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Eloc-Web: Uncertainty Visualisation and Real-Time Detection of Wild Elephant Locations

Imashi Dissanayake[1], Vinuri Piyathilake[1*†],
Asanka P. Sayakkara[1†], Enosha Hettiarachchi[1†], Isurika Perera [1†]

[1*]University of Colombo School of Computing, Colombo, 00700, Western, Sri Lanka.

*Corresponding author(s). E-mail(s): piyathilakev@gmail.com;
Contributing authors: imashi.dissanayake97@gmail.com ;
asa@ucsc.cmb.ac.lk; eno@ucsc.cmb.ac.lk; isurikaperera.hip@gmail.com ;
[†]These authors contributed equally to this work.

Abstract

The substantial decline in elephant population, primarily caused by human-elephant conflict, necessitates the proactive engagement of conservationists to devise and implement effective monitoring strategies. Monitoring elephants is essential for gaining insights into their movements and ensuring the preservation of habitat corridors. Conservationists have increasingly shifted towards adopting passive acoustic monitoring as an affordable and non-invasive method for determining the spatial distribution of wild elephants through acoustic localization. The main challenge with remote sensing techniques like passive acoustic monitoring is the time-consuming data analysis, which hinders real-time tracking of elephant whereabouts. To address this issue, the study presents *Eloc-Web*, a web application that visualizes real-time elephant locations using elephant vocalizations recorded by acoustic sensors in the wild, which utilize machine learning to classify the captured audio. *Eloc-Web* has taken into account the uncertainties associated with classifying captured audio using machine learning models. This ensures that the potential uncertainty of whether the captured sound truly belongs to an elephant is appropriately considered during the visualization process. By following the user-centered design process, the study integrates expert knowledge from elephant ecologists to inform the design and functionality of the application, ensuring its relevance and usability. *Eloc-Web*, assessed through the System Usability Scale, ranked it in the top 10% of scores, demonstrating above-average user experience and promising potential in assisting elephant ecologists in studying and conserving elephant populations with real-time data visualization.

Keywords: human-elephant conflict, real-time elephant monitoring, passive acoustic monitoring, acoustic localization, uncertainty visualization, user-centered design

1 Introduction

The global elephant population has decreased substantially during the last few decades due to various anthropogenic influences, such as human-elephant conflict, poaching, fragmentation of breeding populations, and forest habitat loss and degradation. The World Wildlife Fund (WWF) reports that there are approximately 415,000 African elephants and 40,000 to 50,000 Asian elephants remaining in the world (WWF, 2023). Accurate and up-to-date data on elephant locations provides valuable insights into their habitat requirements, movement patterns, and social dynamics. This information is instrumental in enabling conservationists and researchers to identify regions with high elephant density, migration routes, and critical habitats that necessitate protection. It empowers them to make well-informed decisions, implement targeted interventions, and ultimately secure the long-term survival of elephant populations.

Passive Acoustic Monitoring (PAM) has recently emerged as a cost-effective approach, employing remote sensing techniques, for monitoring elephants through the analysis of their vocalizations. Elephants produce a wide variety of sounds, ranging from low-frequency rumbles to high-frequency roars and trumpets (Barcus, 2014). Among these vocalizations, the low-frequency rumble has garnered particular attention in PAM for its significance in long-distance communication within family herds (Bjorck et al, 2019). Through the deployment of multiple autonomous acoustic sensors, PAM facilitates the capture of infrasonic rumble calls, thereby enabling the non-intrusive and efficient monitoring of elephants (Gibb et al, 2019). Acoustic localization techniques are then employed to precisely locate the source of recorded elephant sounds by analyzing synchronized data from multiple sensors (Rhinehart et al, 2020).

Data obtained through acoustic localization and seamlessly integrated into detailed maps, offers a highly effective visualization method for tracking and understanding the location and movements of elephants. This visual representation caters to a diverse audience — including researchers, scientists, elephant ecologists, biologists, and wildlife managers — enabling them to easily interpret and utilize the information. The incorporation of real-time data from deployed acoustic sensors ensures that the locations of elephants can be continuously updated, providing up-to-date insights. Currently, there are a handful of visualization applications that allow biologists to view species' location data. However, these applications have a number of drawbacks, including limited accessibility, poor user-friendliness, and inadequate handling of the probabilistic nature of the data.

Despite these existing challenges, the detection of elephant vocalizations from data derived from Passive Acoustic Monitoring (PAM) presents a unique set of complexities due to sources of uncertainty in the data, such as measurement errors, systematic errors, natural variations, model uncertainty, and vagueness. Ignoring this uncertainty when making decisions can lead to misleading conclusions. Rhinehart et al (2020) recommend assessing uncertainty as a priority in an acoustic localization pipeline, along with its robustness in handling noisy data as well as its usability and availability. In this paper, we focus on the inherent uncertainty associated with detecting elephant vocalizations using ML models, referred to as model uncertainty.

This study presents the design and development of a web application called *Eloc-Web*, which not only visualizes elephant location data derived from acoustic detectors in the wild, but also addresses the inherent uncertainty associated with detecting elephant vocalizations using ML models, ensuring a comprehensive representation. *Eloc-Web*'s design follows the user-centred design process, prioritizing high usability. *Eloc-Web* extends from an elephant rumble detection device known as *Eloc*, previously developed by Sayakkara et al (2017). The primary objective of this study is to enhance the visualization of the spatial distribution of elephants within a specific area using a web application. The hypothesis underlying this research proposes that an innovative data visualization interface can effectively represent spatial distribution data in correlation with probabilistic values. Overall, this research contributes to the ongoing efforts to protect and conserve the world's elephant populations.

This paper is organized as follows. Section 2 thoroughly examines previous research pertaining to animal location data visualizations, with a particular emphasis on identifying the gaps that currently exist within the literature. Section 3 presents an overview of the methodology employed for developing the web application and explains the evaluation process used to assess its effectiveness. Section 4 presents the evaluation and results of this work, followed by the conclusion in Section 5.

2 Background & Related Work

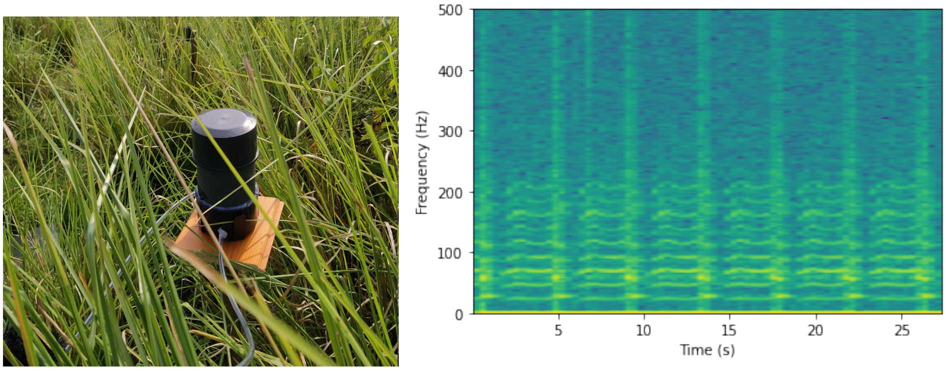
2.1 Acoustic Detection and Localization

Passive acoustic detection of wild animals requires specialised hardware equipment. Different field biologists are using acoustics recorders from various vendors for this purpose. *AudioMoth* is an open-source hardware platform that has multiple variants of devices (Hill et al, 2019). It has sampling rates from 8 kHz up to 384 kHz. Therefore, AudioMoth is effectively capable of covering audible and ultrasound frequencies. *SwiftOne* is a similar recording device with a sample rate starting at 48 kHz up to 96 kHz (SwiftOne, 2023). Both AudioMoth and SwiftOne are battery operated devices that store captured acoustic data internally on Secure Digital (SD) cards. Once these devices are deployed in environments where specific animal species need to be monitored, field biologists have to retrieve the revises in regular intervals to replace batteries and to copy their recorded data.

After acoustic data are captured and retrieved by a field biologist, the data needs to be analysed to identify the presence of acoustic vocalisations of a specific animal species. Various software tools, such as Audacity (Audacity, 2023), Raven (Raven, 2023), and PAMGuard (Gillespie et al, 2008), can be used for this purpose. These tools facilitate the generation of spectrogram images of the recorded data for visual observation by bioacoustics experts. Additionally, it is possible to use automated detection techniques — assisted by digital signal processing and machine learning models — to identify the occurrences of specific acoustic events in the data without manual inspection. In addition to the animal acoustics studies, such analysis of specific animal vocalisations confirms that the considered animal was present at a particular time and place, i.e., the recorded time and the location of the recorder. By deploying a large number of acoustic recorders and analysing their captured data, it would be possible to monitor the presence and movements of a particular animal species. However, as the analysis is conducted later in time, such analysis does not help track animals in real-time.

For the specific purpose of acoustic monitoring of wild elephants, Sayakkara et al (2017) introduced a low-cost hardware equipment, called *Eloc*. It consists of a pair of microphones that are placed 3 metres away from each other and captures sounds continuously. It has been shown empirically that the pair of microphones are sensitive to infrasonic frequencies, i.e., below 20Hz, and therefore, can be used to capture infrasonic vocalisations of elephants. To capture these low-frequency sounds, a sound filtering process is employed, incorporating denoising techniques to reduce noise in the captured sounds. The availability of two microphones on board enables the Eloc device to perform time-difference-of-arrival (TDOA) calculations and identify the direction of the infrasonic source, i.e., the direction to the elephant. Figure 1a illustrates the placement of an Eloc node in a forest area, while Figure 1b illustrates a spectrogram of captured recording of infrasonic data. Currently, the device is equipped with audio capturing and classification capabilities, enabling it to discern and identify elephant presence, and it also has the capability for network transmission.

Although a single Eloc device is only capable of calculating the direction of the infrasonic source, a large network of Eloc devices can be used to identify the location of elephants spread across a large geographic area (see Figure 2). Elephant ecologists typically deploy Eloc nodes within the forest at intervals of approximately 500 meters from one another, avoiding long distances between them. This close spacing of devices simplifies the synchronization of their data during network communication. Additionally, it significantly reduces the time required for data to travel from the source to its intended destination. This efficient data transmission ensures that data reaches the base station promptly, resulting in a more immediate and responsive communication experience that facilitates real-time communication. However, it lacks a frontend that can effectively visualize the real-time data received by the base station, thereby allowing users to intuitively witness the estimated locations of elephants. This limitation served as the primary motivation for the development of *Eloc-Web*.



(a) (b)

Fig. 1: Recording infrasonic data using Eloc nodes: (a) a node placed in the forest, (b) a spectrogram of captured infrasonic data.

As shown in Figure 2, the Eloc nodes deployed within the forest, serve the purpose of capturing sounds and swiftly classifying whether the detected sound corresponds to an elephant rumble. This classification is executed in real-time, employing embedded machine learning models. The results of this classification are then transmitted via a network to a central base station in real time. Once these results reach the central base station, they become accessible through Eloc-Web. Eloc-Web is the platform through which these classification results are displayed and made available for users to access. This integrated system seamlessly facilitates the flow of information from the forest-based Eloc nodes to a central hub, making it accessible to users through Eloc-Web.

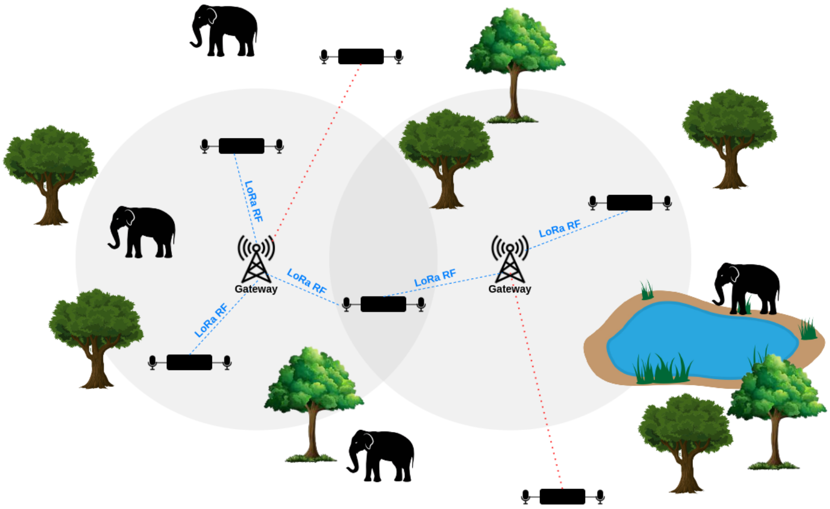


Fig. 2: A typical deployment of an *Eloc* device network, which consists of wireless links to transfer data to a central location.

2.2 Uncertainty Visualization

In the fields of scientific and geographic visualization, multiple definitions for uncertainty have been proposed as different authors have their own interpretations of the term. Terms and concepts such as inaccuracy, inconsistency, imprecision, vagueness validity, data lineage, and data quality are used to interpret uncertainty in the related literature (Duckham et al, 2001; MacEachren et al, 2005; Pang et al, 2001; Buttenfield, 1993). More research has identified and has widely accepted the need for visualizing the uncertainty with the associated data (Zuk and Carpendale, 2006; Bisantz et al, 2009). It is vital to identify different aspects of uncertainty and how they can be represented in the visualization to help the user understand the impact of uncertainty.

Uncertainty can be represented both intrinsically; by incorporating the representation to the object itself or extrinsically; by annotating the object (error bars, numeric tags, pie charts) (Bisantz et al, 2009). Some common intrinsic demonstrations are the use of color dimensions (such as hue, saturation, and brightness), transparency, size, shape, and fuzziness (MacEachren et al, 2012). When visualising uncertain information, usability, effectiveness, and the risks of cognitive overload should be considered. According to Pham et al (2009), an effective uncertainty information visualisation system should be intuitive, interactive, and minimize errors. It should seamlessly integrate information and its uncertainty without artificial separation while facilitating consistent learning effects by identifying parameter-visual variable mappings.

2.3 Visualizing Spatial Distribution of Species via Web Applications

In this section, the previous work that visualizes the spatial distribution of species via the web is explored. The literature was reviewed with an emphasis on the data visualization input, the use of uncertainty visualization techniques, the availability of the application via the web, and whether the application was evaluated for usability.

One example of a web application visualizing position data is *JMesh*, developed by Mouy et al (2015). It is a web-based visualization platform that enables users to listen to marine animal acoustics, locate them, and monitor their positions. However, despite the promising features and quality attributes, the paper fails to address the usability of the application.

Ribeiro et al (2022) presented an end-to-end pipeline for acoustic monitoring of Invasive Alien Species (IAS). They have developed an interactive web interface called *RFCx Arbimon* for storage, spatial distribution visualization, and management of the collected and analyzed acoustic data. While the authors have not provided a usability evaluation for this tool, it appears that they followed design principles to ensure a good user experience after interacting with the application. However, they do not address the inherent uncertainty in the detected data, which can affect the reliability and transparency of the results.

Kabatha (2018) has developed a web application that maps Global Positioning System (GPS) telemetry data of elephants which receive datasets from various data sources and interact with them via a graphical user interface that is accessible over the web, which is advantageous compared to traditional desktop Geographic Information Systems (GIS). While this application offers an array of features beneficial to interested user groups, the author has not done any usability assessment of the web application, which could impact its effectiveness. Another critical point is that the application does not have access control that could prevent confidential data from falling into the wrong hands.

Klein et al (2021) presented a web-based system for the visual analysis of cheetah movement data collected from GPS collars. The authors have considered the environmental context, which is critical for interpreting and analyzing animal behaviour patterns. To ensure that the resulting application is effective and efficient while providing a good user experience, the authors collaborated with ecologists to determine the application requirements, let users interact with prototypes, and developed them iteratively. However, similar to the previously mentioned application, this tool does not visualize the uncertainty of data.

Dodge et al (2021) have developed *DynamoVIS*, an interactive tool that visualizes animal movement data and the impact of both internal factors (such as animal speed and turn angle) and external factors (such as vegetation and weather conditions) on animal movement. However, it does not address the uncertainties in movement data since it only visualizes the data that has been imported by the user. This is a significant drawback as various factors can affect the accuracy of movement data and have a significant impact on data interpretation. Furthermore, *DynamoVIS* is not web-based, which limits its accessibility.

MarineVis, an application that visualizes electronic trajectory data of marine animals has been developed by Mostafi (2011). The application is not web-based, making it less accessible. However, it features multiple techniques such as glyphs, modifying geometry, and animation to visualize the positional uncertainty of the data. The paper does not provide information on the user-friendliness of the application, which raises concerns about the quality of the user experience.

Table 1 highlights the research gap identified in the context of user-friendly and accessible visualization applications for the spatial distribution of species that also accounts for the uncertainty of data.

Table 1: Comparison matrix of visualization applications for spatial distribution of species

Research	Monitored Species	Input Data	Uncertainty Visualization	Web-based Application	Usability Evaluation
Mostafi (2011)	Marine animals	Electronic tracking data	Visualized	Not available	Not available
Mouy et al (2015)	Marine animals	Passive acoustic data	Not visualized	Available	Not available
Kabatha (2018)	Elephants	GPS telemetry data	Not visualized	Not available	Not available
Dodge et al (2021)	Terrestrial animals	Any tracking data	Not visualized	Available	Not available
Klein et al (2021)	Cheetah	GPS telemetry data	Not visualized	Available	Available
Ribeiro et al (2022)	Invasive alien species	Passive acoustic data	Not visualized	Not available	Not available
Eloc-Web	**Elephants**	**Passive acoustic data**	**Visualized**	**Available**	**Available**

3 Methodology

An exploratory research method was employed to achieve the objective of designing a user-centric virtual environment aimed at visualizing and analyzing the detection of elephant rumbles from acoustic sensors. Exploratory research serves as a foundation for informed decision-making, user-centric design, and continuous improvement throughout the web application development process. Figure 3 outlines the steps followed in the methodology, which adheres to the User-Centered Design (UCD) process. According to The Interaction Design Foundation (2023), this process includes understanding the context of use, specifying user requirements, designing solutions, and evaluating them against the established requirements.

3.1 Data Collection

The initial step in designing and developing the *Eloc-Web* application involved understanding the context of its use. We collaborated with three elephant ecologists and

Fig. 3: Steps followed in the design and development of the *Eloc-Web*.

conservationists from the *International Elephant Project (IEP)*[1], who had over 45 years of experience studying elephant behavior, ecology, population dynamics, and human-elephant interactions in Malaysia and Indonesia while working on the project. They participated in an interview focused on collecting qualitative data (Appendix A) for discovery research, aimed at identifying their field experience, usage of existing elephant monitoring applications, and high-level requirements for the web application.

The discovery research yielded valuable insights into the significance of elephant rumble locations. By analyzing the spatio-temporal metadata of these rumble locations, researchers can uncover a wealth of information. They can gain a deeper understanding of elephant behavior in different contexts, such as their responses to varying vegetation types or their behaviors in different human-influenced settings, including farmland, settlements, and uninhabited areas. Additionally, researchers can examine how elephant behavior varies throughout the day. Furthermore, rumble locations can serve as indicators of hotspot areas where conflicts between elephants and humans are more likely to occur.

The distribution of rumble frequency within a specific area can provide further insights. This data can shed light on the environmental factors that influence elephant behavioral patterns, including the availability of food and water, the degree of disturbance in their surroundings, and the level of human activity.

[1] A nonprofit project protecting elephants, rainforests, and communities to preserve shared habitats, biodiversity, and ecosystems

The certainty of rumble locations is of paramount importance in certain contexts. For example, accurately determining whether a particular population of elephants has migrated from one area to another is crucial. This knowledge allows researchers to calculate the distance and direction relative to the size of those areas, facilitating effective conservation efforts and management strategies.

Interestingly, the research findings revealed that neither of the elephant ecologists had previously utilized any application to visualize the location data derived from passive acoustic monitoring. This lack of technological implementation resulted in a lack of clear communication regarding the necessary requirements for such an application. These findings underscore the potential for enhanced collaboration and knowledge sharing among researchers in the field, paving the way for an effective virtual environment to visualize elephant location data derived from PAM.

3.2 Initial Prototype Design

Following the data collection stage, we needed to identify the basic requirements of the application. As we were uncertain about the participants' understanding of the application requirements, we searched for similar applications to determine the functionalities. Subsequently, we designed the user interface for the *Eloc-Web*.

The initial prototype of the *Eloc-Web* application introduced several features to enhance its functionality and user experience. One of the main features was the map view, which allowed users to visualize the locations of detected elephant rumbles as shown in Figure 4. Additionally, a heatmap was utilized to identify hotspots of rumble detections. Users could zoom and pan the map to explore different areas and assess the distribution of detected rumbles.

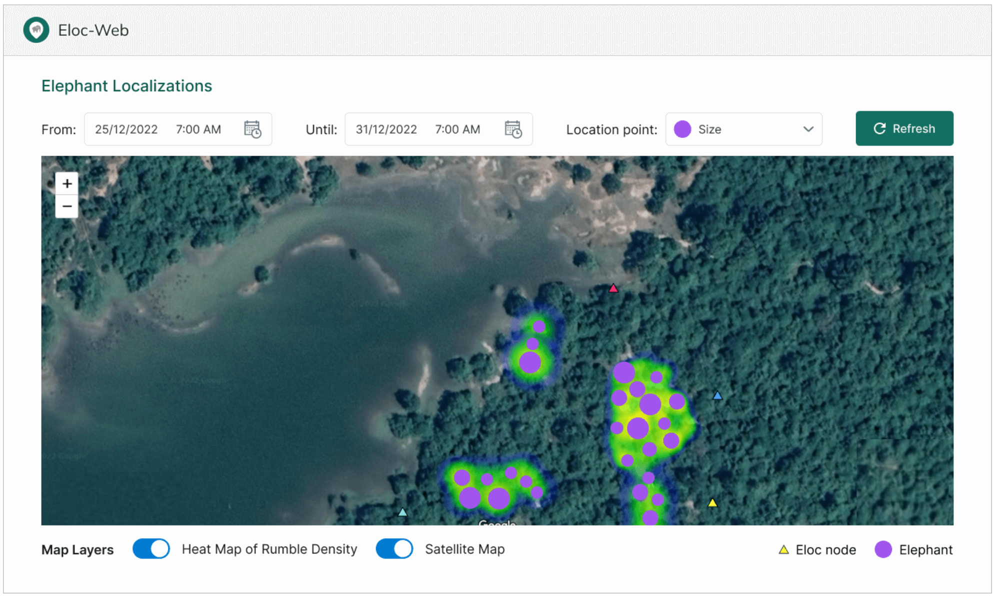


Fig. 4: Map view in the initial prototype of *Eloc-Web*.

The uncertainty of rumble detections was visualized in the initial prototype using a set of visual variables (shown in Figure 5) derived from experiments conducted by MacEachren et al (2012). Furthermore, the prototype included a filtering mechanism that allowed users to narrow down the detected results based on a specific date range and time. This feature enabled users to focus on a particular period of interest, facilitating analysis and interpretation of the data.

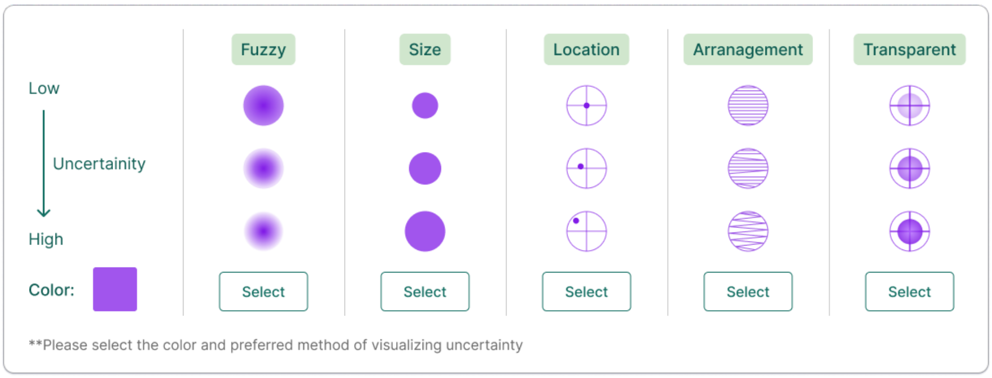


Fig. 5: Visual variables used for visualizing uncertainty in the initial prototype.

Information about each node was displayed in a side panel, as shown in Figure 6. Users could access basic details such as the node ID, coordinates of placement, current battery level, and deployment date. The application also presented line charts showcasing the energy level variation and rumble detections by each node. These visualizations offered insights into the behavior and performance of individual nodes.

Charts and graphs were incorporated to facilitate analysis of the collected data, as depicted in Figure 7. The application presented a graph representing the localization points detected, providing an understanding of the monitored area's magnitude and rumble density. A bar chart displayed the distribution of rumble detections by the hour, aiding in the analysis of elephant behavior. Additionally, a line chart illustrated rumble detections by each node, offering insights into rumble frequency and node health within specific areas.

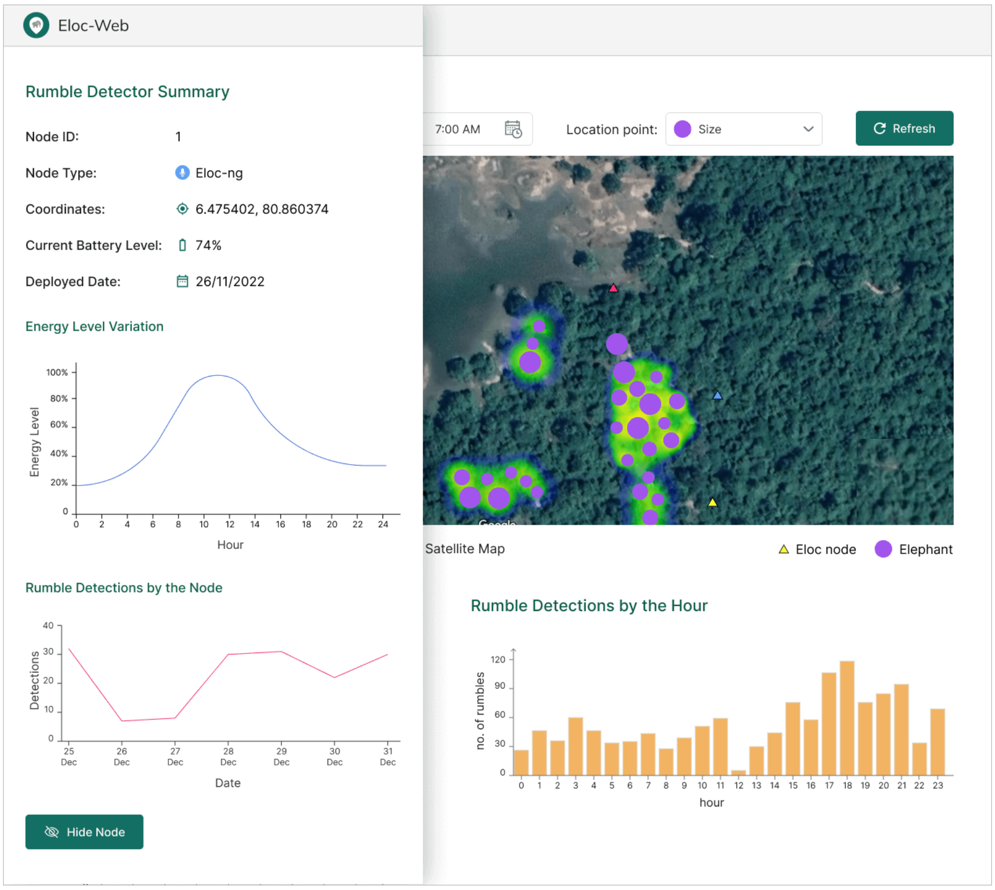


Fig. 6: Node information display in the initial prototype of *Eloc-Web*.

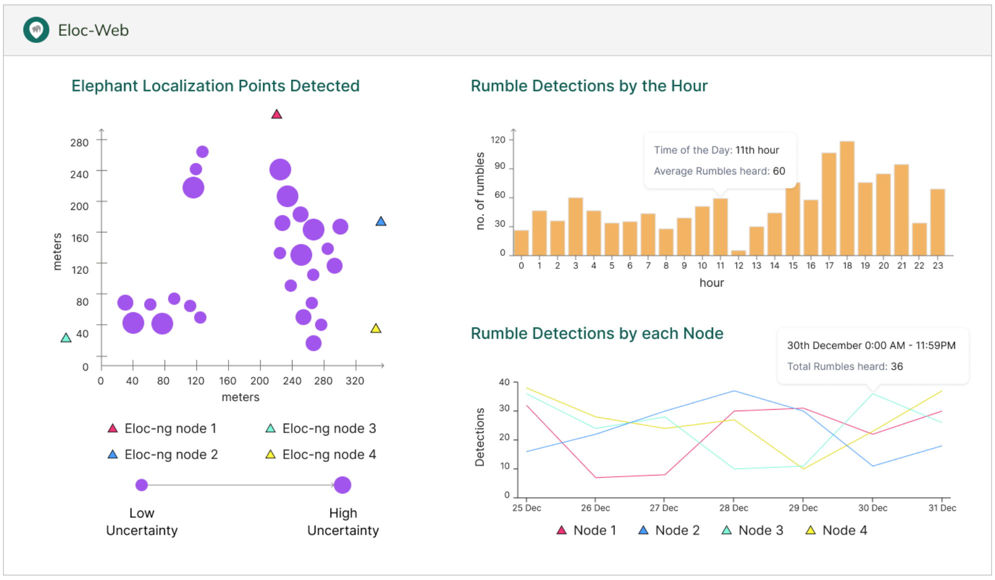


Fig. 7: Charts & graphs in the initial prototype of *Eloc-Web*.

3.3 Focus Group Discussion & User Interviews

To ensure that the application effectively addresses user requirements, we conducted user interviews and a Focus Group Discussion (FGD). The purpose of the focus group discussion was to identify problems in the user interface and to understand users' expectations for achieving their goals. We approached a group of researchers from the *International Elephant Project*, who are monitoring elephants using bioacoustics in Indonesia and are potential users of animal monitoring applications. We presented the initial prototype and encouraged them to share their thoughts and opinions on the design to identify possible improvements. Qualitative data was gathered from the focus group discussion, highlighting requirements for visualizing elephant calls and related information, as well as likes and concerns about the features of the application.

The participants in the focus group discussion raised several concerns about the initial prototype. It was revealed that accurately estimating the density of elephants based solely on acoustic data is an impossible task. The influence of diverse factors, such as environmental conditions, distance, vegetation, and ambient noise, adds complexity to the task of isolating and accurately interpreting the specific signals associated with elephants. Participants recommended developing the visualization app in a manner that fosters compatibility with diverse autonomous recording units (ARU) rather than being restricted to the *Eloc* device. This enhancement would enable users employing different types of recording units to effectively utilize the application and leverage its functionalities. Another key concern expressed was the requirement for a data export feature, accompanied by the necessity of ensuring that the exported data is compatible with commonly used software for data analysis.

The current display of uncertainty was found to be confusing by users. They encountered difficulties in discerning whether the visual variables displayed the certainty of the location estimate or the certainty of an elephant being present at the estimated location. The term 'uncertainty' itself carries a negative connotation, further complicating the interpretation of the visualized data. Furthermore, it has been noted that the detection of rumbles by each node does not necessarily need to be a key feature of the application.

After the focus group discussion, we conducted two user interviews with an elephant conservationist and a conservation biologist who are leading elephant research projects. The interviews were conducted in a semi-structured format, and the participants were asked about their experience in the field, their use of elephant monitoring applications, and their potential requirements (Appendix B). The initial prototype was presented for feedback, and we gathered their opinions on the design and functionality of the prototype.

One key recommendation we obtained to enhance the application's design and functionality was to represent uncertainty as discrete values because it would be more apprehensible and have a straightforward connection between the accuracy of the ML model and the certainty of the rumble. Access control emerged as a crucial feature to prevent the misuse of information that could harm elephants. Restricting certain data from the general public would safeguard sensitive information, ensuring it remains accessible only to authorized individuals. Additionally, the ecologists recommended incorporating more layers into the map that represent variables influencing elephant behavior and activity, such as roads, terrain, and human establishments. It was noted that displaying the heatmap of rumble density and the estimates of elephant locations together could be confusing and should be reconsidered. The inclusion of a chart displaying rumble detections with the magnitude of the monitored area was deemed unnecessary, with the suggestion of a scale on the map being sufficient instead.

3.4 Design Improvement

Based on the qualitative data collected from the focus group discussion and the user interviews, application requirements were reviewed, and necessary changes were made to the interface to improve its usability and user-friendliness. This iterative process of gathering feedback and refining the prototype helped in ensuring that the final web application meets the needs of its intended audience.

The improved design displays elephant rumble detections as points on the map, as shown in Figure 8. The nodes are symbolized by a microphone icon, which helps to identify them as rumble detectors. The different colors of the detector nodes depict the types of nodes. Hovering over a node displays a tooltip containing the node identification number and the current battery percentage. Instead of visualizing the magnitude of the rumble detection in a separate chart, a scale was added to the map to get an understanding of the magnitude of the area. The map has more layers (roads, terrain) that aid in gathering insights into the elephant rumble analysis such as the impact of anthropogenic pressure and the landscape of the monitored area. Based on user feedback regarding the distracting nature of having rumble detection points superimposed on the rumble density heatmap, a modification was implemented. The alteration ensures that the rumble location points and the heatmap cannot be simultaneously viewed, as illustrated in Figure 9.

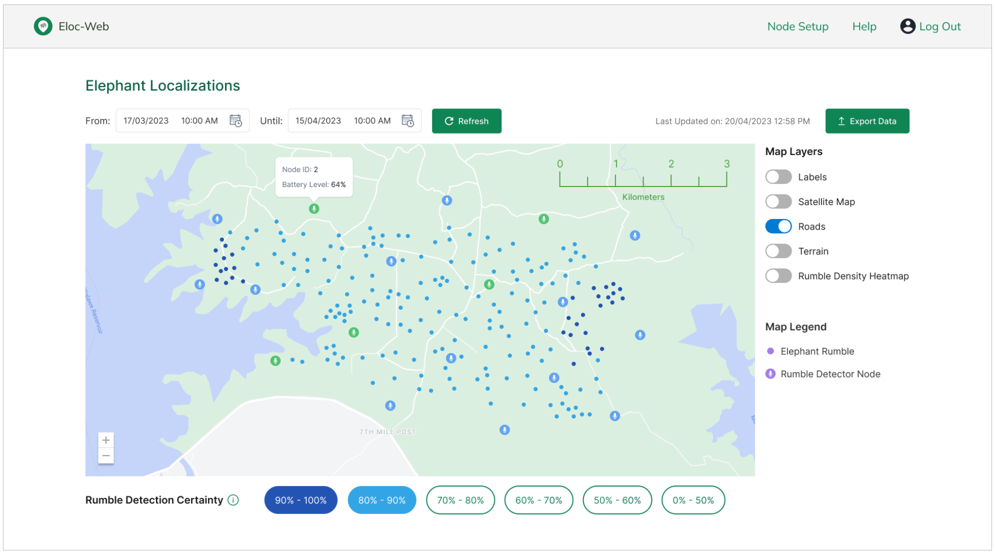


Fig. 8: Map view in the improved design of *Eloc-Web*.

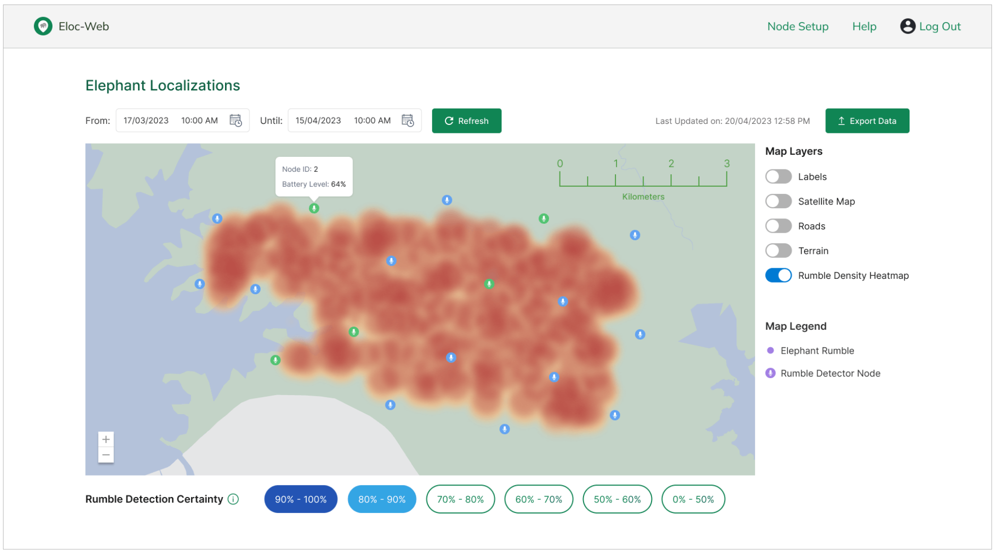


Fig. 9: Rumble Density Heatmap view in the improved design of *Eloc-Web*.

The previously selected visual variables for representing uncertainty, which are shown in Figure 5 were disregarded due to users finding the continuous data representation ambiguous. According to Buttenfield (2001) color is a strong visual variable for providing discrete visual information. Therefore, a color scale was utilized for visualizing the uncertainty of rumble detections, as shown in Figure 10. The probability of a rumble detection is represented as a percentage, and the colors represent ranges of probability percentages depending on the accuracy of the ML model embedded in the node. In the default view, the map shows rumble detections with a high certainty range of 80% - 100% and 90% - 100%. Users can choose to view detections with low certainty if necessary.

As Levin (1987) has concluded, positively valenced descriptions produce favorable associations, which in turn lead to more positive judgments. Therefore, we positively framed the uncertainty of rumbles as 'Rumble Detection Certainty' in the interface.

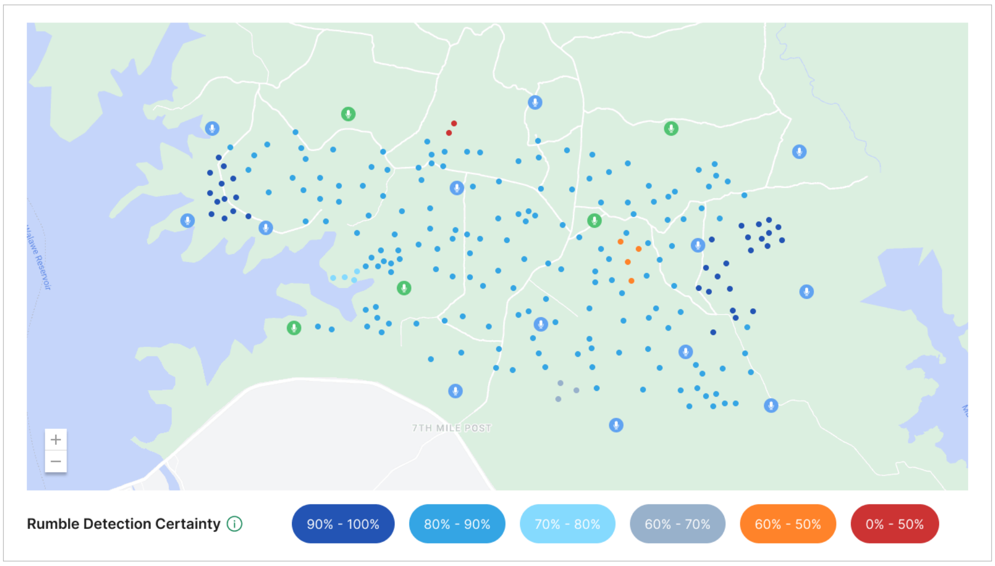


Fig. 10: Use of color to visualize the rumble detection certainty in the improved design of *Eloc-Web*.

As per stakeholder suggestions, it was made available to set up nodes or autonomous recording units (ARU) of different types on the design grid by choosing the node type and choosing a distinct color, as shown in Figure 11. The side panel shows more information about each detector node.

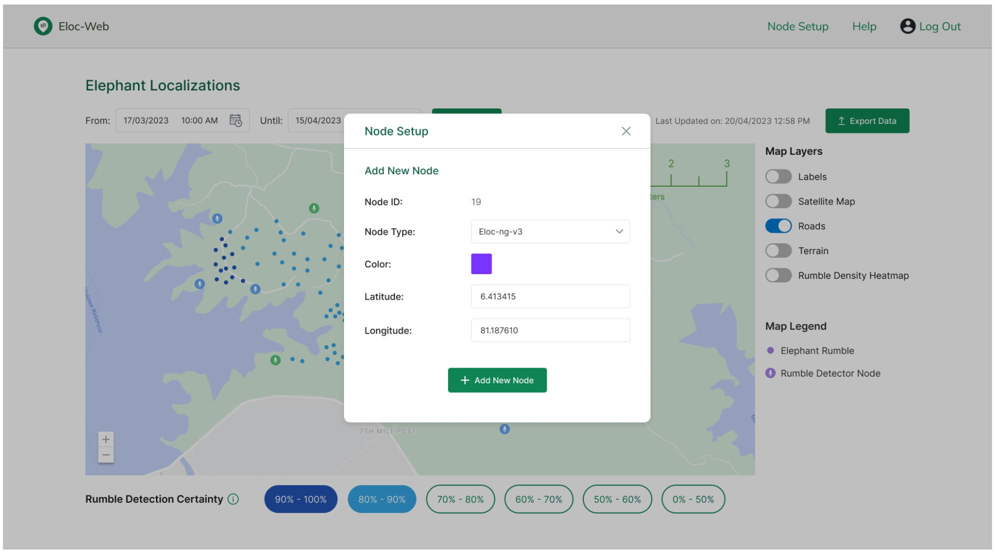


Fig. 11: Add new node feature in the improved design of *Eloc-Web*.

In the improved design, more space has been allocated for the charts by removing non-essential features from the previous design. The Rumble Detections chart (Figure 12) displays the number of rumble detections for each day of the selected date range. The Average Diel Activity chart (Figure 13) displays the average count of rumbles detected every 30 minutes. The bucket size for this chart depends on the user's preference and the level of detail they require. Based on our interview findings, conventional diel activity is plotted hourly or half-hourly. However, we have included a bucket size of half-hour for users who require a more detailed analysis of the data. Additionally, users have the ability to change the chart types according to their preferences.

For in-depth analysis of the data, downloading the detection results and importing them into software such as sound analysis software is necessary. Therefore, a data export feature was added to the *Eloc-Web* design. It enables users to download data for a particular period of time in different file formats (CSV, text). The user is also given the choice to select the detector nodes he would like to see results from.

Access restriction is crucial for this kind of application due to the fact that elephants could be harmed if poachers discover the locations of elephants that they would misuse to harm the elephants. Therefore application will not be available to the general public. Elephant conservationists and ecologists are able to sign up and set up a designed grid of acoustic recorders for passive acoustic monitoring and observe the results.

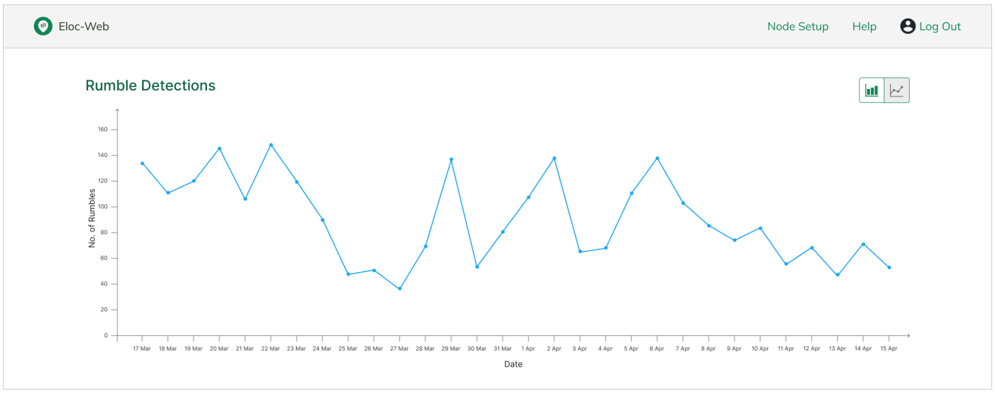


Fig. 12: Chart for rumble detections per day in the improved design of *Eloc-Web*.

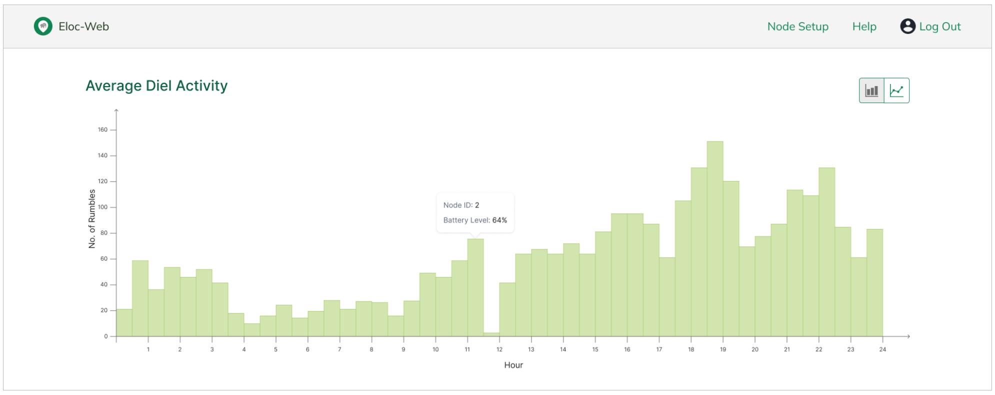


Fig. 13: Average Diel Activity graph in the improved design of *Eloc-Web*.

3.5 Usability Evaluation

After refining the prototype with feedback from elephant ecologists, a usability evaluation was conducted to identify potential usability issues and refine the user interface to be more intuitive. The International Organization for Standardization (ISO) defines usability as the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (ISO, 2010; Hertzum, 2020).

The usability evaluation followed the steps defined by Hertzum (2020), which include preparation, execution, and analysis. The preparation phase involved planning and designing tests, becoming familiar with the elephant ecology domain, recruiting expert users of the domain for the test, and creating test tasks. The execution phase involved launching the usability test and collecting responses from users. In the analysis phase, the test data, screen recordings, and additional feedback were analyzed to identify usability issues.

To validate the design decisions made for the *Eloc-Web* prototype before its development, a usability evaluation was conducted using the *Sprig* software. *Sprig* is a product research platform that enables product teams, researchers, and designers to analyze the user experience and identify areas that need improvement through unmoderated concept and usability testing of ideas, designs, and prototypes (Sprig, 2023). Testing interactive prototypes with *Sprig* allows for observing users engaging with the product features and learning what can be optimized before the implementation of *Eloc-Web*.

The usability of the *Eloc-Web* prototype was evaluated using two methods. In the first method, participants were asked to complete a series of ten tasks and provide feedback. After completing each task, participants were asked to rate the ease of task completion and the ease of finding certain information. Table 2 highlights the user tasks and criteria for successfully completing tasks. In addition to evaluating usability, this test also gathered qualitative and quantitative data that may reveal new insights and unanticipated design issues through user perception, impression, and task completion. Figures 14, 15 and 16 show the questions, tasks assigned, and post-task questions in the prototype testing activity. The *Sprig* software's ability to capture screen recordings of participants interacting with the prototype, the success or failure to complete a task, and the time taken to complete each task facilitated analysis of the collected data.

Table 2: User tasks and success criteria for the tasks

No.	User Task	Success Criteria
1.	View results for a specific time period.	Pick the correct dates from the date picker and click refresh.
2.	Identify the surrounding area.	Click on the 'Labels' toggle.
3.	Identify the surrounding environment.	Click on the 'Satellite Map' toggle.
4.	Identify clusters of rumble density.	Click on the 'Rumble Density Heatmap' toggle.
5.	Identify rumbles with low certainty.	Click on the button that displays a rumble detection certainty.
6.	View information about the acoustic recorders.	Click on the acoustic recorder.
7.	Add a new acoustic recorder to the designed grid.	Navigate to Node Setup and click on 'Add New Node'.
8.	Change chart types.	Navigate to the correct chart and click on the icon button for the bar chart.
9.	Identify the number of rumbles displayed in a chart for a specific time period.	Hover over the bar that displays rumbles for the mentioned time period.
10.	Export the displayed rumble detection results as a CSV file.	Navigate to the 'Export Data' modal and select 'All Nodes' and click on the 'Export' button.

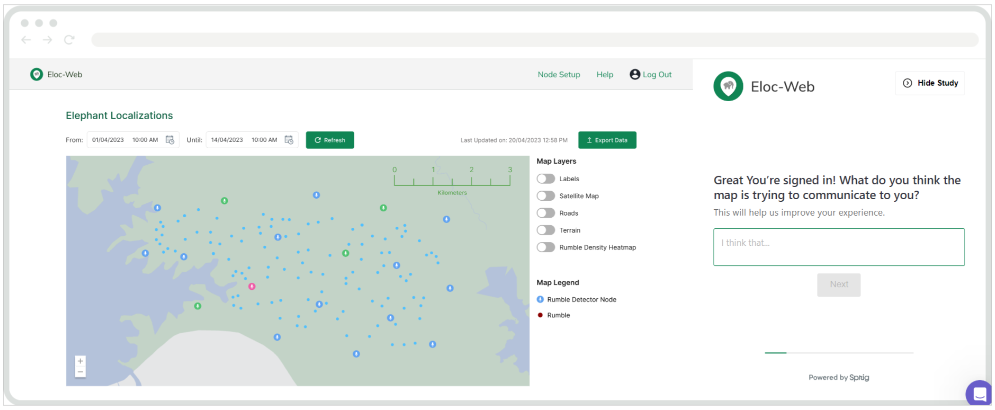


Fig. 14: Gathering qualitative data on the prototype via *Sprig*.

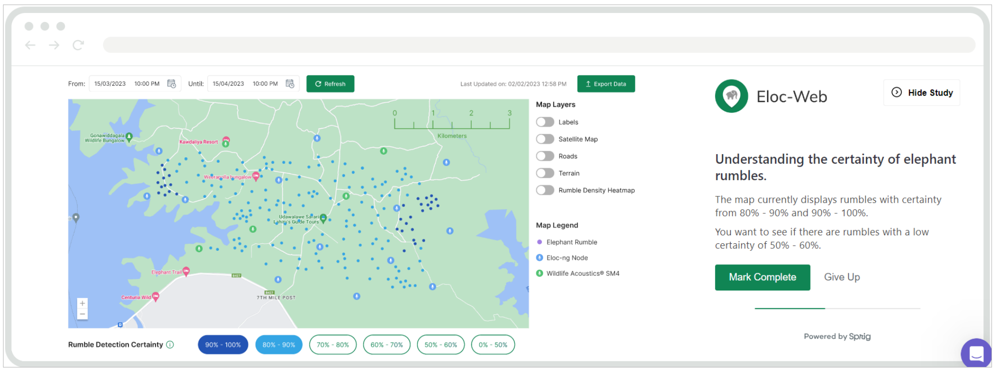


Fig. 15: Task of identifying low certain rumbles in the usability evaluation via *Sprig*.

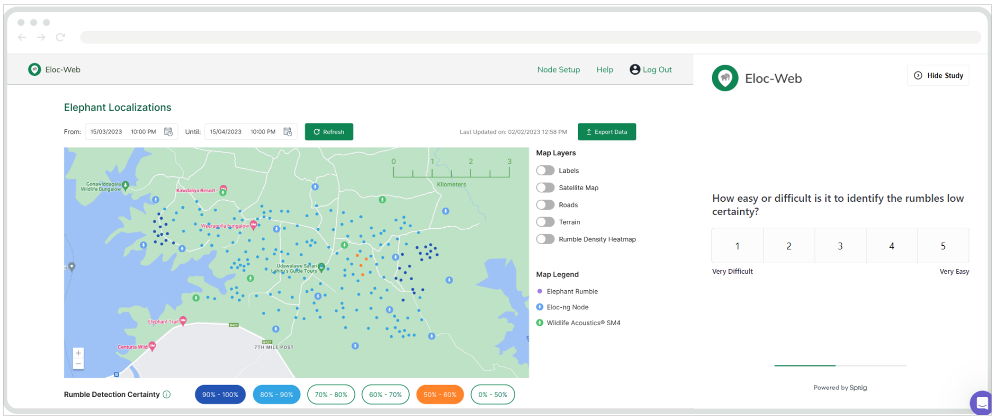


Fig. 16: Asking post-task questions in the prototype testing via *Sprig*.

After completing the task scenarios in the prototype, users were directed to participate in the System Usability Scale (SUS) to evaluate the overall usability of the Eloc-Web application (Appendix C).

SUS is a standardized questionnaire with 10 items (Brooke, 1996). It was developed by John Brooke as a quick way of evaluating usability. It is designed to measure the sub-scales of effectiveness, efficiency, and satisfaction, and also provides a measurement for learnability through SUS items 4 and 10. SUS is developed as a Likert scale that obtains subjective assessments of the system's usability in positive and negative tones. This scale is generally used after users have had the opportunity to interact with the system but prior to any discussions on the system. Participants should take part in recording responses in the SUS immediately after using the system, without thinking about the answers for a long time (Brooke, 1996).

In order to calculate the SUS score for the application, first the score contributions of each item are summed. For items with a positive tone (items 1,3,5,7, and 9) the score contribution is the scale position minus 1. For items with a negative tone (items 2,4,6,8, and 10) the score contribution is 5 minus the scale position. Each item's score contribution should be in the range of 0-4. After obtaining the score contribution, each of them is multiplied by 2.5 which yields the overall system usability score. The overall score has a range of 0-1-00. Sauro and Lewis (2012) have created a grading scale (see Figure 17) where a SUS Score of 68 is considered an average experience. Furthermore in Lewis' work for benchmarking the SUS, he states the common industrial goal is to achieve a SUS score of 80 which is viewed as above average/good experience (Lewis and Sauro, 2018).

The data obtained from the usability evaluation was used to create the final design, which was subsequently approved for development. The Eloc-Web [2] application was developed to present a summary and visualization of all data obtained from passive acoustic monitoring to relevant stakeholders and decision-makers. The application was

[2] https://eloc-web.netlify.app/

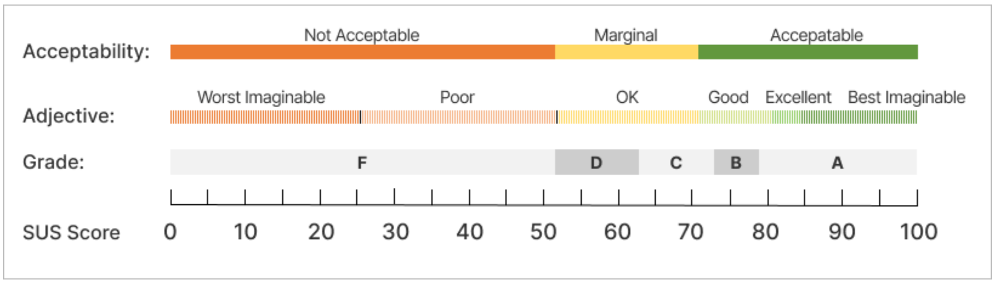


Fig. 17: Grading scale for System Usability Scale (SUS).

constructed utilizing open-source software and technologies that were well-suited to the application's needs within a client-server architecture.

4 Usability Evaluation Results

Data was collected from April 17, 2023, to April 25, 2023, from 14 participants who are members of the *International Elephant Project*, and elephant conservationists, 11 of which were usable for data analysis as the other 3 participants did not complete the test.

4.1 Testing Eloc-Web Interactive Prototype

Both qualitative and quantitative data were gathered during the usability evaluation. The qualitative data (screen recordings of the participants completing tasks, post-study questions, and feedback) were informally reviewed to identify the task success rate and possible issues in the design. The quantitative data were analyzed and the task success, time on task, and ease of learning were quantified.

4.1.1 Overall Task Success

The majority of participants successfully completed most tasks. However, there were a few exceptions: three participants were unable to perform Task 4, which involves identifying clusters of rumble density, and one participant did not complete both Task 1 and Task 7. Task 1 entails viewing results for a specific period, while Task 7 involves adding a new acoustic recorder to the designed grid (see Table 2). The overall task success rate was 95.45% (see Figure 18).

Fig. 18: Graph for overall task success.

4.1.2 Overall Time on Task

The time taken to complete each task by each participant was captured to measure the average time taken for each task. The 11 participants took on average of 25.7 seconds to complete all of the tasks (see Figure 19).

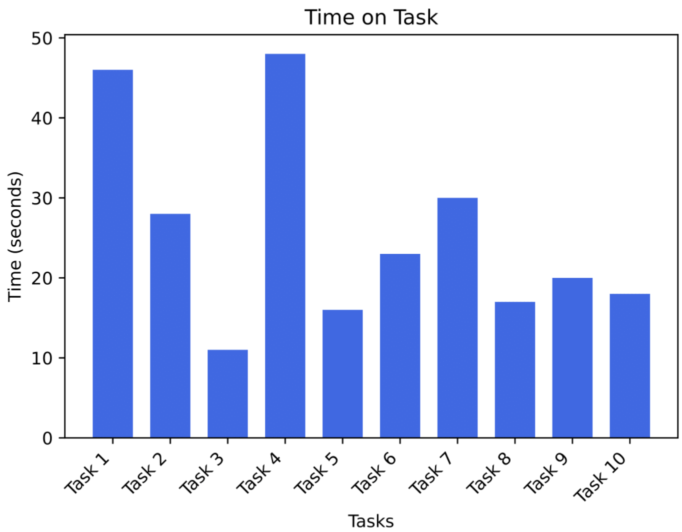


Fig. 19: Graph for overall time on task.

4.1.3 Overall Ease of Learning

First-use learnability refers to how easily a user can understand the design on their initial attempt. Task 4 received a comparatively low score for ease of learning, with a score of 3.63. User feedback indicated that the rumble density heatmap made it difficult to view clusters clearly. However, overall, participants strongly agreed that the interface was easy to learn and use for the assigned tasks, with an average learnability score of 4.83 out of 5 (see Figure 20).

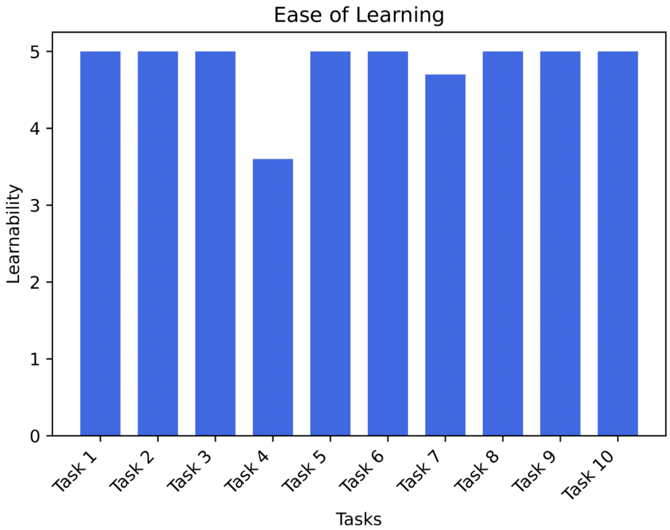


Fig. 20: Graph for overall ease of learning.

5 Conclusion

After investigating the importance of detecting elephant rumbles through passive acoustic monitoring and visualizing their spatial distribution via a web-based application, we have determined that a user-friendly platform for input, manipulation, and visualization of remotely sensed data is beneficial to users such as wildlife conservationists and ecologists. The developed web application has demonstrated its potential in providing useful information for elephant ecologists and conservationists in tracking elephants and studying their behaviour. Our findings suggest that further development is possible in areas such as improving the certainty of location estimates by visualizing high recall or high precision rumbles, expanding the capabilities of the web-based application, and testing the system's efficiency in real-world scenarios. Additionally incorporating data from other sensors such as GPS or weather sensors could provide more comprehensive insights into elephant behaviour and habitat usage. With these improvements, the *Eloc-Web* application could facilitate more proactive conservation efforts and ultimately aid in minimizing human-elephant conflict.

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Appendix A Discovery Research for Eloc-Web

1. Briefly describe your work/ experience in the field of elephant ecology.
2. What is your relation to the Eloc project?
3. What information would you be able to derive from knowing elephant location points across a timeline?
4. How can that information (e.g. behavioral patterns) be derived from the location data?
5. What are the environmental factors that influence elephant behavioral patterns?
6. Is it important to be aware of the uncertainty of the elephant's location? Why do you say so?
7. Please explain your answer to the above question.
8. Have you used any applications to analyze elephant behavior using localization/ movement data?
9. If yes, what application(s) have you used?
10. Are you familiar with MOVE Bank?
11. What have you used MOVE Bank for?
12. If you have used MOVE Bank, what do you like about the application?
13. Was/Is there anything you often looked for on MOVE Bank that is missing or hard to find?
14. What haven't we asked you today that you think would be valuable for us to know?
15. May we contact you if we have any other questions or for possible further research for this project?

Appendix B User Interview Questions

1. How do you typically use location estimation data to inform your research and conservation efforts?
   (a) What data would be most important to understand the distribution and the behavior of elephants? (eg: the surrounding environment)
   (b) What are some of the most important factors to consider when tracking elephant populations and movements, and how can the web application help address these factors?
2. Do you use any software or application currently to visualize or analyze the data that you collect about elephant populations?
   (a) Can you tell us about your experience using that application?
   (b) Are there any limitations or challenges you face when using the application?
   (c) What are some of the key areas for improvement?
3. What are some of the key features that you look for in a web application for monitoring elephant populations?
   (a) What types of visualizations and tools are most helpful for you?
   (b) What specific information would you like to see on the map?
   (c) What would be the most helpful way to visualize that preferred information?
4. How important is accuracy when it comes to estimating the spatial distribution of elephants? Are there any particular sources of error or uncertainty that you find particularly challenging to deal with?

5. How about the certainty of the location estimates? Do you like the way we have represented it on the map?
6. Are there any specific use cases or scenarios you want to see addressed in a web application for monitoring elephant populations?
7. How frequently would you expect to use a tool like this, and in what contexts?
8. How often do you need to update the information you see on the map?
9. How do you share and collaborate on elephant monitoring data with other researchers and conservation organizations?
10. Are there any other specific suggestions or feedback that you have for the development of a web application for monitoring elephant populations?

Appendix C SUS - the System Usability Scale for Eloc-Web

1. I think that I would like to use Eloc-Web frequently.
2. I found Eloc-Web unnecessarily complex.
3. I thought Eloc-Web was easy to use.
4. I think that I would need the support of a technical person to be able to use Eloc-Web.
5. I found the various functions in Eloc-Web were well integrated.
6. I thought there was too much inconsistency in Eloc-Web.
7. I would imagine that most people would learn to use Eloc-Web very quickly.
8. I found Eloc-Web very cumbersome to use.
9. I felt very confident using Eloc-Web.
10. I needed to learn a lot of things before I could get going with Eloc-Web.

Appendix D System Usability Scale (SUS) Score

Table D1: System Usability Scale (SUS) Score

Participant	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**SUS Score**
P01	5	1	5	2	4	3	4	2	5	1	85
P02	5	2	4	1	4	1	5	1	5	1	92.5
P03	5	1	5	1	5	1	5	1	5	1	100
P04	5	1	5	1	5	1	5	1	5	2	97.5
P05	4	2	4	1	4	1	4	1	4	1	85
P06	4	1	5	1	5	1	5	1	5	1	97.5
P07	5	1	5	2	5	1	5	1	5	2	95
P08	5	2	3	2	4	3	2	3	4	3	62.5
P09	5	1	5	3	4	2	4	1	4	4	77.5
P10	5	2	5	3	5	2	5	1	5	1	90
P11	5	1	5	4	5	1	5	1	4	2	87.5
										Average	**88.18**