated coordinate points, we need to transmit the coordinates of the identified animal H_i to the system through the P communication channel.
7. Then we calculate the animal's distance D. Hi (has P_j coordinates using P coordinates) is defined as the safe zone S_i with $|S_j - P_j| < T$, where T is the defined distance.
8. Now we calculate the distance $D < T$, where T is defined as the boundary distance of the animals $\Delta t_1, \Delta t_2, \Delta t_3, \ldots \Delta t_n$, where $n \leq t$ (propagation of waves forward and backward from the ultrasonic sensor) we obtain. Let's define time t as follows:

$$f(t)\begin{cases} t_1, & t < T \\ t_2, & t \geq T \text{ where } T - \text{is the specified limit} \end{cases}$$

9. If the result is t_1 (the calculated limit D is not less than T), then the system warns the farmer to find the animal and return it to the safe zone.
10. Unlike the traditional livestock tracking system, farmers sometimes have to expend physical effort to track livestock outside of common entry points. The designated zone provides convenience with safe and operational management.



[Fig.5: Algorithm for Implementing the Conceptual System]



[Fig.6: Observation of Livestock in the Herd by Geographic Area]

The proposed system uses sensor devices equipped with solar panels for power supply. This research developed a geographical area for observing the spatial and temporal movements of livestock. The grazing, movement, and rest movements of different livestock are considered distinct. Figure 6 illustrates the visual implementation of

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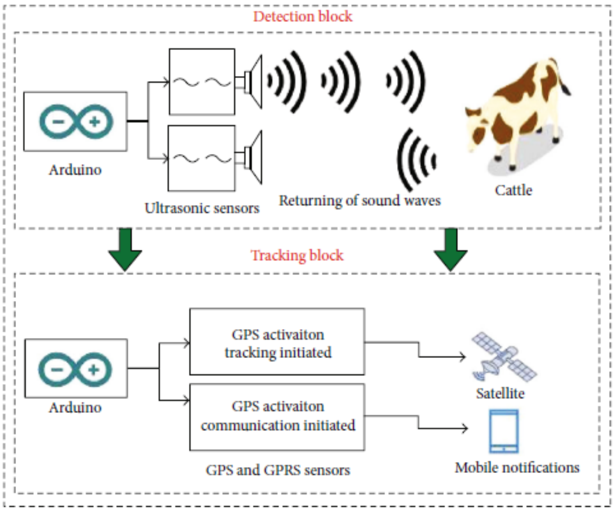
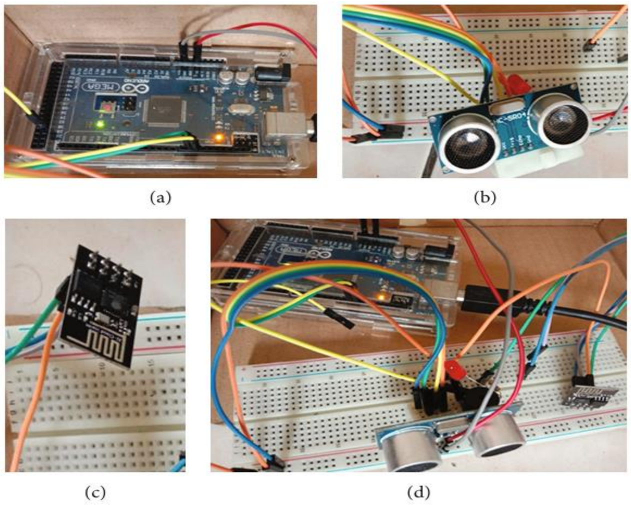
livestock monitoring within a designated geographical area, utilising remote sensing to capture the spatial and temporal activities of livestock. Yellow and red circles indicate warning and anxiety zones for farmers or caregivers. Ultrasonic sensors detect H_i crossing the safe zone S of cattle and trigger GPS to track H_i's location. The application calculates the geographical distance to the centroid H sub i. , i., less than or equal to the ptoH_i, $i \leq N$ of each animal for the number N of animals in the H herd. It also determines the distance limit T, which helps to align the current difference of H_i with the safe zone $S = \{S_1, S_2, S_3, \dots, S_j\}$. When H_i (with geographic coordinates P_j) approaches S_j, the geographic distance $|P_j - S_j|$ is calculated and compared with T. The app alerts the farmer if he is looking for the value of the difference between two geographical distances. Fig. 5 shows the detection and observation phases of the proposed system. Ultrasonic sensors connected to the Arduino detect the presence of cattle. First, Arduino launches an ultrasonic sensor to collect data. Calculates the distance of the cattle and sends the Arduino's distance reading to the ESP8266 module via a serial connection. We need to select a value that allows the sensors to sense the obstacle and calculate the distance. Based on the calculated distance, helps ESP8266 transfer the distance to the cloud using a communication channel.



[Fig.7: Detection and Tracking Blocks]

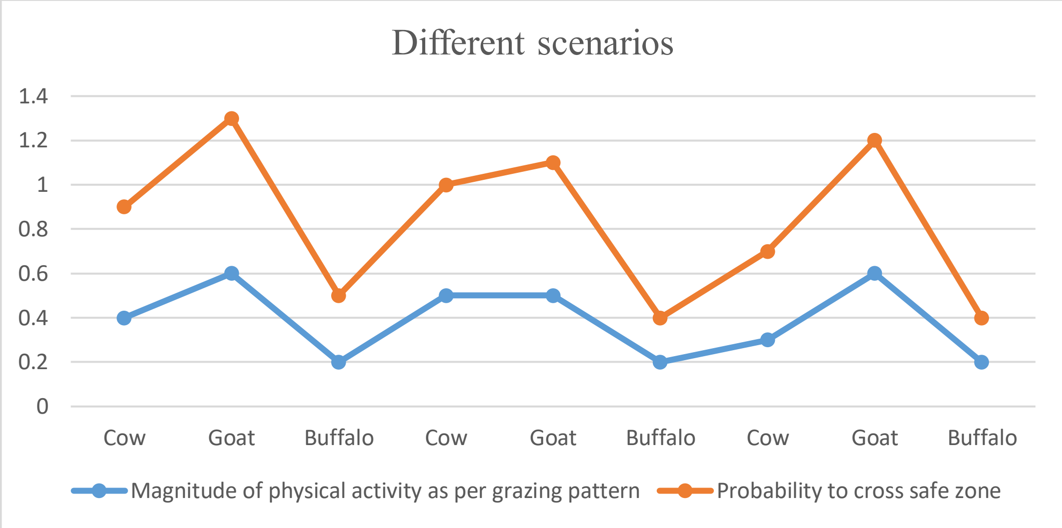
The distance of cattle from the sensors is calculated as follows: Measured distance = 1/2 × Time × Speed; where the level of humidity and temperature affects the speed of the sound wave in a particular location. Cattle Satellite Mobile notifications. Table 1 presents an experimental scenario in which different types of livestock are introduced at various entry points over time. After the system detects the cattle's exit from the safe zone, the GPS module attached to the Arduino is activated, and the module connects to nearby satellites, beginning to read the current location coordinates of the cattle. These location coordinates are transmitted to the farmer's mobile phone through a communication channel attached to the Arduino. Figure 8 shows the general view of the apparatus components used for identifying and monitoring livestock. Figure 8(a) shows the Arduino Uno microcontroller board, which is manufactured using the Microchip ATmega328P. This microcontroller board was used for connecting detection and navigation components. Figure 8(b) shows an ultrasonic sensor, HC-SR04, which uses SONAR to identify livestock and determine their distance from the safe zone. Figure 8(c) shows the NRF24L01 wireless module, which serves as the communication module in the device. Figure 8 (d) shows the installed hardware modules for livestock identification and monitoring.



[Fig.8: Simulation Setup of Detection and Navigation Equipment]

Table 1: Livestock Identification and Monitoring Activities

Instance	Cattle	Safe Zone Threshold (T)	Distance from the Boundary (D)	Tracker Activated	Mobile Notifications
T_1	H_1	5 meters	15 meters	x	x
T_2	H_2	5 meters	3 meters	✓	✓
T_3	H_3	5 meters	5 meters	✓	✓
T_4	H_4	5 meters	1 meter	✓	✓
T_5	H_5	5 meters	7 meters	x	x
T_6	H_6	5 meters	2 meters	✓	✓
T_7	H_7	5 meters	4 meters	✓	✓
T_8	H_8	5 meters	9 meters	x	x
T_9	H_9	5 meters	3 meters	✓	✓
T_{10}	H_{10}	5 meters	4 meters	✓	✓



[Fig.9: Differences in Animals Crossing the Safe Zone in Terms of Physical Activity and Grazing Characteristics]

The importance of the proposed livestock management system is reflected in its reduction of time and energy complexity, as well as the integration of modules, as shown in Figure 8. Different types of livestock have genetically different grazing characteristics, and therefore their physical activity is proportional to these genetic movements [16]. Some livestock, such as cows and buffalo, have been observed to be more sluggish than goats and sheep. After the grazing period, cattle noticeably reduce physical exertion to consume more feed, prefer rest, or lie down. During such passive or inactive periods, the safe zone ensures that cattle remain within the geographical boundaries and do not stray outside. Thus, it is not necessary to launch a tracking system to record the location of livestock, since they are already located within the parameters of the safe zone. On the other hand, goats and sheep become more active after consuming proper nutrition. The probability of such goods appearing is lower or higher compared to passive goods. In this case, more active livestock is required compared to cows and buffalo. The proposed system aims to minimise the excessive use of resources, including time, energy, and labour. All three scenarios identified in Figure 8 illustrate that goats and sheep are significantly more likely to cross the geographical boundary than cows.

This research proposes designing a geographical area for monitoring livestock movements. In the traditional livestock tracking system, farmers have to expend physical effort to track cattle outside of common entry points. The system notifies farmers, indicating their exact location, even when livestock attempts to stray beyond the designated territory and enter an unauthorised zone. Additionally, navigation and communication are automatically controlled based on the genetics of different animals. The system calculates the distance of each animal from the specified geographical boundary and notifies the farmer when it approaches the boundary value. The motion sensor stops navigation and communication when the animal is in a static position, significantly optimising its energy and communication capacity.

IV. DATA PROCESSING AND TRANSMISSION

Currently, most affordable GPS devices store tracking data from sensors, including SOB and onboard storage devices. However, the SOB monitoring equipment does not enable real-time remote monitoring of livestock movements. This is the main limitation, as it is more beneficial for farmers to use GPS tracking to remotely monitor their livestock's health, spatial distribution, and report any issues that arise while grazing in the pasture. Precise monitoring of livestock management using SOB technology is more effective only when proving concepts, developing algorithms, and considering simulated problems. When identifying issues related to the health and well-being of animals, real-time monitoring is crucial for assessing changes in animal movements, spatial distribution, and movement. In addition, the development of real-time GPS tracking will allow managers to identify problems related to livestock placement and implement management practices during pasture grazing [9]. Smartbow has a real-time monitoring system for dairy cows [17]. The Moovement GPS ear tag records the location of the animals every hour and sends the data to the LoRa antenna and then transmits it to the internet using cellular phone technology [18]. These GPS ear tags are designed to transmit data from 8 km to the LoRa antenna. The Moovement app utilises Google Earth images to visualise the location of livestock and sends this information to the mobile app.

Currently, most commercial accelerometers produce vast amounts of data, as they record the movement (acceleration) along three axes at a sampling rate of 12-25 Hz. The transmission of such large amounts of data in real-time is prohibited due to the battery's need for transmission in pastures where livestock graze. To reduce the transmission volume from the sensor (accelerometer), it is necessary to process and summarize the data. The process of analyzing and processing sensor data in the device is called "marginal computing" [19]. In a study conducted by Y. Cheng and colleagues, a locally sensitive Bloom filter was used to

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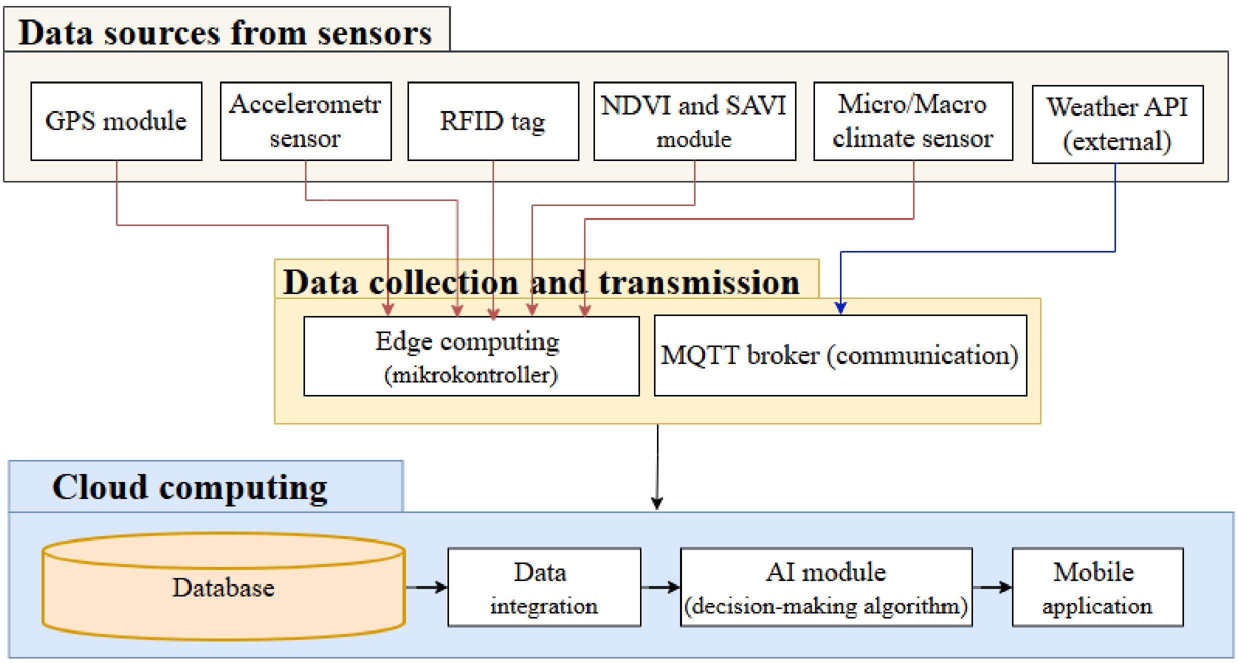
reduce the volume of sensor data [20]. Historical data and machine learning processes, such as random forests and a signal vector machine, are utilised to identify key states or events from data streams collected from peripheral computing sensors [21]. A study by W. Hu et al. demonstrated that marginal computing can reduce response time and energy consumption on mobile devices [22]. Sensors for livestock should be small and not practical for large batteries, especially ear tag sensors. Farmers prefer ear tag sensors, which are a reliable method for monitoring activities using accelerometers [23]. Herddogg developed an ear pad with an accelerometer to monitor the health and well-being of livestock. When data from ear tags approaches a reader placed in a place frequently visited by an animal (such as water), the data from the tag is automatically transmitted. The readings recorded by the Herddogg three-axis accelerometer at a frequency of 24 Hz are compressed to one value every 6 minutes. This reduces the amount of data being transmitted and minimizes battery consumption. Algorithms used for detecting diseases, spatial distribution, and other problems from real-time location streams, accelerometers, and other sensors should be developed using experimental and field studies.

V. RESULTS AND DISCUSSION

The research results demonstrate that the proposed approach plays a crucial role in enhancing the efficiency of livestock management, reducing time and energy costs, and improving the health and productivity of animals. At the same time, one of the main problems in existing monitoring systems is the lack of consistent and harmonious data processing from various sources, as well as their lack of mutual synchronisation. To solve this problem, an integrated modern technological approach is proposed, operating based on multilayer sensor data exchange, where:

- Location, movement, and identification data are obtained using GPS, accelerometer, and RFID modules through devices attached to animals.
- The vegetation state of pastures is assessed using remote sensing methods, including satellite imagery based on NDVI or SAVI indices.
- Sensors installed in the pasture area are used to measure temperature, humidity, soil condition, and atmospheric pressure to determine microclimatic and macroclimatic conditions.
- Weather forecasts received from external meteorological services will also be integrated into the system.



[Fig.10: Decision-Making System Based on Multilayer Information Exchange]

All these types of information are integrated into the decision-making module using a data fusion approach. As a result, the system enables the assessment of livestock condition, the quality and nutritional value of pastures, as well as the level of ecological and climatic risk. For the real-time transmission and processing of information flows, the Edge computing architecture, operating based on the SCS protocol, is recommended. This enables the preliminary filtering and processing of information from sensors at the local level before sending it to the central system. This approach simplifies system operation, reduces transmission delays, and optimises network load.

VI. CONCLUSION

The study demonstrates that integrating modern geospatial technologies and IoT-based sensor systems into livestock management significantly enhances operational efficiency and decision-making. By utilizing GPS, accelerometers, RFID, remote sensing indices like NDVI and SAVI, as well as environmental sensors and meteorological data, a multilayered data ecosystem is formed. This system enables real-time monitoring of animal movement, pasture quality, and climatic conditions. The proposed multilayer sensor-based information fusion and Edge computing architecture reduces manual labour, energy consumption, and response latency, while also increasing the reliability and autonomy of livestock monitoring systems. Moreover, the use of automated geofencing and innovative alert mechanisms ensures timely interventions, minimises livestock losses, and promotes the sustainable use of pasturelands. This research confirms the potential of intelligent monitoring systems not only to optimize animal welfare, pasture productivity, and overall farm profitability, but also to reduce the time and energy complexity associated with system operation and integration of its modules. The further development and scaling of such solutions will play a key role in advancing precision livestock farming, particularly in remote and large-scale grazing areas.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
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- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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