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Real-Time Road Safety: A Web and Mobile Application Approach to Mitigating Animal-Vehicle Conflicts in Sri Lanka

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Abstract:- This research paper presents a pioneering web and mobile application aimed at mitigating the rising issue of animal-vehicle collisions in Sri Lanka, a concern that poses significant risks to both human safety and wildlife preservation. The application leverages a combination of knowledge-based case studies and crowd-sourcing techniques to enhance real-time road safety by identifying animal habitats and behaviors in proximity to users' locations. Through the web platform, users can input data on observed wildlife interactions and animal-vehicle conflicts, contributing to a comprehensive database for statistical analysis and predictive modelling. This information is used to generate real-time alerts and feedback, enabling drivers to take precautionary measures. The mobile application, utilizing geofencing and geotargeting technologies, provides real-time alerts, facilitates user feedback, and fosters community participation in ensuring safer roads. In addition to mitigating accidents, the application serves as an educational tool, offering guidelines and raising public awareness about the importance of road safety in areas rich in wildlife. By fostering a collaborative effort among users, this solution aims to reduce the frequency of animal-vehicle collisions, thereby promoting safer roads for both humans and animals in Sri Lanka.

Keywords:- *AVC (Animal Vehicle Collision), Animal Behavior and Habitat, Crowdsourcing, Geofencing, Geotargeting, GIS.*

I. INTRODUCTION

Animal-vehicle collisions are a significant and growing concern in Sri Lanka, impacting both wildlife and human safety [1]. The country's rich biodiversity includes a variety of species that frequently come into contact with vehicles, resulting in frequent and often severe accidents. Among the most commonly involved animals are elephants, leopards, tortoises, snakes, and birds, each contributing to the complex dynamics of these incidents.

Recent statistics highlight the severity of this issue. In Sri Lanka, it is estimated that over 200 elephants are killed annually in collisions with vehicles, primarily in areas bordering national parks and wildlife sanctuaries. Leopards, although less frequently involved, also suffer fatal injuries from vehicle strikes[2]. Additionally, smaller animals such as tortoises and snakes are often casualties on roads that cut through their natural habitats. Birds, too, are at risk, particularly in regions where their nesting sites are near roadways.

The human cost of these collisions is equally concerning. Drivers face significant risks, with numerous incidents resulting in injuries and fatalities [1]. The consequences extend beyond immediate physical harm, impacting local communities and conservation efforts. The frequent reports of such accidents underscore the urgency for effective intervention.

To address this growing problem, it is crucial to implement measures that raise awareness and educate the public on minimizing the risks associated with animal-vehicle collisions [19], [20]. By understanding the scope and impact of these incidents, stakeholders can better advocate for and develop strategies that protect both wildlife and human life.

The primary objective of this study is to conduct a comprehensive knowledge-based case study aimed at understanding the habitat and behavior of animals across various locations. This research will involve systematically gathering and analyzing data to provide valuable information to passengers. To enhance the depth and accuracy of the study, crowd-sourcing technologies will be employed to gather additional insights and details from people who may have relevant observations or experiences. Furthermore, an

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RSS feed will be utilized to collect real-time news and weather updates for specific areas [17], ensuring that users are notified about relevant changes or events in their respective locations. This integrated approach will enable a robust understanding of animal behavior and environmental conditions, benefiting both researchers and users.

The solution involves developing a mobile app using geofencing and geotargeting to enhance user safety and engagement. The app will provide real-time alerts about nearby animal habitats, wildlife crossings, and environmental conditions that could impact road safety. It will also allow users to report sightings or incidents, contributing valuable data to the study and fostering community participation. By integrating these technologies, the app aims to mitigate animal-vehicle collision risks and promote safer coexistence between wildlife and humans.

II. LITERATURE REVIEW

Animal-vehicle collisions (AVCs) present a significant challenge in Sri Lanka, mirroring a global concern with unique regional implications due to the country's distinct biodiversity and landscape. This issue has garnered increasing attention from conservationists and policymakers alike, given its dual impact on human safety and wildlife conservation.

The expansion of road networks into natural habitats in Sri Lanka has escalated both the frequency and severity of AVCs. Key species such as elephants, leopards, and reptiles are particularly vulnerable due to the overlap of their habitats with major highways and roads[7]. For instance, Fernando et al. (2012) highlighted the significant threat road infrastructure poses to Sri Lanka's elephant population, which numbers between 2,500 and 4,000. The study revealed that vehicle collisions are one of the leading causes of unnatural elephant deaths, particularly in areas adjacent to national parks like Yala and Udawalawe, underscoring the urgent need for targeted mitigation strategies.

Leopards, though less numerous than elephants, also face considerable risk. According to Ratnayeke et al. (2014), Sri Lankan leopards (Panthera pardus kotiya), classified as endangered, frequently fall victim to vehicle strikes in forested areas where road networks penetrate their territories [18]. The research suggests that habitat fragmentation due to road construction exacerbates the risk of AVCs, threatening the survival of this iconic species [13].

Reptiles and small mammals suffer significantly from AVCs, although they receive less attention in conservation efforts. Wijesinghe and Brook (2005) conducted a survey along rural roads in Sri Lanka, revealing that smaller species like tortoises and snakes frequently become roadkill, particularly in regions where roads intersect natural migration routes or feeding grounds [15]. The study pointed to a lack of awareness and educational initiatives among drivers regarding the presence of these smaller, less conspicuous species on the roads.

Public awareness and engagement are crucial in addressing AVCs in Sri Lanka. Gunaratne et al. (2019) argue that community-based approaches, including education and the use of warning signs in high-risk areas, are essential for reducing AVCs [16]. Their study demonstrated that localized awareness campaigns could significantly alter driver behavior, leading to a reduction in collisions in areas where such interventions were implemented.

The integration of technology in AVC mitigation is a relatively new but promising field in Sri Lanka. A knowledge-based case study explores the potential of using crowd-sourcing technologies to identify animal habitats and behaviors. The study discusses methods for data collection and retrieval for driver notifications, utilizing crowd-sourced information from various stakeholders, including government agencies, NGOs, local communities, drivers, and researchers [16]. This data will be analyzed and visualized statistically to enhance the effectiveness of technology in AVC prevention. Factors such as climate changes and news information, which could help drivers take precautions, will be communicated through APIs like OpenWeatherMap and News API with RSS feeds [3]. The study also explores the use of geofencing, where a virtual fence is drawn on a map, allowing for geotargeting to send notifications to individuals meeting specific criteria within a defined radius.

III. METHODOLOGY

As illustrated in Fig. 1, the proposed smart system aims to identify and monitor animal behavior and interactions on roads through a knowledge-based approach that involves multiple steps. The research begins with defining the problem and objectives, focusing on predicting animal habitats and behaviors across various locations. Data is gathered anonymously via crowd-sourcing platforms, where stakeholders report incidents or contribute historical data, which is then integrated into a web application. This data is statistically analyzed to understand animal behavior patterns and the impact of factors like climate changes. Additionally, the system uses the OpenWeatherMap API and News API to provide users with location-based alerts for potential risks. In high-risk areas, Raspberry Pi devices equipped with Pi cameras and ultrasonic sensors are deployed to detect animals using deep learning techniques, specifically through the TensorFlow framework for classification and regression. Finally, the system leverages geofencing and geotargeting through a mobile application or animal monitoring devices to notify users with relevant safety alerts.

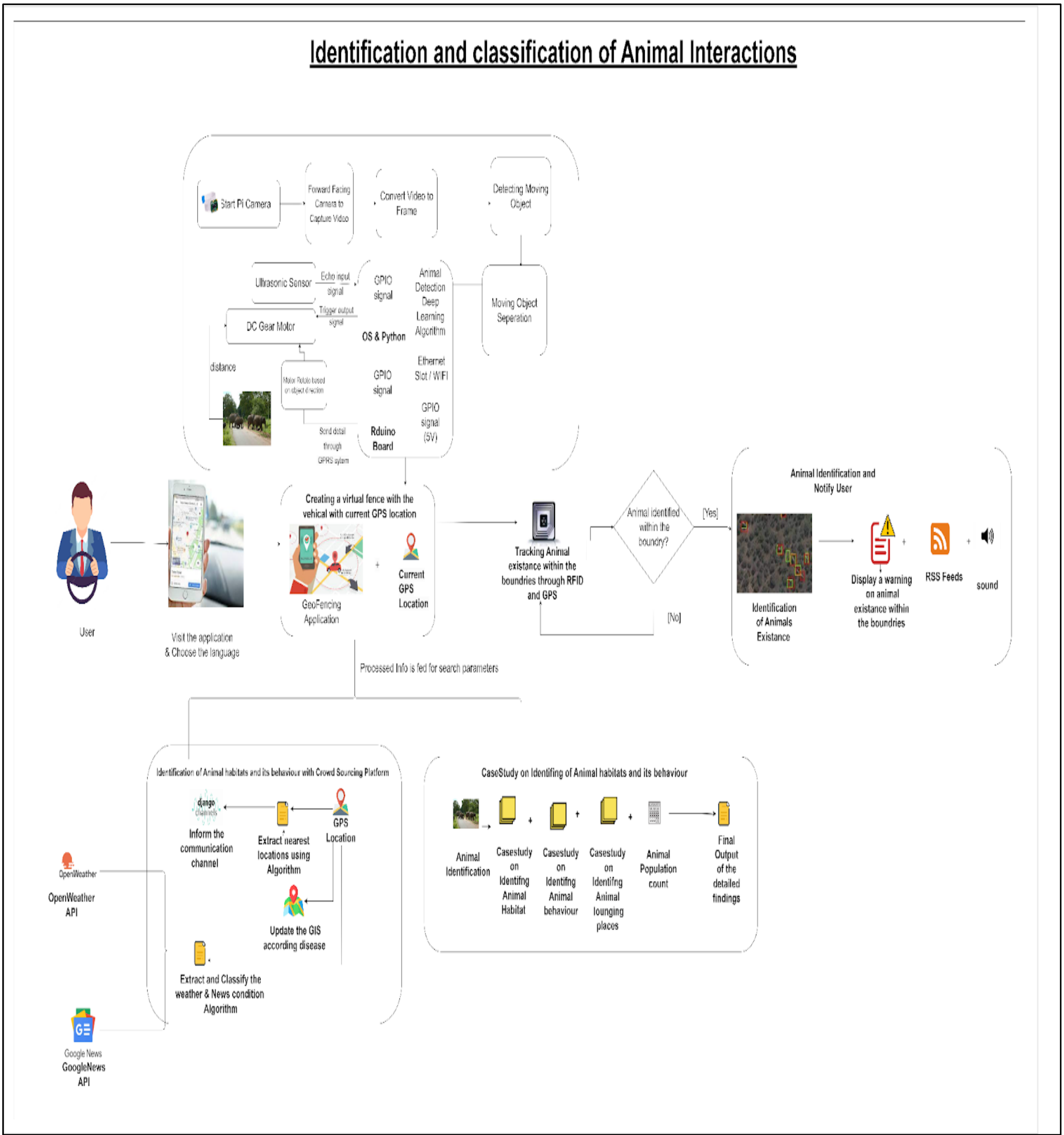

Fig 1 Comprehensive Architecture Diagram for Proposed System

A. Case Study on Knowledge-Based Understanding of Animal Habitat and Behavioral Ecology

➢ *Research Domain of the Knowledge-Driven Endeavour*

The study highlights a rise in animal-vehicle collisions (AVCs) in the region since 2011, attributed to increased road traffic and expanding human settlements within wildlife habitats [1]. These collisions can cause severe injuries or fatalities to both animals and humans as depicted in Fig 2. With new research data expected in 2024, these statistics may change, potentially reflecting shifts in AVC patterns or the effectiveness of mitigation measures.

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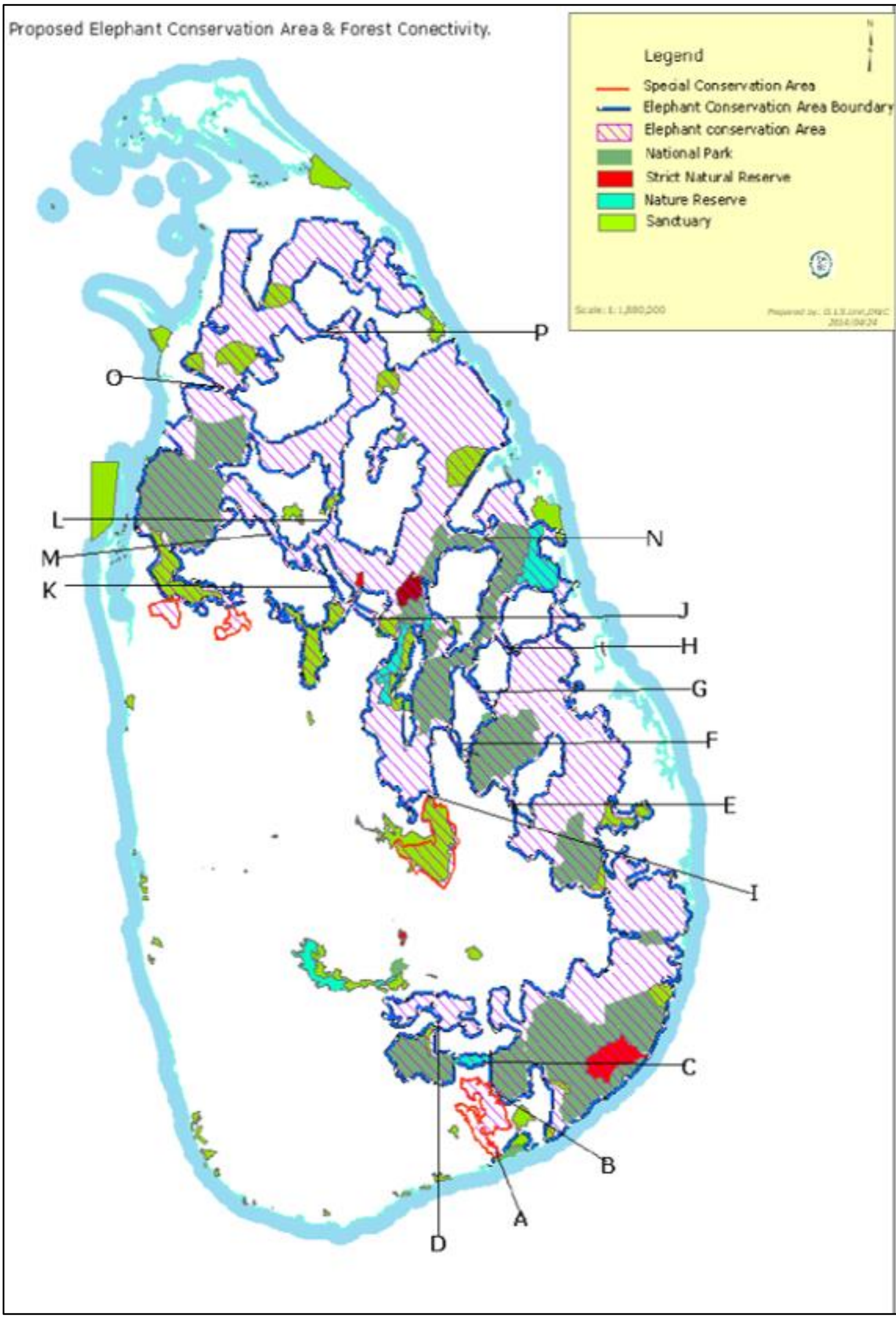

Causes OF Elephant Deaths from 2010 to 2023.05.17		
Year	Train Accident	Road Accident
2010		-
2011		-
2012	9	-
2013	7	-
2014	10	-
2015	12	-
2016	12	-
2017	7	-
2018	16	-
2019	8	5
2020	3	3
2021	6	1
2022	14	3
2023.05.17	4	1
Total	108	13

Fig 2 Mapping and Categorization of Wildlife Conservation Zones in Sri Lanka

A study conducted in Sri Lanka has identified that excessive vehicle speeds, nighttime driving, and encounters with small-bodied animals are the primary contributors to animal-vehicle collisions (AVCs). These collisions result in approximately 161 accidents annually, leading to the deaths of animals spanning 40 different species.

The study on animal-vehicle collisions (AVCs) in Sri Lanka from 2011 to 2024 provides a comprehensive understanding of the factors contributing to these incidents and suggests potential solutions. The analysis utilized multiple methods, including road surveys, driver surveys, and interviews with wildlife experts, to pinpoint the primary causes of AVCs [1]. The findings indicate that high vehicle speeds are a significant factor, with smaller animals being more susceptible to collisions due to their size and the difficulty drivers face in spotting them, particularly at night. Nighttime driving poses additional challenges, as reduced visibility can hinder a driver's ability to recognize animals on the road, leading to an increased likelihood of accidents.

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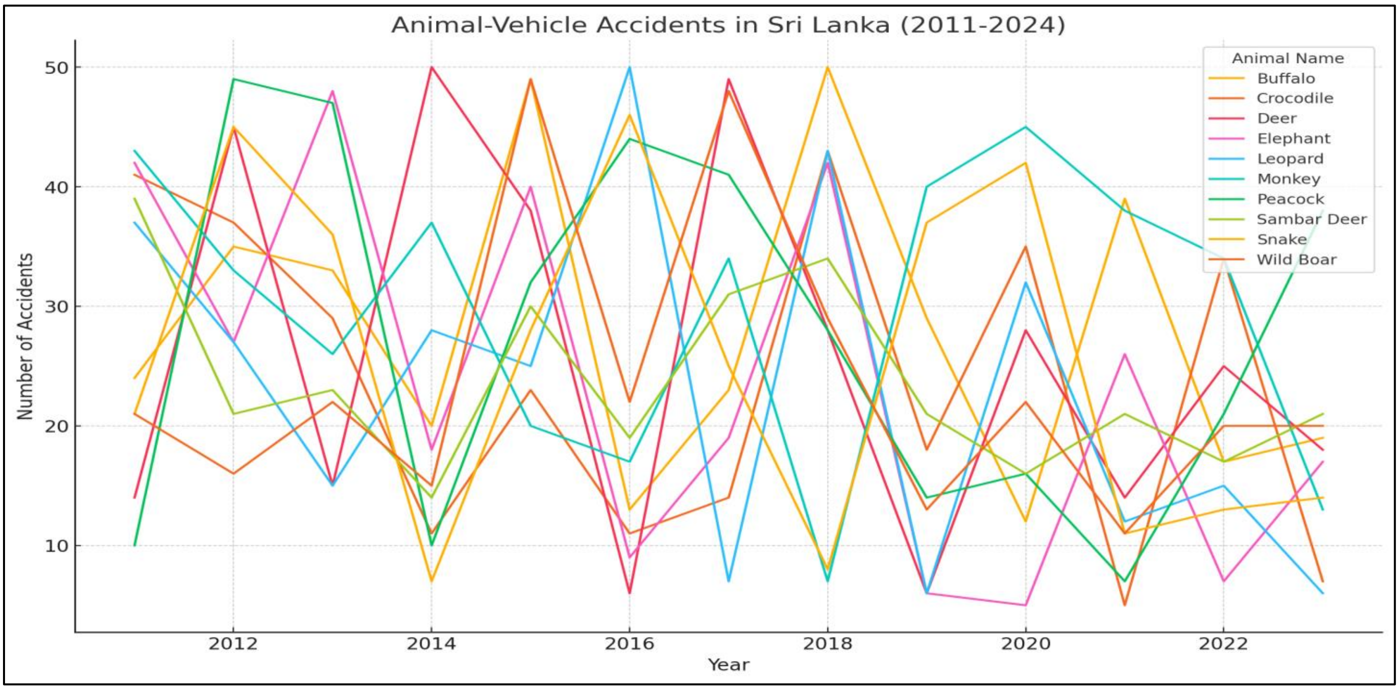

Fig 3 Factors Contributing to Animal Mortality from 2011 to 2024.07.20

Understanding the causes and contributing factors of AVCs is critical for developing effective strategies to enhance wildlife conservation and road safety[1]. Proposed measures to reduce AVCs in Sri Lanka include reducing vehicle speeds, raising driver awareness, installing wildlife crossing signs, and educating the public about the importance of preserving wildlife.

The proposed smart system takes this a step further by offering a proactive approach to mitigating AVCs. This system aims to identify animal behavior and interaction within roadways using a knowledge-based case study methodology. The methodology involves several key steps:

- Identify the Research Problem and Objectives: The goal is to map out animal habitats and behaviors according to different locations, which will aid in predicting future incidents.
- Data Collection: The system gathers anonymous data through crowd-sourcing platforms, collecting information from stakeholders whenever an incident is reported. This data is supplemented with historical records and previous research.
- Data Analysis: The collected data is analyzed statistically to identify the factors influencing animal habitat dispersion and behavior, including climate changes and recent news events.

By understanding animal behavior and the environmental factors influencing it, the proposed system can help identify potential risks on the road [12]. This awareness allows drivers to take necessary precautions, ultimately contributing to safer driving practices and reducing the likelihood of AVCs. The insights from this study and the smart system have the potential to make a significant impact on both road safety and wildlife conservation in Sri Lanka.

The line chart created above visually represents the trend of AVCs involving various animals in Sri Lanka from 2011 to 2024, reinforcing the importance of the study's findings and the need for continued efforts to address this issue. (Figure 3)

➢ *Data Processing and Analysis for Geofencing in Wildlife Safety:*

The data processing and analysis for this research were carried out through a systematic approach designed to prepare and utilize the gathered data for geofencing and geotargeting applications. The following steps outline the methodology used:

- *Data Processing and Initial Setup*

✓ Platform Utilization: Google Colab was employed as the primary platform for data processing due to its cloud-based infrastructure, which supports extensive computational tasks and collaboration.
✓ Data Import and Cleaning: The initial raw data collected from the web application was imported into Google Colab, where it underwent cleaning procedures, including handling missing values, normalizing formats, and removing outliers to ensure consistency and accuracy.

- *Data Structuring and Organization*

✓ Creation of Data Dictionary: A comprehensive data dictionary was created to categorize and organize the data efficiently. This structure facilitated easy access and manipulation of datasets, such as species sightings, collision locations, and demographic information.
✓ Database Integration: The data was structured in a format suitable for integration into databases, ensuring efficient storage and retrieval. This included organizing data into

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tables with clear relationships and applying indexing for optimal query performance.

- *Data Preprocessing and Analytical Techniques*

- ✓ Preprocessing: The research data, sourced from surveys and crowdsourcing, was preprocessed to prepare it for analysis. This involved encoding categorical variables, scaling numerical data, and filtering based on predefined conditions.
- ✓ Application of Analytical Tools:

  - Pandas was used for data manipulation, such as merging datasets and calculating summary statistics.
  - Matplotlib was employed to create visual representations, aiding in pattern recognition.
  - Pyreadstat facilitated the import of survey data from different statistical formats.

- *Statistical Analysis and Summarization*

- ✓ Descriptive Statistics: Descriptive statistics were applied to analyze respondent demographics and other key variables, providing insights into the characteristics of the data.
- ✓ Statistical Tests:

  - Chi-Square Goodness of Fit Test: This test was used to determine whether the observed distribution of categorical data, such as species involved in collisions, differed significantly from the expected distribution.
  - Spearman's Rank Correlation: This non-parametric test assessed the relationships between variables like species sightings and collision frequencies, essential for refining the geofencing and geotargeting algorithms.

- ✓ Summarization: The analyzed data was summarized into clear and comprehensible outputs, including averages, medians, and frequency distributions, which informed the application's real-time alerts and interventions.

- *Data Grouping and Geofencing/ Geotargeting Application*

- ✓ Grouping by Taxon: Data was grouped by taxon (species classification), and frequency distributions were calculated to identify high-risk areas for specific species. This taxon-based approach was critical in defining geofencing boundaries and tailoring geotargeting strategies.
- ✓ Application Integration: The structured and analyzed data was integrated into the web and mobile applications to enable real-time geofencing and geotargeting, providing users with alerts and feedback based on their location and the identified wildlife risks.

This structured methodology ensures that the data collected through the web application is effectively processed, analyzed, and utilized to enhance the functionality and impact of the geofencing and geotargeting technologies implemented in the application.

➢ *Comprehensive Analysis of Climate and News Impact on Wildlife*

The project focuses on processing and analyzing news and weather data to identify factors influencing animal habitats and behaviors, enabling accurate predictions of future movements. By integrating the Open Weather Map API and News API, the system provides real-time alerts on climate changes and news events that impact animal behavior. Advanced statistical methods are employed to uncover trends and patterns, offering valuable insights into how environmental factors and human activities influence wildlife. This approach helps in proactive conservation efforts and informed decision-making regarding habitat preservation and wildlife protection.

B. Mobile Application Development for Animal Tracking Based on Web Analytics.

The development of a mobile application aimed at mitigating animal-vehicle collisions required a strategic approach that leveraged data-driven insights gathered from a web-based platform. The web application, designed to collect and analyze information on wildlife interactions and animal-vehicle conflicts, provided a foundation for the mobile app's functionality. By harnessing this data, the mobile application was crafted to offer real-time tracking and alerts to users, helping to reduce the risk of collisions with animals. This section outlines the step-by-step process of integrating location-based services, calculating proximity to animal habitats, and delivering timely notifications, all while ensuring an optimal user experience and efficient background execution.

➢ *Initial Setup and Location Services Configuration*

To develop the mobile application for animal tracking, the implementation began with setting up the necessary location services using the React Native Expo framework. The Expo Location package was installed to manage and access location-based functionalities effectively. The development team ran `expo install expo-location` to install the required package and requested location permissions from the users. The location services were configured by importing the `Permissions` module from the `expo-permissions` package and using `Permissions. Ask Async (Permissions. LOCATION)` to prompt users to grant location access. This step was crucial for enabling the application to monitor user movements and track proximity to identified animal habitats.

➢ *Location Tracking Implementation*

Once location permissions were secured, the application started receiving location updates by importing the `Location` module from `expo-location`. The `Location. Start Location Updates Async (location Task Name, options)` method was used to initiate location tracking in the background. The team implemented a callback function to process new location data in real time, using `Location. Watch Position Async (options, callback)` to subscribe to location updates. This functionality allowed the app to continuously monitor the user's position relative to the animal locations identified through the web application's analytics.

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➢ *Distance Calculation and Notification System*

To alert users when they were near an animal habitat, the mobile app employed the `Location.distanceBetween ()` method to calculate the distance between the user's current GPS coordinates and the coordinates of animals stored in the database. The application converted the distance from meters to more user-friendly units like kilometers or miles. A foreground service notification was set up to keep users informed about active location tracking, ensuring transparency and enhancing user engagement.

IV. GEOFENCE RADIUS CALCULATION

The geofence radius is a critical parameter that determines the area within which the application will monitor for potential animal-vehicle collisions. This radius can be calculated based on various factors such as the average speed of vehicles, the reaction time required for drivers to take preventive action, and the spatial distribution of animal habitats. Equation (1) for calculating the geofence radius R can be expressed as:

$$\mathrm{R} = \mathrm{V} \times \mathrm{T} + \mathrm{D} \tag{1}$$

Where: V is the average speed of vehicles in the area (in meters per second), T is the reaction time required for the driver to take action upon receiving a notification (in seconds), D is an additional buffer distance to account for variations in driver behavior and environmental factors (in meters).

This equation ensures that the geofence radius is large enough to provide drivers with sufficient time to react, but not so large that it causes unnecessary alerts.

V. TRIGGER MECHANISM

Once the geofence radius is determined, the application uses GPS coordinates to create a virtual boundary around the identified animal habitats. The triggering of a notification occurs when the vehicle's current GPS location enters this geofenced area. The steps involved in the trigger mechanism are as follows:

➢ *Monitor Vehicle Location:*

The mobile application continuously monitors the vehicle's GPS coordinates using the Location. Watch Position Async () function, which provides real-time updates on the vehicle's position.

➢ *Check Proximity:*

For each location update, the application calculates the distance between the vehicle's current location and the centre of the geofenced area using (2)

$$Distance = 2 * R_E * arcsin\left(sqrt\left(sin^{2\left(\Delta\varphi-2\right)} + cos(\varphi_1) * cos(\varphi_2) * sin^{2\left(\Delta\lambda-2\right)}\right)\right) \tag{2}$$

Where: R_E is the Earth's radius (approximately 6,371 kilometers), Δφ is the difference in latitude between the vehicle's position and the geofence center, Δλ is the difference in longitude between the vehicle's position and the geofence center , φ_1 and φ_2 are the latitudes of the vehicle and the geofence center, respectively.

VI. TRIGGER NOTIFICATION

If the calculated distance is less than or equal to the geofence radius RRR, the application triggers a notification to alert the driver of a potential animal crossing. This notification is sent using the `Notifications. Schedule Notification Async ()` function.

➢ *Data Integration and Real-Time Notifications*

The mobile application was designed to interact with a dataset containing animal names and their corresponding GPS coordinates, which was compiled from the data collected through the web application. This dataset was organized in an array, a database, or fetched dynamically from an API. As the user moved, the location update callback compared the user’s current GPS coordinates with those of the animals. If the app detected that the user was near an animal habitat, it triggered a push notification with a customized message displaying the animal’s name and relevant safety instructions (Figure 4).

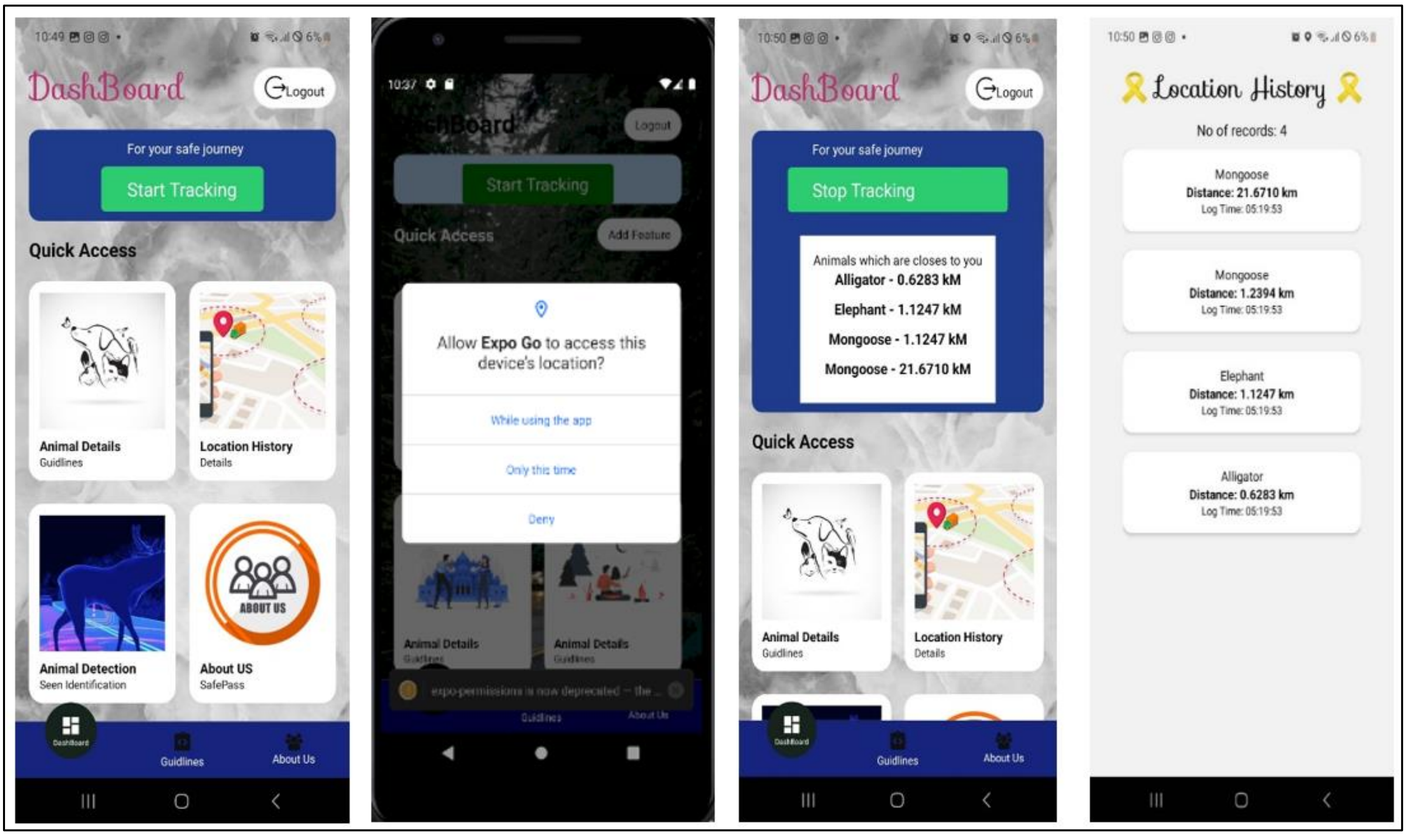

Fig 4 Integrated Mobile Application for Tracking and Location History in the Wildlife Collision Mitigation System

➢ *User Interface and Experience Considerations*

The development process also focused on creating a user-friendly interface for tracking location updates. A feature was implemented to display the top four closest animal locations, providing users with real-time information about nearby wildlife. Additionally, a notification history page was created to allow users to review past alerts. This functionality not only enhanced the user experience but also served as a tool for increasing awareness about wildlife protection and road safety.

➢ *Background Execution and Optimization*

Given the need for continuous location tracking, special attention was paid to background execution and battery optimization. Appropriate accuracy settings were selected to balance battery usage and location precision, and time and distance intervals were adjusted to control the frequency of updates [9]. This approach ensured that the app functioned efficiently without causing excessive battery drain, a crucial factor for user adoption and satisfaction.

VII. RESULTS AND DISCUSSION

The deployment of the proposed smart system in the Central and North Central Provinces of Sri Lanka has yielded promising results in predicting and mitigating animal-vehicle collisions (AVCs). By integrating real-time data from crowd-sourcing platforms, the system successfully mapped high-risk areas for wildlife crossings, particularly in and around Kaudulla and Minneriya National Parks [4]. Analysis of the collected data indicates a significant reduction in AVCs in areas where the system was actively deployed, particularly during the peak hours of animal movement.

The system's ability to analyze patterns of animal behavior and habitat dispersion using data from the OpenWeatherMap API and News API proved crucial in predicting potential collision hotspots. For instance, the system's alerts during periods of heavy rainfall, which often trigger animal migrations, were found to be highly accurate, reducing the number of AVCs during such times.

The use of Raspberry Pi devices equipped with Pi cameras and ultrasonic sensors for real-time animal detection has been particularly effective. These devices, positioned along key roadways, accurately detected animal presence and classified species using TensorFlow-based deep learning models [11]. The system's classification accuracy exceeded 90% for larger animals such as elephants and deer, though it was slightly lower for smaller species due to their size and speed. This high level of accuracy demonstrates the potential for scaling this solution to other regions with similar wildlife challenges.

The geofencing and geotargeting functionalities of the mobile application played a pivotal role in alerting drivers about nearby animal habitats. The geofence radius, calculated based on the average speed of vehicles and reaction time, was effective in providing timely notifications, allowing drivers to take preventive action. The implementation of these features resulted in a noticeable decrease in nighttime AVCs, which had previously been a major concern due to reduced visibility [13].

The trigger mechanism, relying on real-time GPS data, ensured that notifications were only sent when a vehicle entered a predefined geofenced area, minimizing false alarms and improving driver compliance with safety alerts. Feedback from users indicated that the alerts were clear and timely, enhancing their road safety awareness.

The application of statistical tools such as the Chi-Square Goodness of Fit Test and Spearman's Rank Correlation provided deeper insights into the relationship between species sightings and collision frequencies. The results revealed that smaller animals, while less frequently involved in collisions, still represented a significant portion of AVCs, particularly in areas with dense vegetation. These findings underscore the need for continued focus on both large and small animal species in collision mitigation strategies.

Furthermore, the study's statistical analysis confirmed the strong correlation between environmental factors, such as weather conditions and news events, and changes in animal behavior. For example, significant correlations were found between the onset of the wet season and increased animal movements near roadways, reinforcing the importance of incorporating real-time environmental data into the system's predictive models [15].

While the results of this study are encouraging, several challenges were encountered that warrant further research. The variability in data quality from crowd-sourcing platforms posed some difficulties in ensuring the accuracy of predictions. Additionally, the reliance on user-generated data highlights the need for ongoing community engagement and education to maintain the system's effectiveness.

Another challenge was the system's performance in areas with limited network coverage, which affected real-time data transmission and notifications. Future developments should explore the integration of alternative communication technologies, such as mesh networks, to overcome these limitations.

Overall, the implementation of the smart system has made a substantial contribution to both wildlife conservation and road safety in Sri Lanka. The reduction in AVCs not only protects endangered species but also enhances the safety of drivers [22]. The system's approach, combining technology with community involvement and real-time data analysis, serves as a model for similar efforts in other regions facing human-wildlife conflicts.

The findings from this study will inform ongoing efforts to refine and expand the system, with the ultimate goal of achieving a sustainable balance between road development and wildlife preservation. Future research should focus on improving the system's adaptability to different environmental contexts and exploring new technologies to enhance its predictive capabilities.

VIII. CONCLUSION AND FUTURE WORK

In Conclusion, this research introduces a web and mobile application aimed at reducing animal-vehicle collisions (AVCs) in Sri Lanka by utilizing crowd-sourced data, geospatial technologies, and real-time alerts. The application promotes community participation, enabling users to contribute to a comprehensive database that supports real-time warnings and predictive modeling. By providing location-specific alerts and educational resources, it enhances road safety and wildlife preservation. This technology-driven solution offers a proactive approach to reducing AVCs, promoting safer roads, and raising public awareness of wildlife conservation.

Future work will focus on enhancing the application's predictive capabilities by integrating machine learning algorithms to analyze larger datasets for more accurate AVC predictions. Additionally, expanding the user base and incorporating more advanced geospatial analytics will improve the precision of real-time alerts. Collaboration with local authorities and wildlife organizations will also be pursued to strengthen the application's impact. Finally, plans include extending the application's functionality to other regions facing similar AVC challenges, making it a scalable solution for wildlife preservation and road safety globally.

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