

Ecogrid: A serverless AWS solution for vegetation encroachment severity evaluation using contour detection and area ratio algorithm with open-source satellite imagery

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Abstract

Vegetation encroachment is an issue faced by power grids due to trees and plant growth, which is harming grid components. This study proposes a system that takedown high-resolution satellite imagery from Google Earth Engine (GEE) based on target corridors established with Open Street Map (OSM) data. Effective imagery analysis results in a preprocessing step comprising cropping, color conversion, and additional inversion, which also analyzes the images by using contour detection and area calculations to quantify vegetation encroachment and categorize severity zones. With ReactJS and Leaflet, we build an interactive web dashboard for stakeholders to visualize these zones classified by the robust algorithm in real time to see the severity of vegetation. Data are stored and retrieved using a database and Flask Application Programming (API) in the backend. The research concluded that Serverless Image Processing Architecture with Amazon Web Services (AWS) Lambda for Cost Efficiency and Future Data Scalability is achieved. This will equip stakeholders with the information they need for better decisions when proactively managing vegetation. This monitoring system helps ensure the safe and reliable operation of the power grid.

Keywords

Satellite Image Analysis, Google Earth Engine, Open Street Map, Serverless Vegetation Monitoring, Web Dashboard

1. Introduction

Continuous supply of electricity is the lifeline of the modern world. This essential work is done through a web of connected electric wires called a grid [1]. To keep the current flowing through these complex networks, constant monitoring and maintenance are required. Vegetation encroachment along grid line corridors is one of the biggest challenges faced by grid operators. This is also true here, where the growth of trees, shrubs, and other forms of vegetation near power lines can jeopardize the safe and

reliable operation of the power grid [1, 4]. Does monitoring vegetation encroachment usually involve manual checks? This approach, however, has a variety of weaknesses. Manual inspections are labor-intensive and time-consuming and tend to be insufficient on account of the great distances required to be covered in several grid networks [1]. Luckily today, technology has advanced to present solutions to this problem.

Remote sensing and image processing methods: Based on the high-resolution satellite image from remote sensing satellite platforms such as Google Earth Engine (GEE), these are also a revolutionary

method to monitor vegetation intensity encroachment. Using satellite images, grid operators can learn more about vegetation along grid corridors and identify and map potential issues proactively [1, 3].

Advanced image processing techniques, driven by intricate algorithms, magnify the potential of satellite imagery. Some of the vegetation encroachment features that these algorithms can automatically find and measure the amount of vegetation cover in the corridor are identified [1, 3]. Such automated processes can substantially decrease the burden of collecting vegetation monitoring data and facilitate a more holistic, consistent evaluation of risk factors.

a. Design and data

Web development technologies are indispensable in presenting the information derived from satellite imagery and image processing in an actionable, user-friendly manner. Utilizing custom web-based dashboards alongside multiple data sources is made possible using these technologies. These dashboards can include:

- Satellite image of the grid corridors (high resolution).
- Data on zones of vegetation severity processed.
- Interactive maps, enabling users to navigate to areas of interest.

These dashboards, which are driven by web interfaces, provide stakeholders with the ability to access real-time information on vegetation encroachment further down the pod and throughout the network grid. This enables better decision-making on vegetation control methods and resource allocation.

b. Benefits of web-based dashboards for vegetation encroachment monitoring

Web-based dashboards have several significant advantages for monitoring vegetation encroachment:

- Increased efficiency and accuracy: Automating vegetation detection from satellite images and image processing considerably lessens dependence on manual inspections, resulting in enhanced efficiency and accuracy in vegetation monitoring.
- Real-time monitoring: Web-based dashboards allow the stakeholders to view real-time data on vegetation encroachment across the entire grid network. This real-time visibility

enables proactive identification and mitigation of potential hazards.

- Enhanced decision-making: The information shown on the dashboards provides stakeholders with the relevant data necessary for making informed decisions about vegetation control approaches and resource distribution, which enables more focus and cost minimizing vegetation management gearing practices.
- Enhanced communication and collaboration: Web-based dashboards can act as a central hub for communication and collaboration among different stakeholders in the grid management process. This enables a more coordinated response to vegetation control, which can provide increased overall grid reliability.

Related studies on vegetation encroachment monitoring: The research project is based on a solid foundation of prior research in vegetation encroachment monitoring for power grids. A few key examples of what the state of the art can do currently include:

- The study used satellite images and support vector machines to detect vegetation growth in energy carrier corridors [1]. This reveals the power of satellite imagery in detecting vegetation at scale.
- A useful dataset is called VEPL, a vegetation encroachment in power line corridor, which uses drone aerial imagery [2]. This resource can help train and refine machine learning algorithms for vegetation detection [2].
- Land cover classification is crucial for managing power line corridors using big and open satellite imagery data [3]. Their research emphasizes the almost ubiquitous availability of satellite data for holistic vegetation monitoring [3].

c. Research project details

This research is based on satellite imagery and image processing for vegetation encroachment monitoring. But, as noted above, a number of complementary technologies exist and can be implemented as part of a holistic grid management approach.

II. Literature Review

Reliable electricity delivery is the backbone of modern societies. Power grids—networks of interconnected

transmission lines—underlie this critical infrastructure. Yet, if vegetation encroaches on their designated rights-of-way (ROW), and it almost always does, the operation of those lines can be compromised. One major danger of vegetation overgrowth in these egress corridors is the potential for power outage, financial loss, or worse, safety hazards. The role of vegetation encroachment on transmission line infrastructure is examined along with the challenges it presents and various detection and monitoring methodologies underscored in this review.

Historically, utility companies have depended on a host of time-tested methods to track vegetation growth in proximity to power lines. While accurate data on vegetation characteristics can be obtained at a high cost from these methods, upscaling is limited.

LiDAR stands for Light Detection and Ranging and uses pulsed laser beams to provide very detailed 3D models of terrain and vegetation. These LiDAR data can help accurately measure the height of vegetation to assess the potential for encroachment on power lines. LiDAR surveys can be very accurate but also expensive and may cover large areas of transmission line corridors [1, 5].

Unlike LiDAR, which uses laser light, Synthetic Aperture Radar (SAR) uses microwave pulses to scan the Earth's surface. It analyzes the signals that bounce back to create detailed maps, even through clouds or in poor weather conditions. SAR is a suitable technique for vegetation mapping when hindering weather conditions. Nevertheless, SAR data comprising complex amplitude and phase information must be processed with high expertise, making their implementation more complex [4, 6].

Airborne photogrammetry allows one to take aerial photographs and creates 3D models of the landscape using specialized software. Airborne photogrammetry is more cost-effective than LiDAR for vegetation monitoring over great distances. Its capacity to measure vegetation height could, however, be less accurate than LiDAR [4].

Of the above techniques, the former two yield important information in vegetation management. Alternatively, LiDAR, despite its precision, is expensive, and SAR data are complex to process, limiting their wide-reaching application; hence, new methods must be formulated for effective comprehensive monitoring. This need for vegetation encroachment detection at a reduced cost and scalable approach has led to the evolution of modern technologies. Emerging approaches provide utilities with options for the maintenance of vegetation near power lines.

Satellite imagery is a low-cost, large-scale monitoring tool of vegetation. High-density vegetation zones

adjacent to power lines have been classified into satellite images using statistical properties of color spaces and computed textural features by the researchers. This is a promising method for high-throughput monitoring but may need more development to achieve comparable screen-to-hit ratios seen with conventional approaches [1, 5]. Drones, also known as unmanned aerial vehicles (UAVs), are used readily for many applications, including monitoring vegetation. These maps focus on sections of transmission line corridors, offering significant market value. Their mobility and flexibility enable the capture of high-precision images and videos. This can be facilitated by applying deep learning algorithms to analyze UAV imagery, significantly reducing the burden on the manual detection of vegetation encroachment. By reducing or even eliminating reliance on the aforementioned manual approaches, it can vastly improve the speed and efficiency of monitoring strategies [2].

The convergence of these novel technologies with existing practices has a great potential for vegetation management. The future of vegetation encroachment detection will likely involve a multifaceted approach that incorporates the strengths of multiple technologies. From the effective disease treatment perspective, here are some areas of ongoing R&D:

- **Multisource data fusion:** Merging data from LiDAR, satellite imagery, and UAVs can provide a fuller understanding of vegetation growth. LiDAR provides very accurate height data though satellite imagery covers more of the area. Targeted inspections of identified risk zones can be performed by UAVs. When fused together, these sources of data can provide utility companies with a more robust monitoring methodology [4].
- **Enhanced machine learning approaches:** Utilizing deep learning algorithms for detecting vegetation intrusion from UAV imagery has yielded significant promise. These algorithms can therefore be trained on large volumes of labeled images, thereby making them able to correctly classify vegetative features. This allows them to reduce their dependence on manual analysis, which may be time-consuming and error-prone [2].
- **Standardized datasets:** Creating open-source datasets specifically for training deep learning models for vegetation encroachment detection is vital. These datasets would enable researchers to easily and usefully access standardized data for developing and refining their algorithms. This would speed up

research work and thus increase efficiency in vegetation management solutions [2].

a. Additional research on complementary monitoring techniques

Though satellite imagery combined with an image processing pipeline represents the primary focus of this Public Service Utility/ Common Service Centre (PSU/CSC) research effort, it is worth noting that other complementary technologies can also advance the monitoring of vegetation encroachment around power lines. Some examples include:

- **LiDAR:** The study compares the methods of estimating individual tree height and explores the difference between LiDAR and digital aerial photogrammetry (DAP) [5]. LiDAR technology uses pulsed laser light to create high-precision three-dimensional (3D) point clouds of the Earth's surface. By accurately measuring the heights of trees in a power line corridor, these dense 3D data become quite valuable in determining how much of a potential vegetation encroachment hazard the tree net presents.
- **DAP:** The research describes the use of DAP for tree height estimation [5]. Due to this limitation, UAV methods provide unique DAP capability that can be done by getting a series of overlapping aerial photographs taken from different perspectives and later on processed to build a 3D image of the vegetation and terrain. DAP provides lower accuracy than LiDAR but can provide a more cost-effective solution for 3D data acquisition in certain scenarios.
- **High-voltage direct current (HVDC) transmission lines:** The research explores monitoring technologies for HVDC transmission lines [6]. Although the basic principles of monitoring vegetation encroachment are similar for HVDC lines, there may be some special considerations. Hence, the awareness of these aspects and potential uses of monitoring technologies such as satellite imagery and LiDAR in the scope of HVDC grids is an interesting research trail.
- **Machine learning for forest height estimation:** The study used machine learning and satellite data combined with GEE for forest height estimation [7]. This research suggests the potential of applying machine learning algorithms on satellite imagery to extract information about forests, such as tree height.

Concerning power line corridors, especially in forested regions, these data could be valuable for evaluating vegetation encroachment.

- **Sag control methods:** Sag monitoring methods were surveyed for power grid transmission lines, which can be auxiliary to vegetation encroachment monitoring [8]. Sag is the vertical deflection felt by a power line due to its own weight, tension, and weather. Too much sag raises the risk that power lines will contact vegetation, which can ultimately cause outages and pose safety risks.

The inclusion of vegetation encroachment in sag inspection will only lead to increased sag, and thus independent sag monitoring of transmission lines for their overall integrity is required. It discusses different sag monitoring techniques, such as:

- **String vibration analysis:** It analyzes the vibrations of the power line to determine its tension and sag.
- **Overhead power line factors with sagging:** To estimate the electrical characteristics and sag of the overhead power line, an overhead traveling wave is used, which is generated by switching events on the power line.
- **Sensors for direct measurement:** Physical sensors may, in certain cases, be attached to the power line to directly measure its sag.
- **Monitoring vegetation encroachment could be combined with sag** if it were augmented further, giving grid operators a more robust awareness of potential hazards and higher-resolution mitigation plans. This would ensure the use of more efficient and cost-effective vegetation management practices at utility companies. This will also ensure that the power grid can operate safely, reliably, and uninterrupted, protecting the electricity supply that is so vital to modern life.

III. Methodology

a. Data collection

a.i. Establishing the grid network

The objective of this research was the development of a web-based vegetation incursion dashboard to help monitor vegetation encroachment along grid line corridors. A large piece of this puzzle was getting satellite images for the target grid network. Ideally, this would have been by far the most effective method if

geo-referenced (latitude and longitude pegged) satellite images had already existed. Since information of such level is not easy to obtain, a different strategy for data collection was adopted. This study's approach benefited from the synergistic use of two public web resources: Open Street Map (OSM) API and GEE. (1) We used the OSM API to extract the spatial coordinates of power towers along the grid corridor. These coordinates were then used as the basis for the grid network offer. We then used Google Earth to make a visualization of the grid network. This visualization helped describe where the corridor edges were. Then, we used GEE to request high-resolution satellite image snapshots of the defined grid corridor. This data collection method ensures that the satellite imagery collected is specific to the target grid

network. The dataset we developed formed the foundation for subsequent stages of this research, which led to the final output of a web dashboard for monitoring vegetation encroachment severity in a water treatment region (Figures 1–4). The aim of this research was to develop a web-based vegetation encroachment monitoring dashboard for grid line corridors. The methodology adopted consists of the following systematic steps:

Step 1: Define the objective and study region

- The goal was to monitor vegetation encroachment along power grid corridors using satellite imagery.
- A specific geographical region (in a water treatment area) was selected as the study zone.



Figure 1: Data preprocessing ROI extraction by cropping. ROI, region of interest.

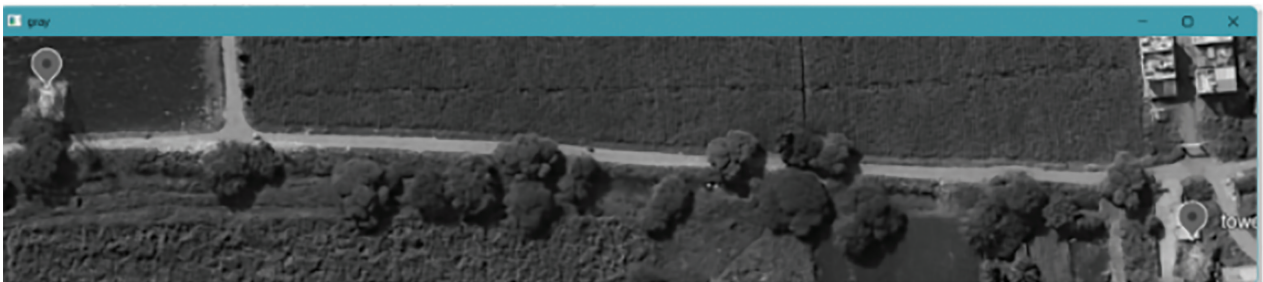


Figure 2: Color conversion from RGB to gray scale. RGB, red, green, blue.



Figure 3: Binary inversion of the image in gray scale.

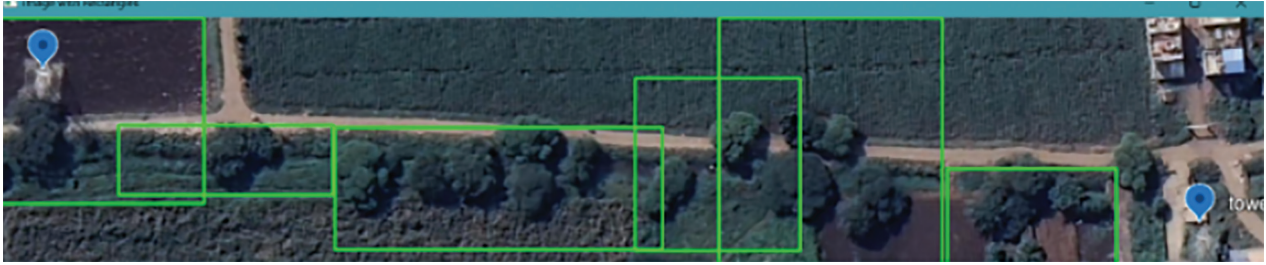


Figure 4: Vegetation cover detected in the image.

Step 2: Extract grid network coordinates

- Utilized OSM API to extract spatial coordinates (latitude and longitude) of power towers along the grid corridor.
- These coordinates formed the structural framework of the grid network.

Step 3: Visualize grid corridor edges

- Imported the extracted coordinates into Google Earth to visually trace and define the boundaries of the grid corridor.
- This step helped to clearly demarcate the area of interest for vegetation monitoring.

Step 4: Acquire high-resolution satellite images

- Leveraged GEE to request high-resolution satellite snapshots of the predefined grid corridor.
- This ensures the satellite imagery was geo-referenced and specific to the target corridor.

Step 5: Build the dataset

- Compiled and organized the satellite imagery along with spatial metadata (coordinates, timestamps).
- This dataset became the foundation for all subsequent processing and analysis steps in the research.

This methodological approach, in combination with OSM API, Google Earth, and GEE, provided a reliable and scalable way to collect geographically relevant satellite imagery for vegetation monitoring, forming the core input for the web-based dashboard.

b. Data preprocessing

After extraction of the corridor of interest once satellite images were obtained from GEE, the next step was to preprocess the data to prepare them for further analysis. This stage of preprocessing aimed at isolating the region of interest (ROI)—the corridor between the power towers containing the grid line—and converting the image data into a format ready for

the detection of vegetation encroachment. The preprocessing pipeline included three main steps:

- **ROI extraction:** The GEE_initial image from which one captured imagery was likely much wider than just the grid line corridor. To solve this, we used image cropping techniques based on OpenCV (OpenCV.org and open-source community), a widely used library for computer vision tasks. It accurately cropped out the pixels in the wide field of view image to only those pixels that contained the narrow vertical corridor between the power towers. The defined image was set to a narrow aspect ratio to prevent focusing on anything but the ROI for monitoring vegetation encroachment. Figure 1 shows the data preprocessing ROI extraction by cropping. The satellite images one receives from GEE might have been in Red, Green, Blue (RGB) color space. RGB is fine for visualization but not necessary for vegetation. Therefore, a conversion to gray scale was used. Figure 2 demonstrates color conversion from RGB to gray scale. The data were then transformed into a 1D array of pixels with each pixel being represented by a single number for intensity to remove redundant color information.
- **The post-processing step** potentially used after gray-scale conversion is an image inversion (Figure 3) where the pixel values of the image are inverted. This inversion process reversed the pixel density values and thus rendered a bright vegetation dominance image into a dark vegetation domination image. Whether to use image inversion would be written on the specific vegetation detection algorithm used in the next step (Figure 4). With the preprocessing, the raw satellite images were suitable for detecting vegetation encroachment in the grid line corridor. This resulted from the algorithm on their severity

detection in order to help the web dashboard monitor the vegetation cover.

- **Severity detection algorithm:** Once the preprocessing of vegetation from satellite imagery to crop grid corridor and vegetation pixels from satellite imagery is completed, step 2 is focused on developing a robustness severity detection algorithm. This algorithm was meant to quantify the degree of vegetation encroachment along the corridor and would feed its way into the web dashboard, allowing for visual indications of severity. The approach of using a research paper took advantage of contour detection, a popular computer vision technique. For the binary-inverted images that have been preprocessed, a dark pixel represented vegetation cover. Thus, by implementing contour detection algorithms, it became possible to group together areas of contiguous dark pixels, effectively outlining the detected sections of vegetation within the corridor. A separate step to create bounding boxes was added after each detected vegetation part. This generates a rough rectangle around each vegetation contour on the image. These bounding boxes served as a way to account for the size of each block of vegetation. We used a ratio-based metric of area ratios to quantify the severity of vegetation encroachment within the grid corridor.

b.i. Severity detection algorithm—step-by-step

Step 1: Satellite image acquisition and preprocessing

- Acquire satellite images along the grid corridor.
- Preprocess images to:
 - Enhance vegetation features.
 - Isolate the grid corridor.
 - Convert to binary-inverted format where vegetation is marked as dark pixels (foreground).

Step 2: Contour detection

- Apply contour detection algorithms (e.g., OpenCV's findContours) on binary-inverted images.
- This step identifies contiguous regions of dark pixels representing vegetation patches.

Step 3: Bounding box generation

- For each detected contour (vegetation patch):
 - Generate a bounding box (minimum rectangle enclosing the patch).
 - Store bounding box coordinates.

Step 4: Area calculation

- Calculate the area of each bounding box (vegetation patch area).

- Determine the total area of the grid corridor (predefined or computed).

Step 5: Severity metric computation

- Compute vegetation encroachment severity as:

$$\text{Severity Score} = (\text{Sum of all vegetation patch areas} / \text{Total grid corridor area}) \times 100$$

Step 6: Severity level classification

- Based on the severity score, classify encroachment into categories:
 - Low: 0–30%
 - Moderate: 31–60%
 - High: >60%
- (Thresholds can be domain-specific and adjustable.)

Step 7: Data storage

- Store results (e.g., image ID, bounding box data, severity score, classification) in the Amazon relational database service (RDS) database.

Step 8: Visualization

- The processed severity data is displayed on the flask-powered web dashboard.
- Users can interactively view vegetation encroachment severity overlaid on the map.

This method mathematically mapped how much vegetation cover was within the corridor in relative terms. The main calculation was performed as shown in Figure 5.

Area calculation: The area of each individual vegetation bounding box was computed.

Total area determination: The total area of the preprocessed image, representing the entire grid corridor, was calculated.

Ratio computation: The severity detection algorithm then computed the ratio between the sum of the areas of all individual vegetation bounding boxes and the total area of the preprocessed image.

This ratio can be mathematically expressed as:

$$\text{Severity ratio} = (\sum (\text{Area of Vegetation Bounding Box}_i)) / \text{Total Area of Image} \quad (1)$$

where “ Σ ” represents the summation over all “i” detected vegetation segments.

The resulting severity ratio is a numerical value ranging from 0 to 1. This inherent range provided a convenient basis for defining severity thresholds.

By establishing predefined thresholds, the algorithm categorized the level of vegetation encroachment

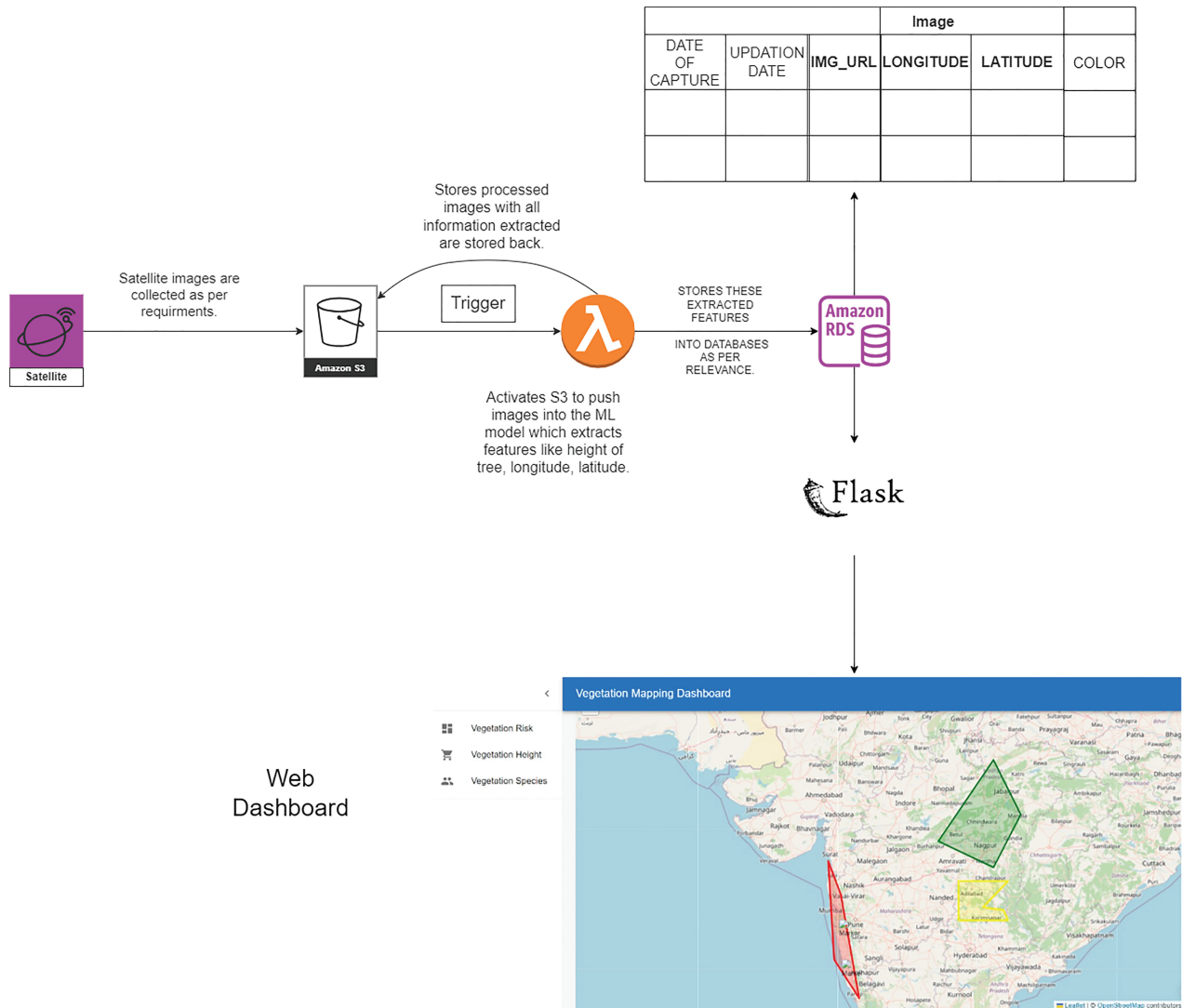


Figure 5: Serverless system architecture for vegetation detection system.

into three distinct zones for visualization on the web dashboard:

- **Blue zone (least severe):** If the severity ratio is less than 0.3, the corridor segment is classified as having minimal vegetation encroachment, represented by a blue zone on the dashboard.
- **Yellow zone (medium severe):** A severity ratio between 0.3 and 0.55 indicates moderate vegetation encroachment, visualized as a yellow zone on the dashboard.
- **Red zone (most severe):** Severity ratios exceeding 0.55 signify a critical level of vegetation encroachment, depicted as a red zone on the dashboard. This severity detection algorithm, based on area ratios and predefined thresholds,

effectively transformed the raw image data into a quantifiable measure of vegetation encroachment. This information subsequently fueled the creation of a user-friendly web dashboard for visualizing and monitoring vegetation cover along the grid line corridor.

IV. Results

a. Web dashboard development: Visualizing vegetation encroachment

The culmination of the research involved the development of a user-friendly web dashboard to effectively visualize the severity of vegetation encroachment

along the grid line corridor. This dashboard served as the primary interface for stakeholders to monitor and assess vegetation cover within the grid network.

b. The web dashboard development process can be segmented into three key components

b.i. Frontend development

Focusing on user interaction and visual representation, the frontend utilized the ReactJS (Meta Platforms, Inc.) framework. This popular JavaScript library facilitated the creation of a dynamic and interactive interface. Additionally, Leaflet (Creator: Vladimir Agafonkin, now maintained by contributors on GitHub), a renowned JavaScript library specifically designed for interactive maps, was integrated. By leveraging Leaflet, the dashboard seamlessly incorporated a map visualization of the grid corridor. The combined power of ReactJS and Leaflet enabled the dynamic display of key information on the map, including starting and ending latitude/longitude coordinates of each grid segment (obtained from OSM) and color-coded representation of vegetation encroachment severity along the corridor (derived from the severity detection algorithm).

b.ii. Backend development

To effectively manage and store the data utilized by the dashboard, a relational database management system was employed. This research paper employed MySQL (Oracle Corporation), a widely used open-source relational database system. Within the MySQL database, a dedicated table was designed to store the following critical data points:

- Latitude and longitude coordinates of the starting and ending points of each grid segment.
- Color code corresponding to the vegetation encroachment severity level for each segment.

b.iii. API integration

To establish a bridge between the frontend user interface and the backend database, a Flask API was implemented. This lightweight web framework, written in Python, facilitated the retrieval of data stored within the MySQL database. By incorporating the Flask API, the frontend could dynamically request and display the necessary information on the web dashboard. Furthermore, the API facilitated the seamless

integration of any updates to the database, ensuring the dashboard reflects the latest vegetation encroachment data. The culmination of these development efforts resulted in a dynamic and informative web dashboard. This user-friendly interface provided stakeholders with a clear and comprehensive visualization of vegetation encroachment severity along the grid line corridor. The serverless deployment of the backend functionalities further enhanced the system's efficiency, guaranteeing instant updates on the dashboard whenever new satellite images are processed. This web dashboard serves as a valuable tool for proactive monitoring and informed decision-making regarding vegetation management within the grid network.

b.iv. Deployment: Streamlining vegetation monitoring with serverless architecture

The final stage of this research involved effectively deploying the developed system, culminating in a dynamic web dashboard for vegetation encroachment monitoring. To achieve this, we embraced a serverless approach, leveraging the power of AWS Lambda for image processing and data storage. This deployment strategy offered several advantages, including scalability, cost-efficiency, and streamlined maintenance. When a satellite image is uploaded to an S3 bucket, the Lambda function extracts metadata (e.g., size and timestamp) and stores it in an RDS database.

Here, we delve into the key components of the deployment process:

Event-driven image processing: Amazon S3 served as a data lake in this research, acting as a central repository for user-uploaded satellite images. A trigger mechanism was established between S3 and AWS Lambda (Figure 6). Whenever a new image was uploaded to S3, it triggered the activation of a predefined Lambda function. This function housed the core vegetation encroachment detection algorithm, methodically processing the uploaded image.

Containerized function deployment: To ensure seamless deployment within the serverless environment, we meticulously addressed function dependencies. A Docker container provided a Linux-based environment to install all necessary packages and modules required for image processing.

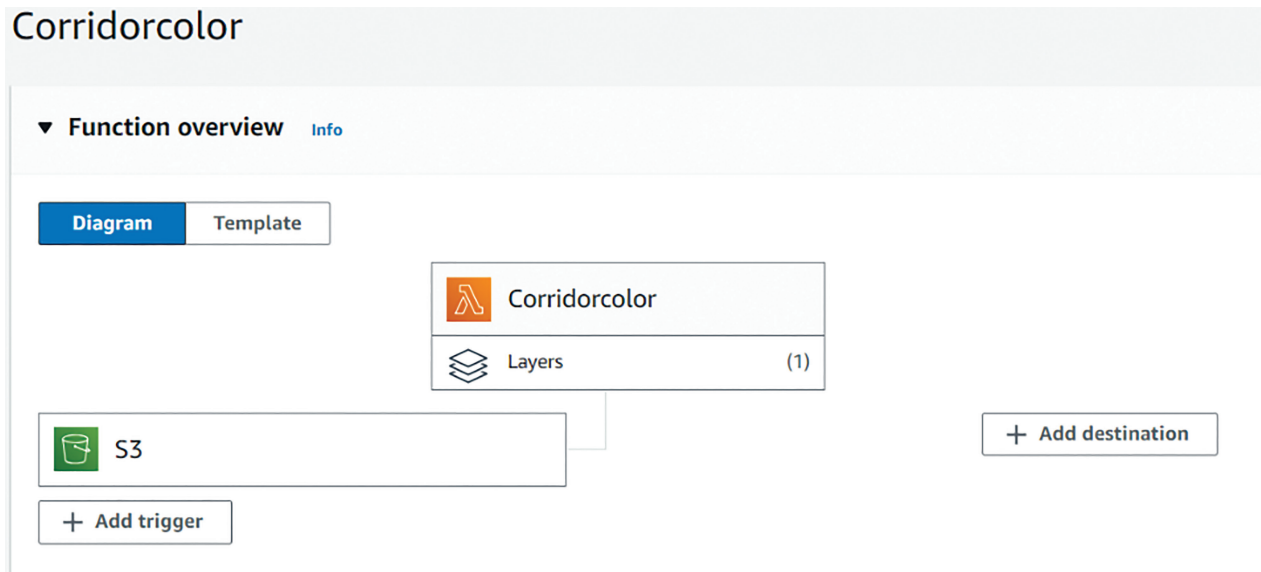


Figure 6: S3 bucket event triggering Lambda function for monitoring.

Leveraging Docker, proposed work has meticulously constructed layers for AWS Lambda, essentially reusable code segments within the Lambda function. These layers optimized deployment efficiency and minimized cold start times. Following layer creation, we configured them to be compatible with the specific AWS Lambda execution environment.

Database integration: The processed results, generated by the Lambda function containing vegetation encroachment severity data, needed to be persisted for subsequent visualization on the web dashboard. To achieve this, we utilized Amazon RDS in conjunction with MySQL Workbench. A dedicated MySQL database server was established within RDS, hosting a specifically designed table. This table comprised the following attributes:

- `img_id` (primary key): Unique identifier for each uploaded image
- `starting_lat_long`: Starting latitude and longitude coordinates of the grid segment
- `ending_lat_long`: Ending latitude and longitude coordinates of the grid segment
- `severity`: Encroachment severity level for the segment (color code).

To populate this database table with the processed results, a subsequent Lambda function was implemented. This function utilized the `mysql-connector` library to facilitate seamless

interaction with the MySQL database. The first Lambda function, responsible for image processing, was configured to invoke this second function upon completion. This chained invocation ensured the processed data, including severity information, was effectively stored within the database as shown in Figure 7.

Serverless backend and API integration: This validates serverless backend and API integration image uploaded in the S3 bucket (Figure 8). As previously discussed, the backend components, including the database (deployed on AWS RDS) and the API for the web dashboard, were also deployed using a serverless approach on AWS Lambda. We employed Flask, a lightweight web framework, to construct the API responsible for fetching data from the database. This API seamlessly integrated with AWS API Gateway, establishing a trigger mechanism. Whenever the API was triggered (such as by a request from the web dashboard), the corresponding Lambda function would execute, retrieving the latest vegetation data from the database (Figure 9).

Flexible frontend deployment: The frontend user interface of the web dashboard could be deployed using various AWS services such as AWS Beanstalk. This flexibility allows developers to choose the deployment method that best suits their specific needs and preferences. By adopting a serverless architecture with AWS Lambda at its core, we successfully deployed a dynamic and scalable vegetation

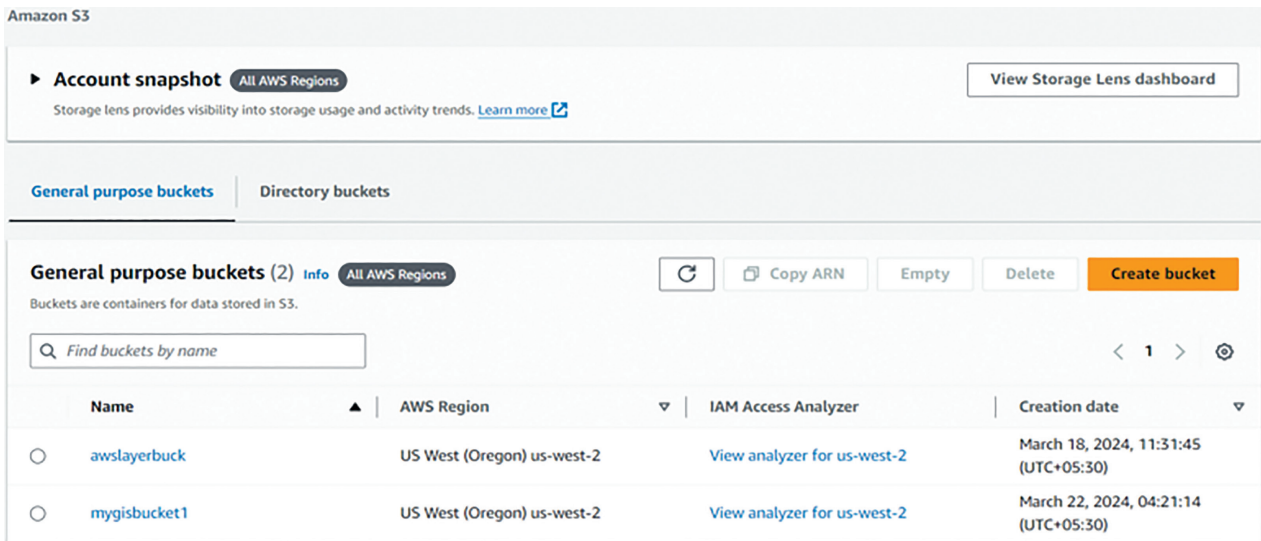


Figure 7: Snapshot of S3 bucket used as a data lake.

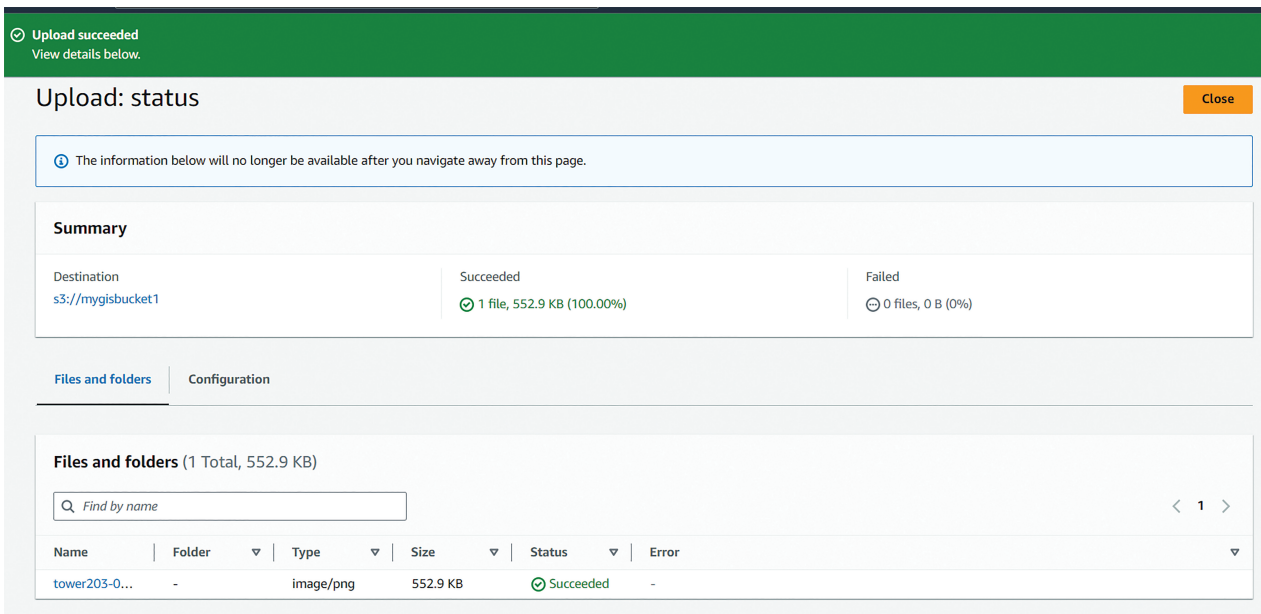


Figure 8: Image uploaded in the S3 bucket.

monitoring system. This approach facilitated efficient image processing, streamlined data storage, and cost-effective backend operations. Ultimately, this deployment strategy contributed significantly to the creation of a user-friendly and informative web dashboard, empowering stakeholders with real-time insights into vegetation encroachment along the grid line corridor (Figure 10).

V. Conclusion

This research successfully developed a web-based dashboard system for monitoring vegetation encroachment along grid line corridors. To avoid the limitations on acquiring already existing NASA's Advanced Topographic Laser Altimeter System (ATLAS) satellite image data, we proposed a method for data collection using OSM and GEE. A preprocessing stage was

Log events		Actions	Start tailing	Create metric filter
You can use the filter bar below to search for and match terms, phrases, or values in your log events. Learn more about filter patterns				
Filter events - press enter to search		Clear	1m 30m 1h 12h Custom	Local timezone Display
Timestamp	Message			
No older events at this moment. Retry				
2024-04-12T10:55:32.656+05:30	INIT_START Runtime Version: python:3.10.v29 Runtime Version ARN: arn:aws:lambda:us-west-2::runtime:5ef29c5e36f6669db12fb1f93...			
2024-04-12T10:55:33.614+05:30	START RequestId: 35fe8699-a8ba-4ad6-9bde-20dc56972fdf Version: \$LATEST			
2024-04-12T10:55:35.196+05:30	Dimensions of the rectangle: 76 x 90			
2024-04-12T10:55:35.196+05:30	Dimensions of the rectangle: 146 x 92			
2024-04-12T10:55:35.196+05:30	Dimensions of the rectangle: 242 x 111			
2024-04-12T10:55:35.196+05:30	Dimensions of the rectangle: 113 x 67			
2024-04-12T10:55:35.198+05:30	Dimensions of the rectangle: 109 x 176			
2024-04-12T10:55:35.237+05:30	Dimensions of the rectangle: 212 x 182			
2024-04-12T10:55:35.237+05:30	blue			
2024-04-12T10:55:35.275+05:30	END RequestId: 35fe8699-a8ba-4ad6-9bde-20dc56972fdf			
2024-04-12T10:55:35.275+05:30	REPORT RequestId: 35fe8699-a8ba-4ad6-9bde-20dc56972fdf Duration: 1661.05 ms Billed Duration: 1662 ms Memory Size: 128 MB Max...			
No newer events at this moment. Auto retry paused . Resume				

Figure 9: CloudWatchLogs: Severity color detected by algorithm as blue.

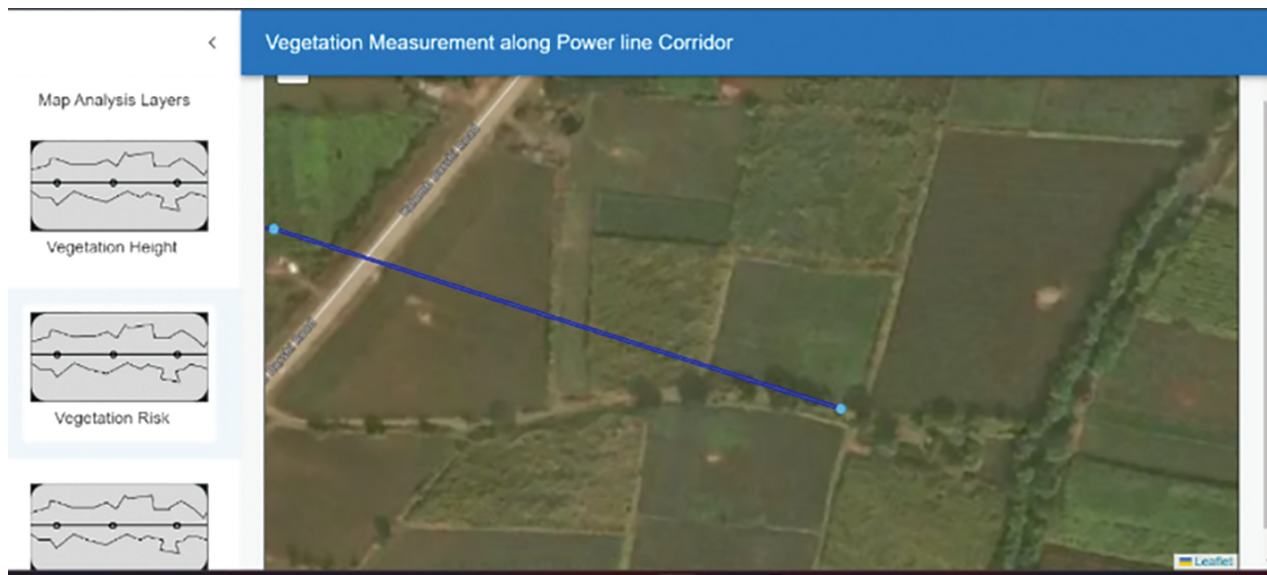


Figure 10: Power grid corridor marked as blue on the web dashboard.

carried out to refine the satellite imagery by extracting the girdle corridor and creating the data for the context of vegetation analysis. Excavating the severity detection algorithm formed the center of the system, utilizing contour detection and ratio of area calculations to identify the level of encroachment of vines.

The outcome of all these was the creation of a simple web dashboard. The dashboard, developed with a ReactJS frontend and a serverless backend deployed via AWS Lambda, provided a dynamic and informative interface. Stewards were able to see color-coded segments on a map that conveyed important

information about the severity of vegetation encroachment along the grid corridor.

This not only makes a novel approach to vegetation monitoring in grid networks but also proves that such applications could be successfully solved with serverless architecture. The proposed approach correctly returns the severity of encroachment for 80% of the images but there is still potential for improvement of smudgy pictures and detection of dark shades as vegetation. One can only imagine that the flexible, cost-effective, and low-maintenance nature of serverless deployment could have a massive role to play in the evolution of environmental monitoring systems in the future.

VI. Future Scope

Based on the success of this research, there are many pathways for future research:

- Advanced vegetation classification involves separate vegetation cover from background. More advanced algorithms for categorizing various vegetation classes in the corridor could be integrated into future versions.
- Integration of machine learning: Machine learning methodologies can be utilized to enhance the severity detection algorithm, which may improve the accuracy and adaptability to varying environments.
- User-Prompted Images: The current system also allows users to upload their own images for processing. Future work may use these data to incorporate real-time satellite data feeds in order to provide near instant monitoring and early warning systems to detect encroaching vegetation.
- Mobile application development: This can be done by providing the functionalities of the web dashboard into a mobile application, ensuring user accessibility whenever and wherever they are and enabling monitoring efforts that require field staff to be on the ground.

Implementing these technologies will improve the functionality of the vegetation monitoring system and aid in optimizing maintenance for the grid line network and strategic decision-making in vegetation control.

Author Contributions

Sonali Patil: Data Curation, Methodology, Software, Writing—Original Draft; Sonali Kothari: Methodology, Writing—Original Draft, Visualization,

Conceptualization; Devata Anekar: Project administration, Methodology, Writing—Review & Editing; Shweta Koparde: Project administration, Methodology, Funding acquisition, Writing—Review & Editing; Avishkar Patil: Methodology, Supervision, Writing—Review & Editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

References

- [1] Mahdi Elsiddig Haroun, F Mohamed Deros, S.N. Bin Baharuddin, M.Z. Md Din N. Detection of Vegetation Encroachment in Power Transmission Line Corridor from Satellite Imagery Using Support Vector Machine: A Features Analysis Approach. *Energies* (2021), 14, 3393.
- [2] Cano-Solis, M.; Ballesteros, J.R.; Branch-Bedoya, J.W. VEPL Dataset: A Vegetation Encroachment in Power Line Corridors Dataset for Semantic Segmentation of Drone Aerial Orthomosaics. *Data* (2023), 8, 128.
- [3] TxominHermosilla, Michael A. Wulder, Joanne C. White, Nicholas C. Coops. Land cover classification in an era of big and open data: Optimizing localized implementation and training data selection to improve mapping outcomes (2021). *Remote Sensing of Environment* 268 (2022) 112780.
- [4] Leena Matikainen, Matti Lehtomäki, EeroAhokas, JuhaHyypä, Mika Karjalainen, AnttoniJa] akkola, Antero Kukko, TeroHeinonen. Remote sensing methods for power line corridor surveys. *ISPRS Journal of Photogrammetry and Remote Sensing* 119(2016) 10–31.
- [5] Gyawali, A. Aalto, M. Peuhkurinen, J. Villikka, M. Ranta. Comparison of Individual Tree Height Estimated from LiDAR and Digital Aerial Photogrammetry in Young Forests. *Sustainability* (2022), 14, 3720.
- [6] Laninga, J. Nasr Esfahani, A. Ediriweera, G. Jacob, N. Kordi. Monitoring Technologies for HVDC Transmission Lines. *Energies* (2023), 16, 5085.
- [7] Bao, J. Zhu, N. Chen, R. Cui, B. Li, W. Yang. Estimation of Forest Height Using Google Earth Engine Machine Learning Combined with Single-Baseline TerraSAR-X/TanDEM-X and LiDAR. *Forests* (2023), 14, 1953

- [8] Yunfei Chen, Xiaolin Ding. A survey of sag monitoring methods for power grid transmission lines. IET Generation, Transmission & Distribution (2023).
- [9] Deepa P., Venugopal K.R, Sowmya Revanna. Remote Sensing Satellite Image Processing Techniques for Image Classification: A Comprehensive Survey. March (2017) International Journal of Computer Applications 161(11):24-37 DOI:10.5120/ijca2017913306
- [10] Reem M. Hussien, Karrar Q. Al-Jubouri, Mohaimen Al ghuri, Al Gburi Hussein Qahtan, Al HamamiDuaa Jaafar. Computer Vision and Image Processing the Challenges and Opportunities for New Technologies Approach: A paper review August (2021) Journal of Physics Conference Series 1973(1):012002DOI:10.1088/1742-6596/1973/1/012002
- [11] Vincent Lannurien, Laurent D’Orazio, Olivier Barais and Jalil Boukhobza. Serverless Cloud Computing: State of the Art and Challenges May (2023) DOI:10.1007/978-3-031-2661_11
- [12] Yingying Tan and Jiang Chang. The Garden Vegetation Coverage Monitoring and Spatial Analysis Model based on Remote Sensing Technology October (2024) Scalable Computing Practice and Experience 25(6) DOI:10.12694/scpe.v25i6.3429
- [13] Anuradha Yadav, Shivani Shivani, Vijaya Kittu Manda, VikramadityaSangwan, Anna Demkiv. Blockchain technology for ecological and environmental applications July (2024) Ecological Questions 35(4):1-20 DOI:10.12775/EQ. 2024.050
- [14] Flavio Piccoli, Simone Giuseppe Locatelli, Raimondo Schettini and Paolo Napoletano. An Open-Source Platform for GIS Data Management and Analytics April (2023) Sensors 23(8):3788 DOI:10.3390/s23083788
- [15] Fatwa Ramdani, Putri Setiani & Riswan Sianturi Towards understanding climate change impacts: monitoring the vegetation dynamics of terrestrial national parks in Indonesia Springer Nature Scientific Reports August (2024)14(1) DOI:10.1038/s41598-024-69276-9
- [16] Waqas Liaqat, CelaleddinBarutçular, Muhammad U. Farooq, Haseeb Ahmad, Muhammad F. Jan, Zahoor Ahmad, Haq Nawaz and Ming Li. Climate change in relation to agriculture: A review March (2022) SPANISH JOURNAL OF AGRICULTURAL RESEARCH 20(2):e03R01 DOI:10.5424/sjar/2022202-17742
- [17] Ramesh Prasad Bhatt. Impact on Forest and Vegetation Due to Human Interventions October (2022) DOI:10.5772/intechopen.105707