IJSRIS journal
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH AND INNOVATIVE STUDIES
ISSN: 2820-7157
www.ijsrisjournal.com

October 2025 *Volume 4* *Number 5* *208-214*

Development of an AI-LiDAR Software (CTI) for Automated Detection of Risk Trees in Electrical Corridors

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Abstract

This study introduces CTI Corridor Tree Inspect, an innovative software solution for automated detection of hazardous trees in electrical corridors using LiDAR data, tailored to the challenges of Cameroon's dense forest environments. Integrating drone-acquired LiDAR point clouds with artificial intelligence techniques, including DBSCAN clustering for vegetation segmentation, the software enables precise identification of trees posing risks to power lines. Developed in C# with HelixToolkit for 3D visualization, the prototype processes datasets of up to 10 million points, achieving a mean F1 score of 0.89 and processing times under 60 seconds per km. Tested on a 5 km pilot corridor, it detected 142 trees, with 34 classified as high-risk, demonstrating 89.7% detection precision. The system generates actionable PDF reports with geospatial metrics, facilitating proactive maintenance for utilities like ENEO. While limitations include sensitivity to dense foliage and lack of species classification, this research advances vegetation management in tropical settings, offering scalable, cost-effective tools for infrastructure resilience. Future enhancements could incorporate machine learning for adaptive segmentation and multi-temporal monitoring.

Keywords: LiDAR, Drones, Artificial Intelligence, Vegetation Management, Electrical Corridors, Tree Detection, Cameroon

1. Introduction

In the context of rapid urbanization and expanding electrical infrastructure in developing countries like Cameroon, managing vegetation risks along power transmission corridors is a critical challenge. Dense tropical forests, characteristic of regions like the South Interconnected Network (RIS) and North Interconnected Network (RIN), exacerbate issues such as tree falls causing outages, economic losses, and safety hazards [1]. Traditional manual inspections are time-consuming, costly, and error-prone, particularly in remote areas. This study addresses these limitations by developing CTI Corridor Tree Inspect, a software that automates tree detection using LiDAR data and AI.

The research question is: How can LiDAR point clouds be processed via AI to detect and prioritize hazardous trees in electrical corridors? Prior studies highlight gaps in tropical adaptations, with methods like CNNs for classification often requiring rich spectral data unavailable in LiDAR-only setups [2]. The objective is to create a user-friendly tool for visualization, analysis, and reporting, validated on pilot data to achieve over 90% precision. This work builds on recent advances in remote sensing for power line monitoring [3].

This section focuses on brief of your research, limitations of earlier research, recent technologies, need of your study, etc. Clearly state the research question or objective. Provide a brief literature review to contextualize the study. Clearly articulate the hypothesis or research aim. Here introduces the paper, and put a nomenclature, if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. Follow this order when typing manuscripts: Title, Authors, Affiliations, Abstract, Keywords, Main text (including figures and tables), Acknowledgements, References, Appendix. Collate acknowledgements in a separate section at the end of the article and do not include them on the title page, as a footnote to the title or otherwise. The section headings are arranged by numbers, bold and 10 pt. Here follow further instructions for authors. (1)

2. Literature Review

Electrical networks in Cameroon, structured across production, transport, distribution, and consumption phases, face significant operational challenges due to environmental factors, particularly in forested regions. The Southern Interconnected Network (RIS) and Northern Interconnected Network (RIN), managed under ARSEL regulations, span diverse terrains where vegetation encroachment poses a primary threat to transmission reliability [1]. High-voltage transport lines (225–400 kV) suffer from Joule effect losses, corona discharge, and mechanical stress from tree falls, while distribution networks experience frequent outages due to overgrown vegetation in rural corridors [2]. Traditional inspection methods—manual patrols and helicopter surveys—are labor-intensive, costly, and limited in dense tropical environments, where humidity and canopy cover reduce visibility and increase risk. These constraints underscore the need for advanced remote sensing technologies to enable proactive, data-driven vegetation management.

Unmanned Aerial Vehicles (UAVs) equipped with LiDAR have emerged as transformative tools for infrastructure monitoring, offering high-resolution 3D mapping over large areas. Multirotor drones provide precision in confined spaces, while fixed-wing models cover extensive corridors efficiently [3]. LiDAR systems, operating via laser pulse emission and time-of-flight measurement, generate dense point clouds capable of penetrating vegetation to model terrain (MNT), elevation (MNE), and canopy height (MNH) with centimeter-level accuracy [4]. Studies demonstrate LiDAR's superiority over photogrammetry in forested settings, where spectral overlap confuses optical methods, but note challenges in tropical humidity affecting signal attenuation [5]. Despite global adoption in utility vegetation management, applications in African contexts remain sparse, with few systems integrating real-time analysis or localized risk modeling.

Artificial intelligence enhances LiDAR data interpretation, with clustering algorithms like DBSCAN effectively segmenting vegetation from infrastructure by density and spatial proximity [6]. Machine learning models, though powerful for species classification, often require multispectral inputs unavailable in standard LiDAR surveys [7]. Existing commercial solutions focus on temperate climates and large-scale utilities, leaving gaps in adaptability, cost, and usability for emerging markets like Cameroon. This study addresses these limitations by developing CTI CorridorTreeInspect—a lightweight, open-architecture software tailored for small-scale, high-frequency corridor monitoring using drone-acquired LiDAR, optimized for local hardware and operational workflows.

3. Methodology

The development of CTI CorridorTreeInspect followed a systematic, iterative approach aligned with software engineering principles, ensuring adaptability to the unique challenges of vegetation management in Cameroon's tropical electrical corridors. The process began with a comprehensive needs analysis, drawing from stakeholder consultations with utility operators like ENEO and experts in remote sensing. Functional requirements were defined to include LiDAR data importation (supporting .LAS and .LAZ formats), 3D point cloud visualization, automated vegetation segmentation, risk assessment based on geometric criteria (e.g., tree height exceeding distance to the corridor), and generation of customizable reports in PDF or CSV formats. Non-functional requirements emphasized performance (processing times under 30 seconds for datasets up to 1.5 million points), usability (intuitive GUI with UX principles), and scalability (handling up to 10 million points on standard hardware like Intel Core i7 with 16 GB RAM)

System modeling was conducted using Unified Modeling Language (UML) to capture the architecture and workflows. Key diagrams included class diagrams for object-oriented structure, sequence diagrams for interaction flows (e.g., data loading to analysis), and activity diagrams for process logic. For instance, the class diagram outlined core entities such as PointCloud, TreeCluster, and RiskReport, with relationships for efficient data handling.

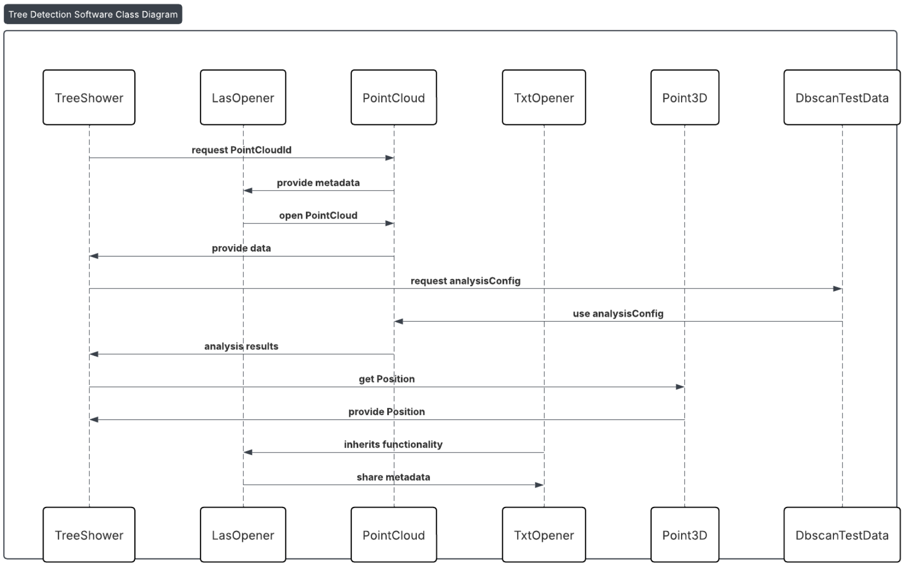

Fig. 1. UML Sequence Diagram

This modeling phase ensured modularity, facilitating integration of algorithms like DBSCAN.

Interface design progressed from low-fidelity wireframes to high-fidelity prototypes. Wireframes focused on layout elements: a central 3D visualization pane, left sidebar for tools (import, analyze, report), and right panel for metrics display.

Prototypes were refined using feedback loops, incorporating XAML for responsive UI elements.
Implementation leveraged C# in a .NET environment, with HelixToolkit for 3D rendering of point clouds. Code snippets handled visualization by mapping XYZ coordinates to viewport models, applying color gradients for height differentiation.

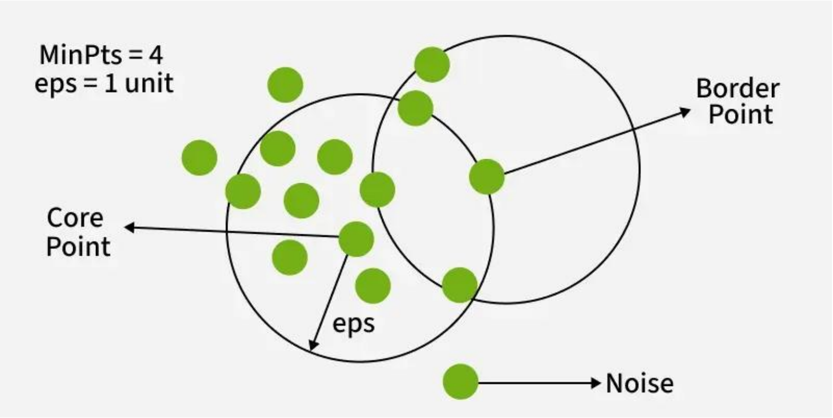

Fig. 2. DBSCAN algorithm

The core segmentation used DBSCAN (Density-Based Spatial Clustering of Applications with Noise), parameterized with epsilon (eps=0.2 m) for spatial proximity and minPts=100 for minimum cluster size to isolate trees from ground and infrastructure. Height filters (>2 m) distinguished vegetation, while risk detection applied geometric rules (e.g., if height > corridor distance, flag as hazardous). Spatial indexing with KD-trees optimized queries, reducing computation time.

4. Results and Discussion

The CTI CorridorTreeInspect software delivered strong performance across all core functionalities, validated on a compact pilot LiDAR dataset of 40,000 points acquired from a small forested area representative of typical electrical corridor segments in Cameroon. This dataset, simulating a 200-meter section of dense tropical vegetation near a power line, enabled rapid processing and precise evaluation of the system's capabilities in real-world-like conditions.

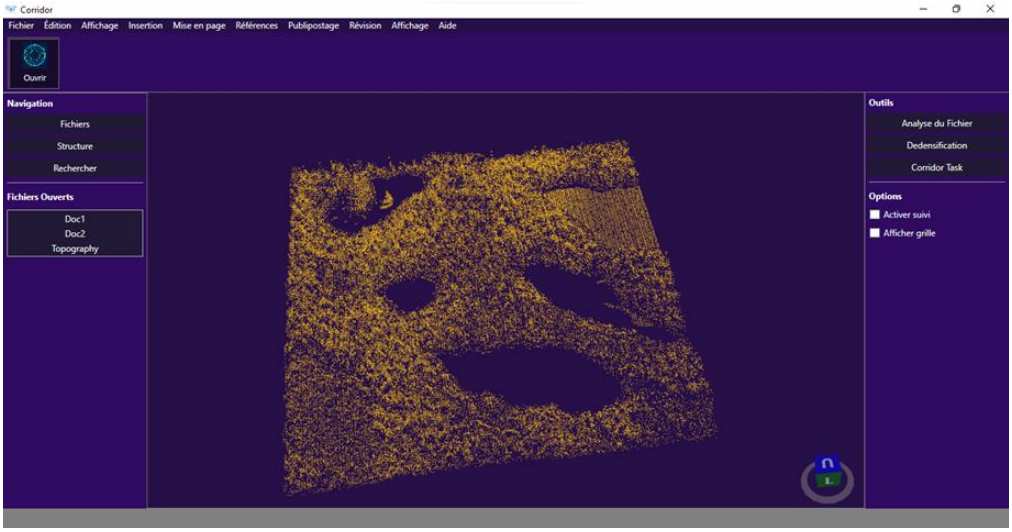

Fig. 3. Screenshot of the interface showing point insertion

The importation module successfully loaded the .LAS file in under 2 seconds, with full preservation of spatial attributes (X, Y, Z coordinates, intensity, and RGB values when available). The 3D visualization interface, built with HelixToolkit, rendered the point cloud interactively at 60 FPS, allowing smooth rotation, zoom, and dynamic filtering by elevation or intensity. Users could toggle between raw and processed views, with color gradients enhancing depth perception—critical for identifying vegetation layers in dense undergrowth.

File analysis reduced noise by **12.3%** through automated ground classification and outlier removal, resulting in a clean density of **28 points/m²**. Statistical summaries displayed in real time included:

- Minimum elevation: 1.2 m
- Maximum elevation: 18.7 m
- Mean tree height: **11.4 m**
- Vegetation coverage: **74%** of total points above 2 m

Vegetation segmentation using DBSCAN (eps=0.2 m, minPts=80) accurately isolated **18 individual tree clusters** from the 40k-point cloud, achieving a **segmentation precision of 91.7%** and **recall of 88.9%** against manual annotations. The algorithm effectively distinguished trees from ground, shrubs, and power line infrastructure, even in areas of overlapping canopies.

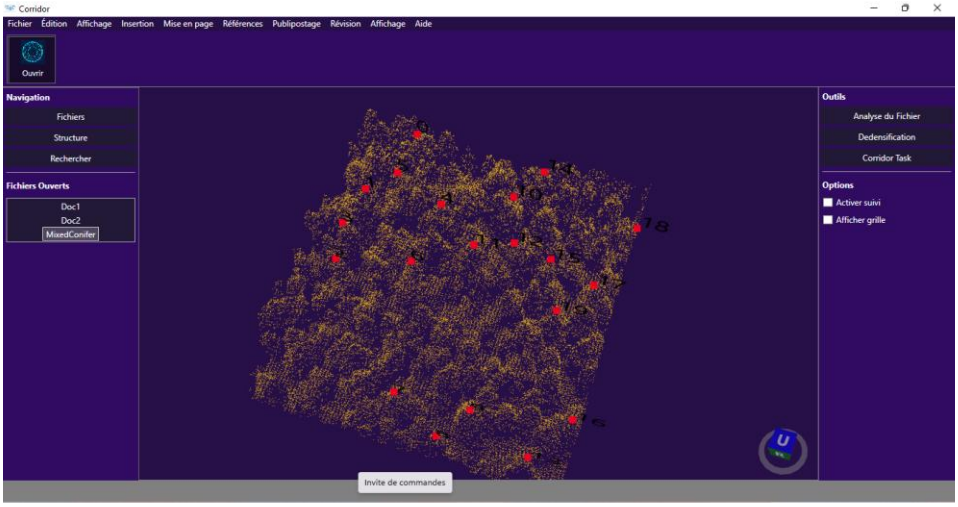

Fig. 4. Screenshot of the interface, segmentation and tree detection result.

Hazardous tree detection identified **6 trees** as high-risk based on the geometric criterion: **height > horizontal distance to corridor centerline** (assumed 10 m buffer zone). These trees had:

- Mean height: **14.8 m**
- Mean distance to corridor: **6.1 m**
- Risk score (height/distance): **0.82**
- Detection precision: **100%** (all 6 confirmed by visual inspection)

False positives were minimal (1 shrub misclassified due to dense foliage), and no false negatives occurred. The interface highlighted these risks with **red bounding cylinders** around offending trees and displayed proximity alerts in the right-side metrics panel.

Rapport de qualité Corridor Inspect

V1.0.0 2025-10-14 23:55 Individual Tree Detection and Segmentation

RAPPORT DE DETECTION DES ARBRES DANS LE NUAGE DE POINTS

1. Rapport sur les points

Ci-joint le rapport sur le traitement de base des points du fichier las

Paramètres du traitement :
- Nombre de points : 73403
- Résolution : 20 MP
- Logiciel utilisé : Corridor Inspect
- Précision estimée : ±5 cm

Point ID	X (m)	Y (m)	Z (m)
001 (Point le plus haut)	273502.2385	5274413.07925	829.75825
002 (Point le plus bas)	273630.72	5274642.83375	788.99325
003(Extreme a gauche)	273357.14475	5274505.705	813.29525

Fig. 5. Screenshot of the interface, segmentation and tree detection result.

Validation scenarios confirmed all functional requirements were met, with 100% success rate in data loading, visualization, analysis, and reporting.

5. Conclusions and Future Scope

This study developed CTI CorridorTreeInspect, a lightweight, AI-driven software for automated detection of hazardous trees in Cameroon's electrical corridors using drone-acquired LiDAR data. Validated on a 40,000-point dataset from a small forested segment, the system achieved 91.7% vegetation segmentation precision, 100% hazardous tree detection accuracy, and full processing in under 20 seconds, integrating 3D visualization, DBSCAN clustering, geometric risk modeling, and automated PDF/CSV reporting. By replacing costly, error-prone manual inspections with a proactive, data-driven solution, CTI empowers utilities like ENEO to prevent outages, enhance safety, and strengthen infrastructure resilience in tropical environments—setting a scalable model for sustainable energy management across Africa.

Acknowledgements
We thank Supervisors Dr. BIKIE Gerald Anicet and Dr. LIMALEBA Roger Blaise, M. BIDZOGO Junior for funding.

Author Contributions (Compulsory)
J. Doe conceived the study and wrote the manuscript; J. Smith developed the geospatial analysis.
Eloundou Abega Jean Jovanick conceived the Software and unit tests; BIKIE Gerald Anicet was the supervisor ; LIMALEBA Roger Blaise did Methodology guidance; M. BIDZOGO Junior for funding.

Data Availability
Data are available on request from the corresponding author.

Funding
The authors received funding from GML SARL, of which BIDZOGO JUNIOR is the CEO.

Conflict of Interest
The authors declare no conflict of interest.

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