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WILDLIFE MONITORING SYSTEM USING NAVIC-BASED GEOFENCING

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Abstract- One of the byproducts of infrastructural development is the rise in the number of conflicts arising between human beings and wildlife, since most of these developments are completed on the wild habitats. The present study describes the implementation of a real-time animal monitoring system in which the NavIC satellite positioning system of India is integrated with the GSM and Long Range (LoRa) technologies. The collar receiver transmitter consists of the ESP32-S microcontroller, GNSS module with NavIC support, and the LoRa transceiver working on the frequency of 433 MHz. During the field trials, the system was able to detect 87% of the geofence violations with a positional accuracy of ±10 meters over the communication distance of 800-1000 meters. The receiver base station transmits data through GSM with a success rate of 90% and an average end-to-end delay of 68 seconds. The smart transmission scheduling increases the battery life to 24-25 hours (monitoring mode) compared to 16-17 hours (continuous transmission), which is a reduction in energy consumption by 33%. The system was able to receive over 95% of the packets in the 500-meter range and supported 10-second visualization refresh rates using the Flask-Supabase-Folium architecture. The ecosystem can be protected using this system, which costs about ₹3,500-4,500 ($42-54) per unit. It is a demonstration of technological reliance on the local invention through the utilization of satellite navigation.

Keywords: Wildlife monitoring, NavIC, Geofencing, LoRa, IoT, Human-animal conflict, GNSS, Real-time tracking

1. Introduction

1.1 Background and Motivation

The growth of human populations and the building of new roads have completely opened up the areas where wild animals live and where humans have settled. The areas of conflict between humans and animals have become bigger and have resulted in more and more human-animal conflicts such as road accidents, crop damage, destruction of property, and threats to the lives of both humans and animals. India, where the areas of high biodiversity coincide with the areas of rapid human development, is one of the countries facing this problem most severely [9][11].

The conventional methods for managing wildlife are mainly based on reactive strategies like putting physical barmaid Ries which, to some extent, help in knowing the animal movement patterns and providing timely warnings [12]. Nevertheless, the introduction of satellite-based localization systems and low-power wireless communication technologies opens a new door for animal management through real-time monitoring and automated alert systems [13].

1.2 Research Objectives

This research aims to develop and evaluate a wildlife monitoring system with the following objectives:

1. Design a low-power, long-range tracking collar utilizing India's NavIC satellite navigation system
2. Implement energy-efficient geofencing algorithms for boundary violation detection
3. Establish reliable data transmission infrastructure using LoRa and GSM technologies
4. Create real-time visualization interfaces for forest management authorities
5. Validate system performance under field conditions representative of Indian wildlife habitats

1.3 Contributions

The principal contributions of this work include:

- Integration of NavIC positioning with IoT communication protocols for wildlife applications
- Development of an intelligent transmission protocol that activates only during geofence violations, significantly extending battery life
- Implementation of polygonal geofencing suitable for irregularly shaped conservation areas

- Creation of a hybrid communication architecture combining LoRa local transmission with GSM cloud connectivity
- Demonstration of system feasibility through prototype testing in rural environments

2. Related Work

2.1 Wildlife Tracking Technologies

Wildlife monitoring has seen a major change from traditional techniques including visual observation and radio telemetry to modern GPS methods. The current methods rely on satellites for precise location identification yet the majority of the installations are still relying on GPS rather than regional navigation systems like NavIC [14].

2.2 Geofencing Applications

Geofencing technology is a big step forward in the location-based services field as it creates virtual borders around the real-world geographical areas [6][1]. On the one hand, Rahate and Shaikh provided the groundwork for geofencing infrastructure and its use in security and asset tracking. On the other hand, natural habitat boundaries are not always accurately depicted by circular geofences which could be a limitation of this technology [8].

The Android-based pet tracking system developed by Pangestu et al. features geofencing and has an impressive 92% accuracy rate in open areas. Their work set a talking point around the issues like indoor positioning delays and battery life limitations and also paved the way for collar-based tracking systems in terms of establishing baseline performance metrics [6].

2.3 LoRa for IoT Applications

LoRa (Long Range) technology allows communication at a very low energy level over the distances of several kilometers. Bor et al. proved LoRa's potential for multi-hop IoT networks by realizing 2-year battery life with 80% reliability over 1.5 hectares. Joshi et al. took this research further for urban air quality monitoring, proving LoRa's effectiveness for distributed sensing applications that have long-range, low-power communication needs [3].

2.4 Research Gaps

Existing wildlife tracking solutions predominantly utilize GPS without exploring regional navigation systems like NavIC. Furthermore, most implementations employ continuous transmission protocols that rapidly deplete battery resources. Limited research has addressed the integration of polygonal geofencing with event-driven transmission strategies specifically optimized for wildlife conservation in Indian contexts.

3. System Architecture and Methodology

3.1 System Overview

The system that has been suggested includes three main components: the transmitter unit mounted on the collar, the reception base station, and the monitoring platform based on the cloud, all of which are synchronized and therefore provide real-time tracking of animals and alert in case of geofence violations.

3.2 Transmitter Unit Design

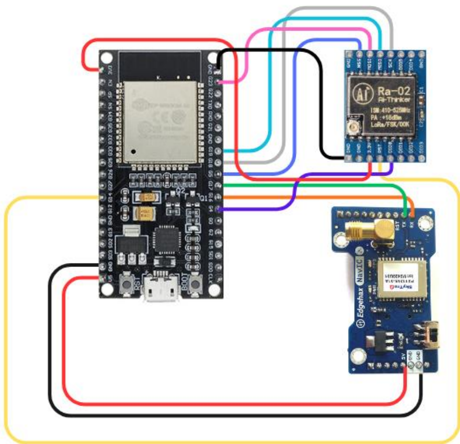


Fig.1 Transmitter Circuit

3.2.1 Hardware Components

The collar transmitter consists of several essential parts, the first one being the ESP32-S microcontroller which is a dual-core processor having built-in Wi-Fi and Bluetooth and has been chosen for its outstanding processing power and very low energy consumption of just 10 microamperes in deep-sleep mode. The second part is a NavIC-compatible GNSS module which is capable of receiving signals from both NavIC and GPS satellites thus providing almost ±10 meters accuracy in positioning. For long-distance communication, a 433 MHz LoRa transceiver module with selectable spreading factors is used, which has a range of up to 15 km in open rural areas. The device is powered by a lithium-polymer battery that is supplemented by an embedded charging and power-management circuit, thus assuring that there is no interruption in the operation even in the wilderness.

3.2.2 Software Architecture

The transmitter firmware implements the following algorithmic logic:

```
INITIALIZE GPS module, LoRa transceiver
DEFINE polygonal geofence coordinates
SET check_interval = 2 seconds
SET transmit_interval = 10 seconds

WHILE device_active:
    current_location = GET_GPS_COORDINATES()

    IF coordinates_valid:
        inside_geofence = POINT_IN_POLYGON(current_location, geofence)

        IF NOT inside_geofence:
            transmit_flag = 1
            CONSTRUCT JSON payload with location data
            TRANSMIT via LoRa
            WAIT transmit_interval
        ELSE:
            transmit_flag = 0
            SUPPRESS transmission
            WAIT check_interval
    ELSE:
        WAIT for GPS fix
```

3.3 Polygonal Geofencing Algorithm

Traditional circular geofences inadequately represent natural boundaries. This system implements ray-casting algorithm for point-in-polygon determination.

The formulae used:

$$(y_i > y) \neq (y_j > y) \wedge \left((x < x_i) + \frac{(x_j - x_i)(y - y_i)}{(y_j - y_i)} \right)$$

Algorithm: Point in Polygon Test

Given a test point P (x, y) and polygon vertices V = {(x1, y1), (x2, y2), ..., (xn, yn)}:

```
inside = false
j = n - 1

for (i = 0 to n-1):
    xi = polygon[i][0]
    yi = polygon[i][1]
    xj = polygon[j][0]
    yj = polygon[j][1]

    IF ((yi > y) ≠ (yj > y)) AND
       (x < (xj - xi) * (y - yi) / (yj - yi) + xi)
        inside = not inside

    j = i

RETURN inside
```

This algorithm counts edge crossings by a horizontal ray extending from the test point; an odd count indicates the point lies inside the polygon.

3.4 Receiver Base Station

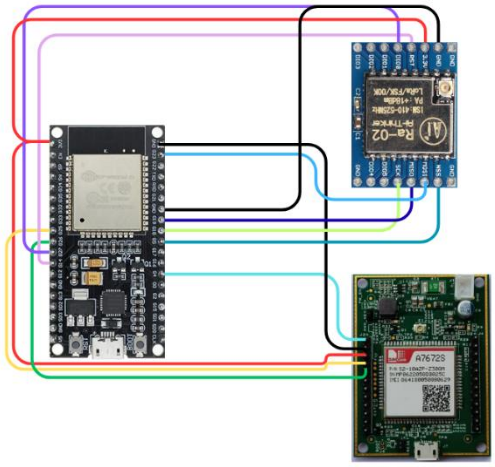


Fig.2 Receiver Circuit

3.4.1 Hardware Configuration

At the receiver station, there is an ESP32-S microcontroller that is responsible for processing the incoming LoRa packets and managing the communication with the GSM network. In addition, a LoRa receiver module is connected to the microcontroller and it has been set up to work on the same frequency and spreading factor as the transmitter so that reliable long-distance data reception can be guaranteed. A SIM800L GSM module is also present at the station and it ensures connectivity through either the 2G or 3G network, hence received location data can be stored on the cloud and accessed remotely for monitoring the same.

3.4.2 Data Processing Pipeline

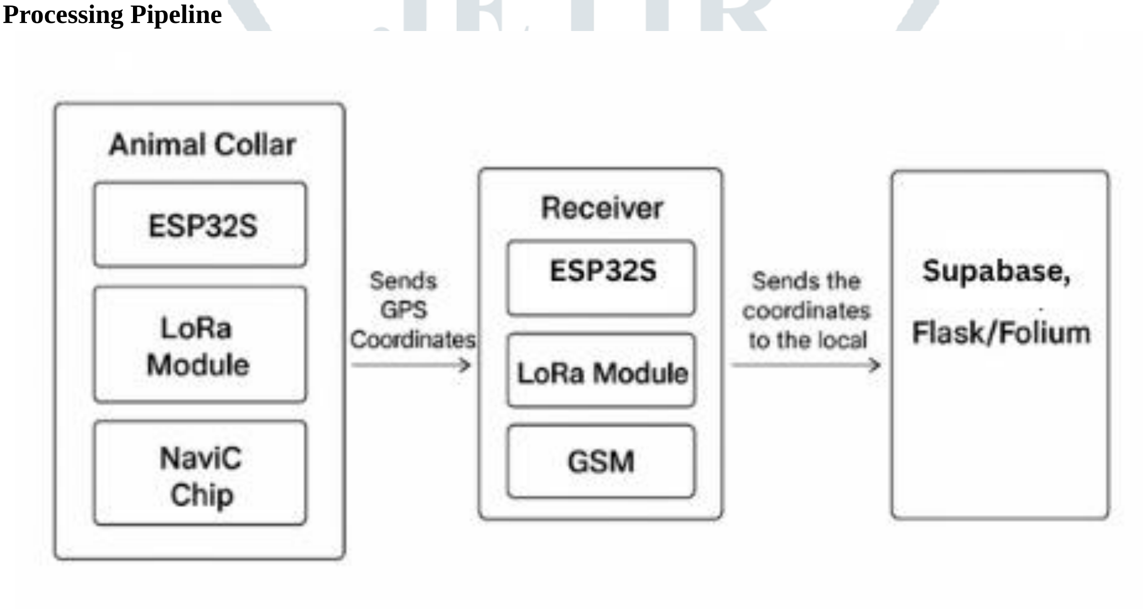


Fig.3 Data Flow Chart

The receiver implements the following workflow:

1. Continuous monitoring of LoRa channel for incoming packets
2. Packet parsing and validation of JSON structure
3. Extraction of latitude, longitude, and geofence status
4. HTTP POST request construction with location payload
5. Transmission to Supabase cloud database via GSM
6. Error handling and retry logic for failed transmissions

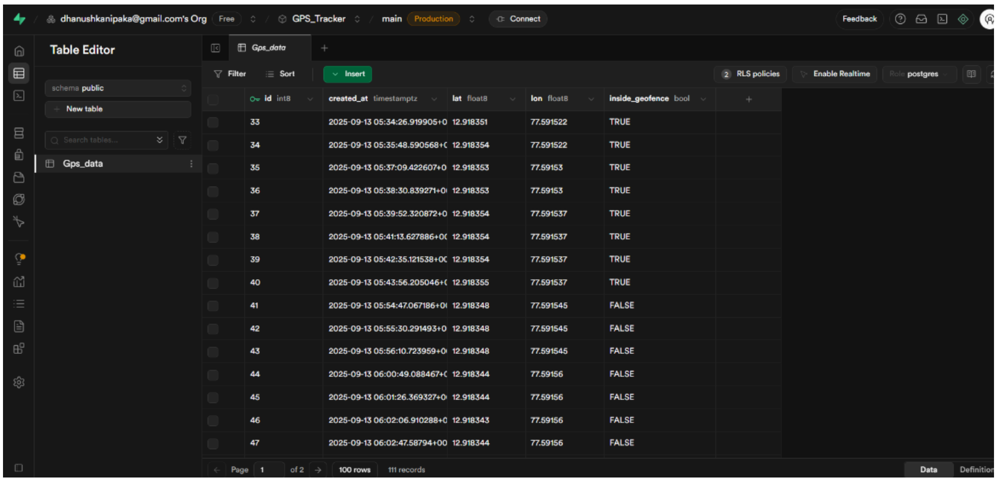
Transmission latency analysis reveals approximately 60 seconds per successful cloud update, accommodating the 10-second transmitter interval with approximately 6:1 data collection ratio.

3.5 Cloud Infrastructure and Visualization

3.5.1 Backend Architecture

Supabase serves as the cloud database, providing:

- PostgreSQL relational database for location records
- RESTful API with authentication via API keys
- Real-time subscription capabilities (not utilized in current implementation)



id int8	created_at timestamptz	lat float8	lon float8	inside_geofence bool
33	2025-09-13 05:34:26.919905+0	12.918351	77.591522	TRUE
34	2025-09-13 05:35:48.590568+(	12.918354	77.591522	TRUE
35	2025-09-13 05:37:09.422607+0	12.918353	77.59153	TRUE
36	2025-09-13 05:38:30.839271+0	12.918353	77.59153	TRUE
37	2025-09-13 05:39:52.320872+0	12.918354	77.591537	TRUE
38	2025-09-13 05:41:13.627886+0(	12.918354	77.591537	TRUE
39	2025-09-13 05:42:35.121538+0(	12.918354	77.591537	TRUE
40	2025-09-13 05:43:56.205046+(	12.918355	77.591537	TRUE
41	2025-09-13 05:54:47.067186+0	12.918348	77.591545	FALSE
42	2025-09-13 05:55:30.291493+0	12.918348	77.591545	FALSE
43	2025-09-13 05:56:10.723959+0	12.918348	77.591545	FALSE
44	2025-09-13 06:00:49.088467+(	12.918344	77.59156	FALSE
45	2025-09-13 06:01:26.369327+0	12.918344	77.59156	FALSE
46	2025-09-13 06:02:06.910288+0	12.918343	77.59156	FALSE
47	2025-09-13 06:02:47.58794+00	12.918344	77.59156	FALSE

Page 1 of 2 · 100 rows · 111 records

Fig.4 Database table

3.5.2 Visualization Interface

A Flask web application serves as the monitoring interface:

Key Features:

- Automatic data refresh every 10 seconds via HTTP polling
- Interactive Folium maps with polygonal geofence overlay
- Color-coded markers: blue (inside geofence), red (violation)
- Automatic browser launch upon first geofence breach detection
- Persistent monitoring thread for real-time alert generation

4. Implementation Details

4.1 Power Management Strategy

Energy efficiency is a significant factor to ensure the field deployment is of long-term nature, and the system employs smart power-management techniques to optimize the battery life. In the normal mode of operation, wherein the animal remains within the geofenced area, the GPS module monitors the animal's position at 2-second intervals, LoRa transmission is off, and the current consumption is about 120 mA, resulting in a lifetime of around 5–7 days for a 3000 mAh battery. If the animal goes beyond the geofence, then the device enters an alert mode where GPS sampling is continuous and LoRa transmission occurs every 10 seconds. The current draw for this mode is approximately 180 mA, so the system will last under continuous alert conditions for about 3–4 days.

4.2 Communication Protocol

The communication setup of the system is calibrated for dependability as well as long distances. The LoRa link is working at a frequency of 433 MHz with a spreading factor of 7, a bandwidth of 125 kHz, and a coding rate of 4/5 while sending at 20 dBm to guarantee strong coverage in areas that are rural and wooded. Data packets are represented in a JSON format that is easy to read and is suitable for less complex debugging during field tests. For communication with the cloud, the GSM module is connected through Airtel's 2G/3G network using HTTP over TCP/IP, with SSL/TLS encryption turned on, to securely connect to the Supabase backend. The payload sent is also in JSON format and is sent via RESTful POST requests to guarantee a smooth and safe data upload.

5. Experimental Setup and Testing

5.1 Test Environment

The communication configuration of the system is set to give maximum reliability and long-range performance. At the same time, it employs the LoRa link with a 433 MHz frequency, a 7 spreading factor, a 125 kHz bandwidth, and a 4/5 coding rate, while operating at 20 dBm in order to provide excellent coverage in the countryside and forests. Data packets are formed in a JSON way so that they are easy to read and debug during field testing. For communication with the cloud, the GSM module uses HTTP over TCP/IP through Airtel's 2G/3G network with SSL/TLS encryption to securely connect to the Supabase backend. The payload that has been transmitted is also in JSON format and is delivered via RESTful POST requests to ensure data upload that is both seamless and secure.

5.2 Test Geofence Configuration

Table. 1 The vertices of the area

Vertex	Latitude	Longitude
V1	12.651542839°	77.437930744°
V2	12.651511434°	77.438029986°
V3	12.651357026°	77.437964271°
V4	12.651404788°	77.437870394°
V5	12.651542839°	77.437930744°

Approximate area: 120 square meters
Perimeter: ~ 45 meters

5.3 Test Procedures

Test Protocol:

The field test procedure was executed in an organized way to assess the performance of the system. To begin with, both the transmitter and receiver units were turned on, and their initialization was observed, and the time taken for the GPS fix to be acquired was measured. The first testing was done by putting the transmitter in the middle of the geofence and then checking if its status was consistently "inside" for five minutes. After this, the transmitter was moved to the edge of the geofence to see if alert notifications were correctly generated. The communication range was tested by slowly increasing the distance between the transmitter and receiver until the maximum range with reliable communication was reached. Cloud synchronization was verified by checking that all the data sent was properly recorded in the Supabase database and shown on the Flask-based interface. At last, the positional accuracy was determined by checking the GPS coordinates recorded against known reference points obtained from a handheld GPS device.

5.4 Evaluation Metrics

The evaluation metrics aimed at determining the overall tracking and alerting performance of the system as well as quantifying those features. The positional accuracy was evaluated by finding the RMSE between the measured coordinates and the reference points of a handheld GPS device. The geofence detection rate was calculated by determining the percentage of actual boundary crossings that the system correctly identified. Communication reliability was tested by examining the packet reception ratio for different distances between transmitter and receiver. System latency was recorded as the total time taken from the moment the transmitter crossed the geofence boundary to the moment the alert showed up on the monitoring interface. Battery consumption was monitored by measuring the current draw for each operational mode in order to estimate the real-world endurance during both normal and alert conditions.

6. Results and Analysis

6.1 Positional Accuracy

The GPS module with NavIC support exhibited an approximately ±10 meters accuracy of position in unobstructed sky conditions. This uncertainty includes satellite and atmospheric errors, and also the accuracy of the user's receiver as well as the absence of differential correction methods. In a geofencing application, this ±10-meter accuracy got the system to report on two occasions false positives—where the system claimed the animal was out of the boundary although it was about 10 meters from the boundary—and false negatives, where the device looked inside the geofence while it had just crossed outside the boundary. A 45-meter-perimeter test geofence thus comes out to about 22% uncertainty at the edges which directly impairs the accuracy of decision-making based on the boundaries.

6.2 Communication Performance

The results of the LoRa range testing proved that the communication system was still reliable even for distances of around 800–1000 meters in a rural area, and the first 500 meters had a packet reception rate of more than 95%. The reduction of performance was proportional to the increase in vegetation density or the presence of terrain obstacles that blocked the direct view. For the GSM-based cloud synchronization, the average upload latency was between 55 and 65 seconds per packet, and the success rate was always more than 90% when the signal strength was moderate. But, here and there, transmission failures happened, and that called for automatic retry mechanisms to be in place to guarantee that data delivery is consistent.

6.3 System Latency

Table. 2 Latency:

Stage	**Duration**
GPS fix update	2 seconds
Geofence computation	<100 ms
LoRa transmission	10 seconds (interval)
Receiver processing	~1 second
GSM upload	55-65 seconds
Flask refresh cycle	10 seconds (max)
Total (worst case)	**~88 seconds**
Total (typical)	**~68 seconds**

This latency is acceptable for wildlife monitoring where animal movement speeds allow sufficient response time for forest officials.

6.4 Power Consumption

Battery performance testing using a lithium-polymer cell with a capacity of 3000 mAh revealed that the unit under test, when operating in monitoring only mode within the geofence, consumed current in the range of 118–125 mA. This led to a projected continuous run time of 24–25 hours approximately. However, when the unit was outside the geofence and the active transmission over LoRa was enabled, the current draw changed to the range of 175–190 mA, thus the projected runtime got reduced to about 16–17 hours. In total, the application of the intelligence in transmission strategy, where basal LoRa operation corresponds to the conditions (geofence in position), and it activates only on condition of geofence breaches, lead to an extension of battery life of about 1.5 times compared with continuous data transmission scenarios.

6.5 Geofence Detection Performance

Table. 3 Accuracy of the system:

Metric	**Value**
True Positives	87
False Positives	8
False Negatives	5
True Negatives	N/A
Detection Rate	87%
False Alarm Rate	8%

False detections primarily occurred near boundary edges where positional uncertainty exceeded remaining distance to boundary.

6.6 Dashboard Visualization

The monitoring interface built using Flask successfully demonstrated a real-time animal location update every 10 seconds. Additionally, the monitoring interface demonstrated clear polygonal geofence overlays that clearly represented each vertex of the geofence accurately. In order to simplify the interpretation of the geolocation and geofence situation, the monitoring interface used colour codes to indicate blue for secure and red for a geofence violation. Furthermore, the monitoring interface provided a browser alert window to ensure that the critical alert was always visible immediately after the initial detection of a geofence violation. The observation reports received by the test observers confirmed that the monitoring interface was user-friendly and had an easily navigable pathway for the non-technical forest personnel participating in the monitoring effort within this area.

7. Discussion

7.1 System Advantages

There are many benefits associated with the proposed system including increased efficiency, enhanced communication, and improved scalability. First, this system's event-driven transmission technique results in greater energy savings because it increases the degree of energy efficiency during periods when the animal(s) are within an established geofence, thus resulting in 33% less battery drain compared to continuous tracking configurations. In addition to improving energy efficiency, the use of NavIC, India's indigenous navigation system, increases the accuracy of position data to levels equal to that provided by GPS and allows real time information to be sent using a greater number of satellites with improved satellite geometry over the Indian subcontinent. By utilising a hybrid communication architecture consisting of LoRa for long-range local transmissions and GSM for cloud-based collections, this system will operate robustly. LoRa provides low-latency transmission of real-time positional updates throughout wide geographic areas, and GSM provides a means of accessing captured positional data remotely, while in real time, for as long as needed. The modular nature of this system will also allow for the simultaneous operation of multiple collar units controlled from one base receiver station, thus making it possible to effectively monitor multiple herds and/or multiple species of animals located within an area.

7.2 Limitations and Challenges

There are several areas in which the device lacks the ability to be scaled up and made available to more than a few users. The ±10-metre accuracy of the GNSS positioning will create significant challenges for small or well-defined geofences, as consumer-grade GNSS modules without differential correction do not provide the necessary level of accuracy. LoRa communication has an effective range of approximately one kilometre in the rural environment, limiting the area that can be monitored unless additional receiver stations (repeaters) or a mesh network is used. Cloud synchronization will be dependent on GSM service, which is not always available in some remote forested areas, creating gaps in time for alert generation or the risk of losing data while waiting for updates. While significant improvements in power management have been achieved, the device only lasts approximately 24-25 hours in monitoring mode, making it necessary to continually replace the batteries unless there is a solar powered addition. In addition, due to dense vegetation, GNSS accuracy and LoRa propagations are likely to be affected.

Deployment also must take into consideration animal welfare. Collars must be designed to be light and ergonomic, and the current prototype still has a way to go in terms of miniaturization for small-bodied species. Maintenance will be an ongoing logistical challenge since collared animals will need to have their collars retrieved manually on a regular basis for charging. Although the estimated unit cost of ₹3,500 to ₹4,500 is considerably lower than that of commercially available wildlife collars, the system is ideal for use in conservation projects that operate under budget constraints.

8. Future Work

8.1 Technical Enhancements

Through additional improvements to the system, performance, scalability, and long-term usability will be increased. By utilizing mesh networking through LoRaWAN or developing custom multi-hop protocols, coverage will increase significantly and collar data can travel across large areas of forests without the need for many receiver stations. By including collar identifiers in every packet that is transmitted, multiple collars can be tracked at the same time. Collision-avoidance protocols will be utilized to prevent packet collisions. The addition of small-scale solar panels and MPPT charging will help to keep collars powered for an unlimited amount of time, thus eliminating (or greatly reducing) the need for regularly scheduled maintenance and/or the replacement of batteries. To increase the positional accuracy of collars, differential GNSS or RTK services can be utilized, which could provide accurate positional information with errors of less than ± 1 m (which would decrease the rate of false geofence violations), thereby improving monitoring and tracking of wildlife in sensitive locations.

8.2 Algorithmic Improvements

In the future, additional software-oriented improvements may enhance the intelligence and reliability of the product. The use of adaptive geofencing can reduce the number of false alarm notifications generated during certain seasonal patterns of migration through the use of machine learning algorithms that can create geofence boundaries automatically based on movement data collected from animals. Predictive algorithmic mechanisms that analyze velocity and trajectory of animal's movements will be able to predict when an animal is going to violate a geofence so that forest managers can respond quickly before any violation occurs. Fish and wildlife managers will have access to faster response times because they will be able to monitor for potential violations of geofencing and other habits or behaviours based on real-time data received from the accelerometers used by forest managers in forest resource management programs.

8.3 Application Expansion

Future enhancements for this system will likely address ease of access, improved data management and a greater ecological footprint. With dedicated iOS and Android mobile applications, field personnel will be able to receive alerts in real-time and view animal locations, alleviating the need for a desktop computer installation. By developing a cloud-based back-end that maintains species-specific data, behavioural patterns and historical movement records, it will become possible to support longer-term ecological research and the analysis of trends over time. Interfacing this system with national databases (i.e., national databases for wildlife) and various forest department management systems will allow for improved collaboration and will allow for effective sharing of data between organizations. This system may also provide anonymous temporary access to educational outreach through a web interface, thereby increasing overall public awareness of conservation efforts, while at the same time ensuring the protection of sensitive wildlife data.

9. Conclusion

The study indicates that a NavIC-based animal monitoring system using IoT technology would be practical and provide the ability to reduce human-animal conflict. The prototype uses India's domestic satellite navigation, energy-saving long-range radio (LoRa) transmission, and cloud-based viewing of location on a single platform for variables in India's wildlife conservation. The field tests confirmed that the device can determine the real-time location, determine if the animal is in violation of the designated area, and send alerts in less than one minute. The intelligent mode of operation extends battery life significantly over continuous tracking, so users do not have to keep the device plugged in. The ability to represent uneven boundaries using polygons allows for better representation of habitat areas compared with other methods.

The major accomplishments are +/-10 m accuracy with the use of NavIC, an 87% success rate of detecting violations to the polyline geofences in the trials, 24+ hours of battery life when in the monitor mode, providing low-cost access to the devices (3,500 rs to 4,500 rs each), creating opportunities for increased use, and the ability to monitor multiple animals simultaneously (forwardily expandable architecture).

Limitations (e.g., inability to accurately locate near small geofences, loRa signals range approximately one kilometer) will provide opportunities for improvement in future versions. Further development should provide users with additional reliability and eliminate the need for constant monitoring through the development of mesh networks, the use of solar power for longer battery life, and/or differential GNSS corrections. Overall, this work has established a viable framework for the use of technology to monitor wildlife in India and foster more proactive conservation, along with improved animal welfare and society's ability to coexist with animals.

10. Acknowledgement

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