Vegetation Monitoring for High Voltage Transmission and Distribution Line Corridors using Satellite Stereo Images: a Case Study of Isingiro District.

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Abstract

In Uganda, monitoring for vegetation encroachment on transmission and distribution line corridors is conducted through ground inspections. Ground inspection is carried out by either pole climbing, foot patrolling, or vehicle inspection. These procedures are time-consuming and stressful. In developed countries, aerial borne inspection methods, such as Light Detection and Ranging (LiDAR), helicopter patrols, Synthetic Aperture Radar, Unmanned Aerial Vehicles, and aerial videography, are being used. These techniques produce accurate results but they are very costly and are hardly accessible. Using satellite stereo pairs for inspecting overhead power line corridors for vegetation can be more effective than inspection through aerial methods.

In this research, 50cm spatial resolution Pléiades1A stereo imagery was used to generate a digital surface model (DSM) showing the spatial relationship between vegetation and the high-voltage power lines in the study area. The resultant Pléiades 1A stereo imagery was then segmented into a chessboard grid and processed using texture classification and Normalized Difference Vegetation Index (NDVI) threshold values to identify any tall trees. Using the DSM, together with the data layer, showing the tall trees and the high-voltage powerline corridors, the degree of vegetation encroachment on high-voltage power lines at the time of image acquisition was determined.

It was found that the DSM generated was accurate to the 17.3cm Root Mean Square Error (RMSE). This demonstrates the capability of stereoscopic techniques using Pléiades 1A data in modelling the spatial relationship between vegetation and high-voltage power lines. A line denoted by Code 4 showed a considerable tree canopy density within its growth limit zone which was further confirmed through site visits.

Keywords*: Vegetation monitoring, satellite stereo imagery, power line corridors, satellite stereoscopy, stereoscopic vision*

1. Introduction

Vegetation interference is the most common cause of outages in electric power systems which, when combined with extreme weather conditions, results in millions of people losing power and billions of dollars being spent on damage control. Uganda, with its diverse species of vegetation, includes a good number of species that can grow taller than 10 m, the height of the tallest transmission power lines. An extreme case is Entandrophragma excelsum (Meliaceae), which can grow to a height of 60m (Hemp, 2017).

The most common practice in Uganda and around the globe for vegetation management in powerline corridors is ground inspection. This type of inspection is done either by using vehicles or by foot patrolling (Zain, 2018). Because a large professional and well-trained team is required, this method is costly. Furthermore, this method cannot be used in inaccessible areas, it exposes inspectors to harsh environmental conditions, it is time-consuming, stressful and, because it is subject to human judgmental errors, it is less accurate (Moeller, 2006; Ahmad *et al*, 2011; Qayyum *et al.*, 2015). In developed countries, aerial-borne inspection methods, such as LiDAR and aerial video photography, are used to manage vegetation under powerline corridors. Such methods are not suitable in developing countries such as Uganda because of the high costs associated with them.

In this research, a novel approach to vegetation monitoring for high voltage powerline corridors using 50 cm spatial resolution Pléiades 1A satellite stereo imagery is described. The initial step is to model the spatial relationship between vegetation and the high-voltage powerlines in the study area at the time of image acquisition. Thereafter the degree of vegetation encroachment on high-voltage power lines is determined. The use of satellite stereo pairs for inspecting overhead powerline corridors for vegetation can be more effective than direct inspection through aerial methods (Moeller, 2006). In their favour, satellites cover a wide area, provide consistent overhead passes, and can access places with restricted access. Furthermore, using satellites enables less involvement of human resources, thus eliminating errors emanating from manual judgment, and the associated costs are low. Therefore, using satellite stereo images for vegetation monitoring along power line corridors can be a suitable complement to ground inspection methods.

This paper is divided into five sections. Section 1 presents a brief introduction to vegetation monitoring of powerline corridors using remote sensing methods and a description of related studies on the same subject. Section 2 is a description of the study area. Section 3 describes the procedures taken to identify vegetation encroachment in the study area. Firstly, the study area within the Isingiro District is identified, a DSM for this area is then generated and subsequently used to determine how close the encroaching vegetation is to the high-voltage powerline conductors. Section 4 incorporates a presentation and discussion of the results of the methodology, as discussed in Section 3, while Section 5 is a discussion of the various conclusions and recommendations that emanate from this research.

1.1. Related Studies

Ahmad et al. (2011 and 2013) and Moeller (2006) have discussed the techniques needed to model the spatial relationship between vegetation and high-voltage powerline conductors using a DSM-generated method based on aerial triangulation. Their sole intention was to demonstrate how to monitor high-voltage powerlines for vegetation encroachment. Besides the theoretical discussion, none of these explanations advanced the actual techniques to be put into practice. As Kerstin (1999) and Doyle (1964) demonstrate, aerial triangulation starts by calculating the absolute parallax of the identified tie points − a process commonly referred to as obtaining disparity maps and converting these into 3D depth maps that show how the earth's surface varies with location. Stereo matching refers to the matching of pixels of the left image to the pixels of the right image to identify the tie points in question (Ahmad et al., 2011). A good stereo matching will result in an accurate depth map. Stereo correspondence search algorithms are techniques that are used to match corresponding pixels in a stereo pair to generate depth maps. These algorithms accomplish the stereo-matching process. In software, such as Erdas Imagine Version 2020, the default stereo correspondence search algorithm is a Sequential Model-based Algorithm Configuration (SMAC). Using this algorithm poses many risks, however. Tall buildings will appear merely as hills, while other small details will not be represented correctly. This is so because SMAC has a low pattern success rate in generating the tie points. Modifying this algorithm requires coding in Python, whereas there are also tradeoffs between the various algorithms currently being applied. However, in ENVI classic 5.6, there is an alternative to monitoring the Y parallax of the tie points and ensuring that it is at a minimum. Tie points can be repositioned to achieve this and those with high values for the Y parallax can be deleted. This can be a tedious process when dealing with many tie points.

2. Study Area

Isingiro District is located in the Western Region of Uganda. As of 2021, and, as also shown in Figure 1, several high voltage distribution lines transverse the district. Isingiro District has an area of roughly 2649.87 square kilometres and for purposes of demonstrating this research, a method, as explained in Section 3.1, was used to identify 36 square kilometres of an area within the Isingiro district that was characterized by dense vegetation and within the high voltage distribution line corridors. This was chosen as our study area.

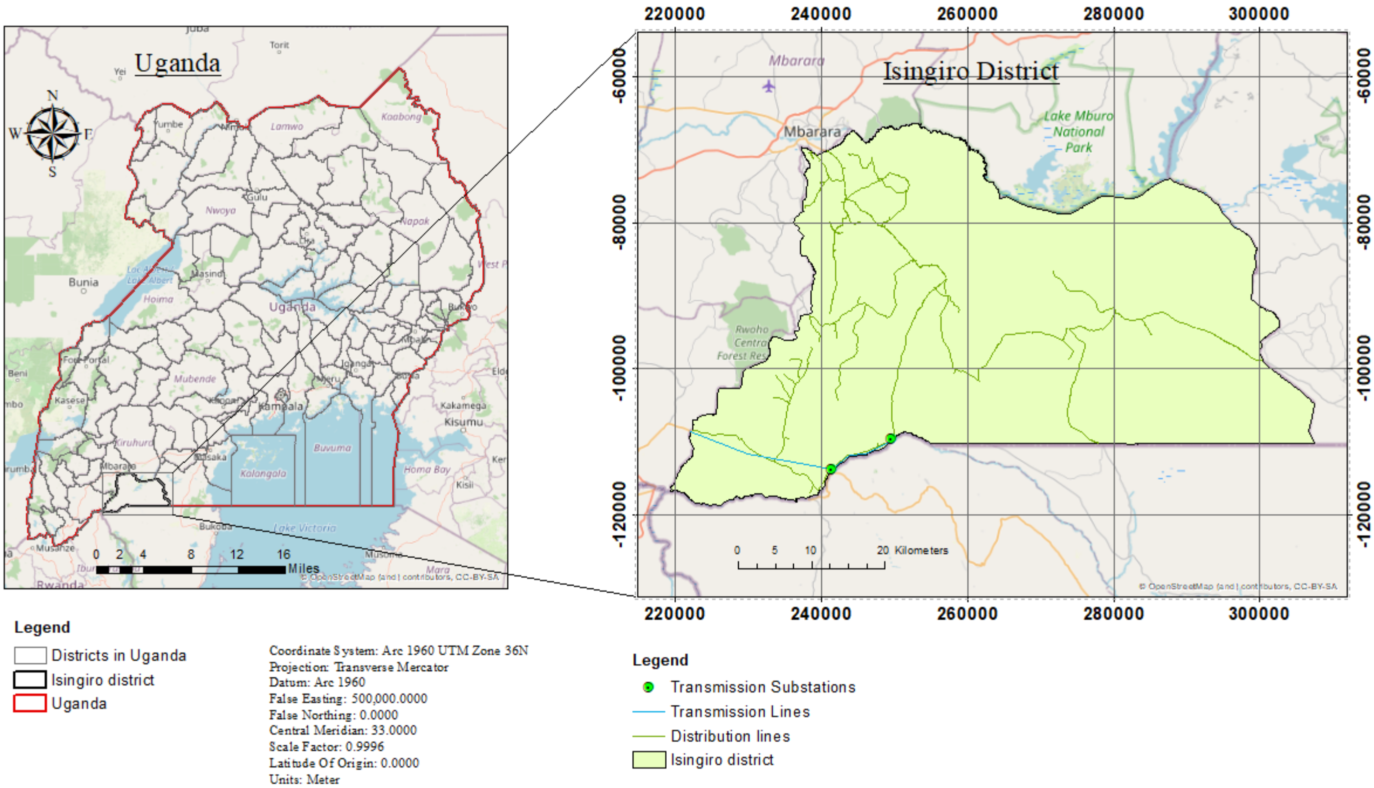

Figure 1. Location map of Isingiro district

3. Methodology

Figures 2a and 2b are a diagrammatic representation of the methods carried out to identify vegetation encroachment along the high-voltage powerlines in the study area. The first step was to identify a particular study area in Isingiro district (Figure 2a). A digital surface model showing the spatial relationship between the vegetation and the high-voltage powerlines in the study area was generated. Finally, tall trees were identified and the respective distances of their canopies from the high-voltage power lines were graded into various vegetation canopy zones (Figure 2b).

3.1. Identifying the study area in Isingiro District

The Apollo Mapping Database was probed for the latest Pléiades 1A stereo image within Isingiro District. An image captured on 30th May 2020 was identified. The footprint of the image was digitized in Google Earth Pro and the KML file was converted to a shapefile in ArcGIS. Landsat 8 data which were captured on 26th June 2020 were downloaded from the USGS Earth Explorer website. Using the shapefile of the footprint of the Pléiades data, the Landsat 8 data were clipped to obtain LandSat 8 data with the same footprint as the Pléiades image. The NDVI values, false-colour composites 5:4:3, 5:6:4 and a true colour composite 4:3:2 were obtained for these LandSat 8 datasets. In the false-colour composite 5:4:3, the dark red areas were identified as forests and the light red areas as grasslands and other short vegetation. Water in the images appears as dark blue in color and built-up areas as shiny green. In the false-colour composite 5:6:4, the black areas represent water, the yellow areas as bare land; and the built-up areas appear as shiny green. The NDVI dataset required a threshold value to distinguish the vegetated from the non-vegetated areas. This threshold was chosen such that all the information in the false-colour composites would be represented in the NDVI dataset. For instance, water bodies, bare land, and built-up areas had to be reflected as non-vegetated areas in the NDVI dataset. A threshold value of 0.65 was found to work well.

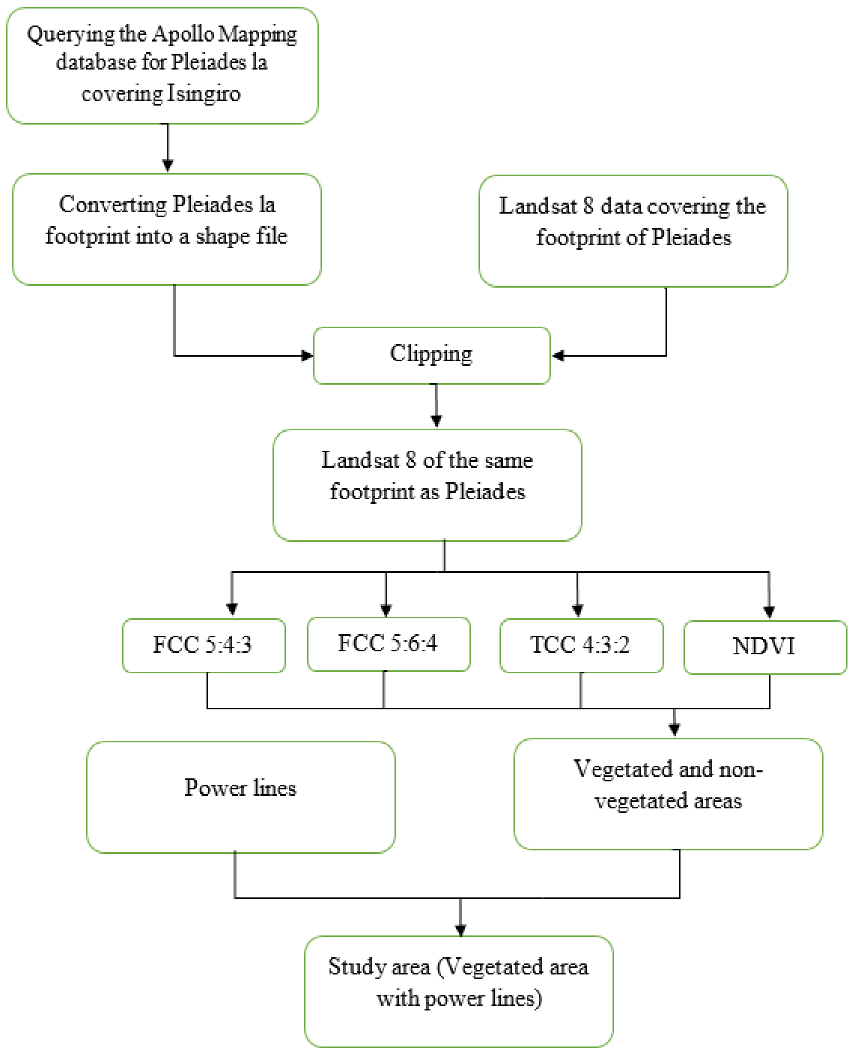

Figure 2a. Methodology for identifying a particular study area in Isigiro District.

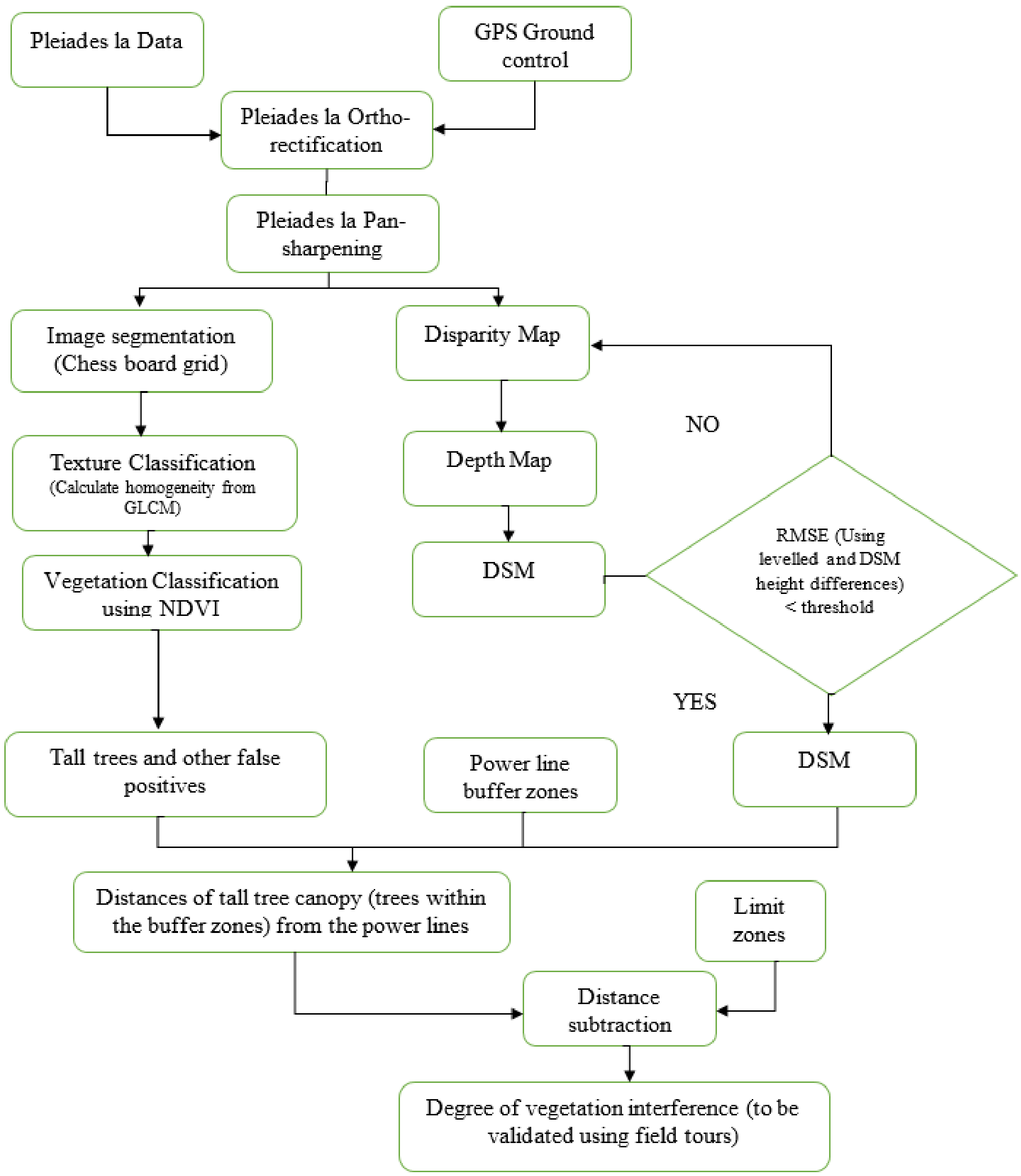

Figure 2b. Methodology for vegetation monitoring for high voltage power line corridors in the study area.

A dataset showing high voltage distribution and transmission lines in Uganda was overlain on the classified NDVI dataset. This dataset was obtained from the geoportal of the Ministry of Energy and Mineral Development (MEMD). A rectangular area (36 square kilometres), of dense vegetation within the high-voltage power line corridor, was chosen as the study area. Pléiades 1A stereo covering this area was purchased from Apollo Mapping.

3.2. Modelling the spatial relationship between the high voltage powerlines and the vegetation

3.2.1. 3.2.1 Orthorectification and Pan-sharpening

Prior to orthorectification, 19 distinct ground points were identified on one of the panchromatic stereo images and their ground coordinates were obtained using the Differential Global Positioning System (DGPS) in the Real Time Kinematics (RTK) mode. This technique was sufficient because Pléiades 1A stereo panchromatic has a resolution of 50cm, while DGPS in RTK mode is accurate to within a centimetre. Ortho-rectification of both the multispectral and panchromatic bands was conducted in Erdas Imagine Version 2020, with the objective of improving the geometric accuracy of the stereo images. A polynomial of Order 3, which required a minimum of 12 ground control points, was used. After ortho-rectifying all images, each of these ground points had a Root Mean Square Error (RMSE). Points with high RMSE were deleted.

The multispectral imagery had a two-meter spatial resolution and the panchromatic image had a 50-cm spatial resolution; hence, there was a need for pan-sharpening. The multi-spectral images were pan-sharpened using the IHS algorithm, as described by Ahmad *et al.* (2011).

3.2.2. 3.2.2 Generating the Digital Surface Model

Having ortho-rectified and pan-sharpened the images, a digital surface model of the study area was generated in ENVI classic version 5.6. This process was started by creating a block, importing the stacked stereo pair into the software, specifying the interior and exterior orientation parameters, generating tie points, carrying out aerial triangulation, generating a DSM, and finally obtaining the orthophotos. The heights assigned to this DSM were arbitrary as the researchers had no benchmarks in the vicinity of the study area that would enable them to incorporate absolute reduced levels in their analysis. However, absolute reduced levels are not necessary since interest in this research pertains to relative heights.

3.2.3. Validating the Digital Surface Model

On inspecting the DSM, a tarmac road running through the study area was identified. This is the Mwizi-Isingiro highway. An uphill and a downhill section along this road were identified. While in the field, levels were taken along these sections. Using the root mean square error technique, the height differences between points along these sections were compared with those taken from the DSM. A similar method of validating the DSM, as described above, was suggested by Moeller (2006).

3.3. Determining the degree of vegetation encroachment

3.3.1. Tall vegetation detection

Tall vegetation in the context of this research is defined as vegetation that is to a height that would cause concern in terms of its possible interference with the high voltage powerlines. A brief description of the method suggested by Blaschke *et al*.(2000) of how tall vegetation can be identified with reliable accuracy follows.

The true colour composite of the Pléiades 1A data was divided into a chessboard grid measuring 1.5m by 1.5m. The intention was to ensure that each grid cell had the same class of features. However, this was not possible, with the consequence being to select a tall tree dataset that had false positives.

The chessboard grid cells were subjected to texture classification by calculating the homogeneity of the grid cells of the panchromatic band and pinpointing those grid cells with a low level of homogeneity. These are supposed to correspond with rough textured features, such as roads, and tall tree canopies, etc. As stated by Marceau et al. (1990), Sebastian et al. (2012), Wang et al. (2010) and Gebejes et al. (2013), homogeneity is calculated using Grey Level Co-occurrence Matrices (GLCM). The GCLM used in calculating the homogeneity of each chessboard grid cell was that which had the maximum probability of occurrence in the ordered pairs. The displacement vectors which were used were d (±1, ±1), d (±1,0), d (0, ±1). These corresponded to eight GLCMs. The panchromatic band was chosen for texture classification because its spectral bandwidth contains all the bandwidths of the red, blue and green bands.

Grid cells with low homogeneity levels were subjected to NDVI classification to determine the densely vegetated areas. These were presumably the tall trees. The NDVI threshold value was 0.65 − the same value as that determined in Section 3.1. The steps described under Section 3.3.1 were incorporated into a spatial model using the Erdas Imagine Version 2020 spatial modeller. The model was run to access the tall vegetation raster dataset.

The researchers needed to define a threshold value for homogeneity. This was initially specified arbitrarily and the entire tall vegetation spatial model was executed. The obtained tall vegetation dataset was linked with the DSM such that navigation in the tall vegetation dataset resulted in simultaneous navigation in the DSM. While navigating in the tall tree dataset, short and medium-height trees were identified in the DSM. It was sought to reduce their numbers in the tall tree dataset by specifying a lower value of homogeneity than that previously specified and once again running the tall tree algorithm. This process was iterative and came to a standstill only after observations were made that some tall trees had started disappearing from the tall vegetation dataset. A homogeneity value of 0.07 was found to work well.

Despite the efforts in trying to eliminate the short and medium-height trees from the tall vegetation dataset, it was found that on linking the tall vegetation dataset with the DSM in the Erdas Imagine Version 2020 spatial modeler, and navigating in the tall vegetation dataset, although the majority of trees were tall, the tall vegetation dataset did not include only tall trees; there were also short and medium height trees. This was so because the chessboard grid cells could not contain only one feature class. Therefore, healthy short and medium-height trees, with smooth textured canopies, grouped with rough textured elements, such as roads, appeared as false positives simply because, in effect, the grid cell had a rough texture and thus a low homogeneity and high NDVI values for some of its pixels. The tall tree detection algorithm assumes that only tall trees have a rough texture for a grid cell and high NDVI values for pixels within the grid cell. Therefore, grid cells with a rough texture and NDVI values above the threshold have tall trees. This is not true. Clearly, short and medium-height healthy trees grouped with rough-textured elements and certain short and medium-height healthy tree species with a rough texture cannot be filtered out by this algorithm.

3.3.2. Determining the Vegetation Canopy Zones

The shapefiles for the high-voltage power lines were clipped to obtain the high-voltage lines passing through the study area. The researchers realized that only 33KV lines were transversing the study area. Furthermore, according to the Ministry of Lands Housing and Urban Development (MoLHD) standards, the wayleave corridors for the 33KV lines are six meters. Thus, a shapefile showing the buffer zones six meters wide to represent these wayleave corridors was generated.

Once the wayleave dataset, the tall tree dataset and the DSM were linked together in Erdas Imagine Version 2020, it was possible to navigate in the wayleave dataset. Similar navigations were also simultaneously made in the other two datasets. Therefore, points could then be identified within the wayleave corridors and notes made of tall trees growing. These points were first investigated by zooming into the 3D Scene window before they were further investigated in the Erdas Imagine Version 2020 tool tab, called Imagine Photogrammetry, which was used to determine the distance of the tall tree canopy from the high-voltage powerlines.

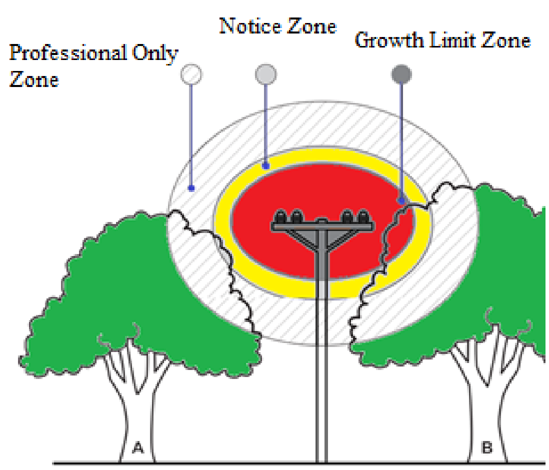

Figure 3. The professional only, notice and growth limit zones of tall trees

False positives within the tall tree dataset were ignored once the tall trees had been identified by zooming into the 3D window and there were no further considerations of them in the Imagine Photogrammetry tool tab. Having measured the distance of the tall tree canopy from the high voltage powerlines, the values obtained were compared with the standards as spelt out by UMEME and UETCL to determine whether the tree canopy was in the growth limit zone, the notice zone or the professional only zone. Figure 3 is a diagrammatic representation of the growth limit zone, the notice zone and the professional only zone.

4. Results and Discussions

4.1. 4.1 The study area

Figure 4 is the location map of the study area. The study area is part of the Pléiades 1A footprint that is densely vegetated and within the high-voltage powerline corridors in Isingiro District.

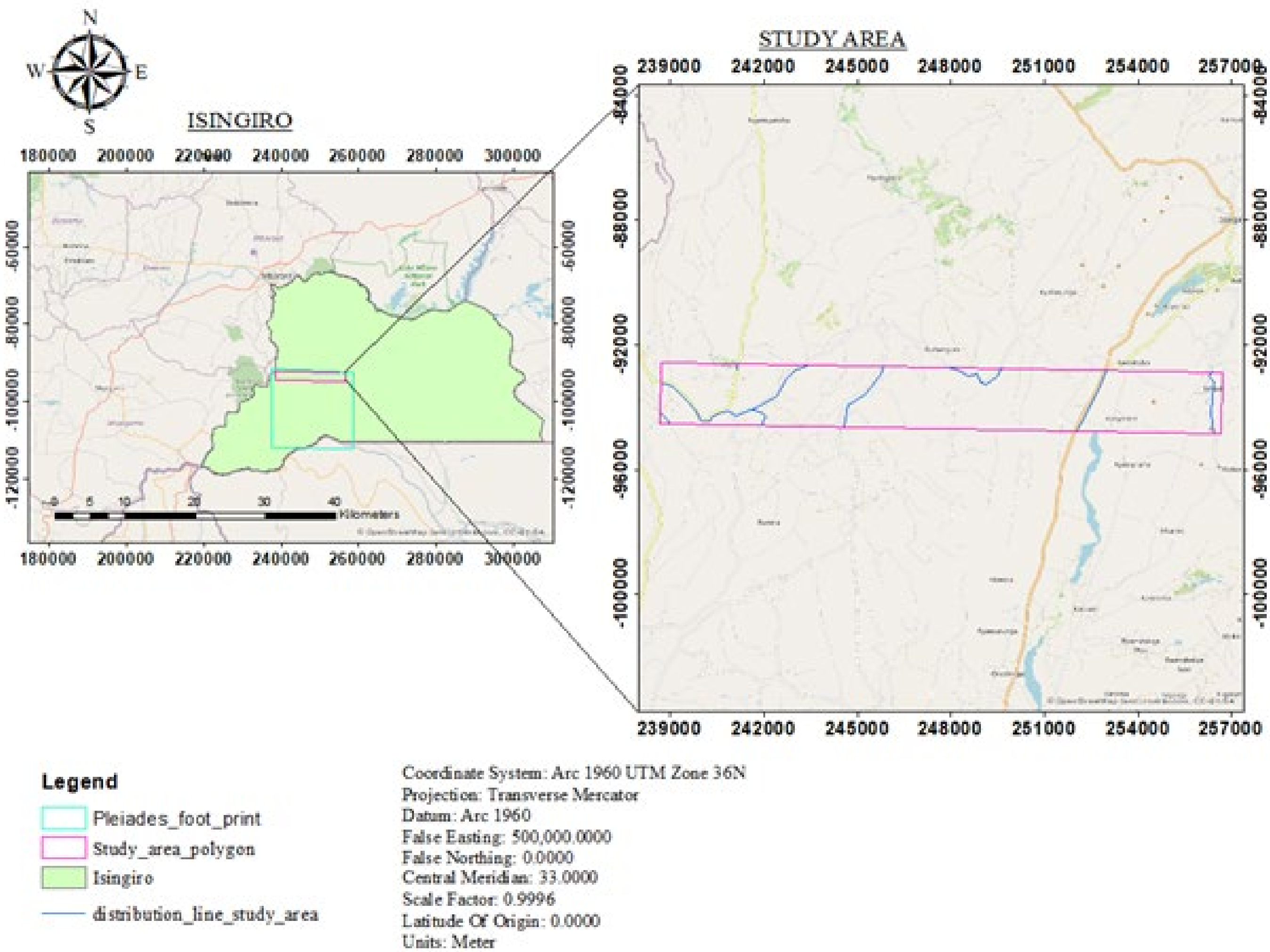

Figure 4. Location map of the study area

4.2. The Digital Surface Model

Figure 5a shows the DSM of the study area. To pinpoint individual features, it is required of the researcher to zoom into the model with a high zoom factor. At the scale presented here, it is, however, impossible to recognise some individual features.

However, clouds can be seen floating in the air and casting shadows on the earth's surface below and this is proof that this DSM is indeed a result of stereoscopy. When the DSM was saved as a raster, the heights at each cell were averaged. Therefore, it became impossible to identify most of the individual features on further visualisations.

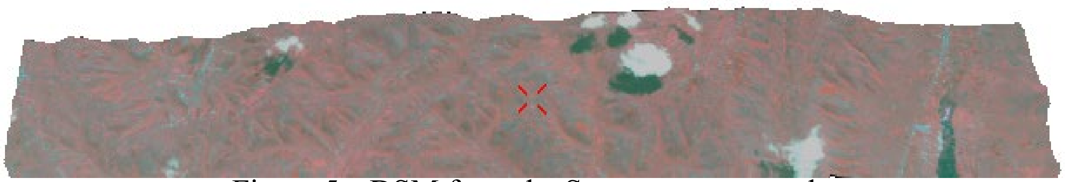

Figure 5a. DSM from the Stereoscopy procedures

On importing the raster file to ArcScene 10.8, and converting it to a TIN, the Raster DSM could be visualized, as shown in Figure 5b. Due to this height averaging process, the clouds cannot be seen. In Figure 5c, the Isingiro -Omukiko and Environs –Nyarwashama Line corridor is shown. Subsequent to image draping and to changing the illumination properties of the scene, short elevation objects, together with the neighbourhood of the line corridor, could be shown in a dark blue colour.

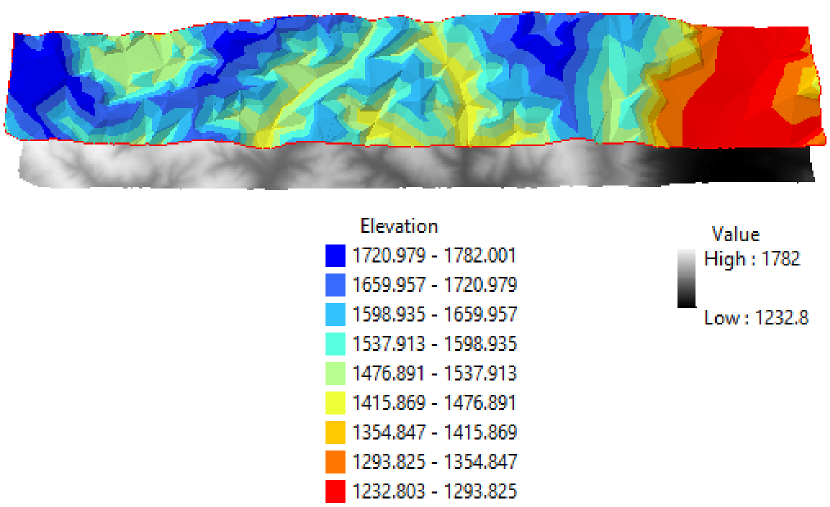

Figure 5b. Raster DSM and its Visualization in ArcScene

Figure 5c. Isingiro-Omukiko and Environs –Nyarwashama Line corridor

This was achieved through the imagine photogrammetry tool tab with the objective of improving the visual appearance of the scene and thus making the powerline conductors more visible. On comparing the reduced level differences of the ground points on the uphill and downhill sections of the Mwizi-Isingiro Highway that are in the study area, together with the values obtained from the digital surface model, a RMSE value of 17.3 cm was obtained. This value was considered sufficient since the spatial resolution of the DSM is 50cm − just the same as that of the Pleiades images. LiDAR technology has the potential to achieve an RSME value of about five centimetres (Zápotocký et al, 2021). However, for the purpose at hand, such high accuracy would not be an added advantage.

4.3. Degree of vegetation encroachment

Figure 6 is a map of the study area showing the degree of vegetation encroachment. Table 1 is a summary of Figure 6. There were in fact scenarios in this study area where the tall trees were above the level of the power lines − to the extent that their canopies obscured the powerlines; thus, they were invisible while in the DSM. Such scenarios were graded as undetermined.

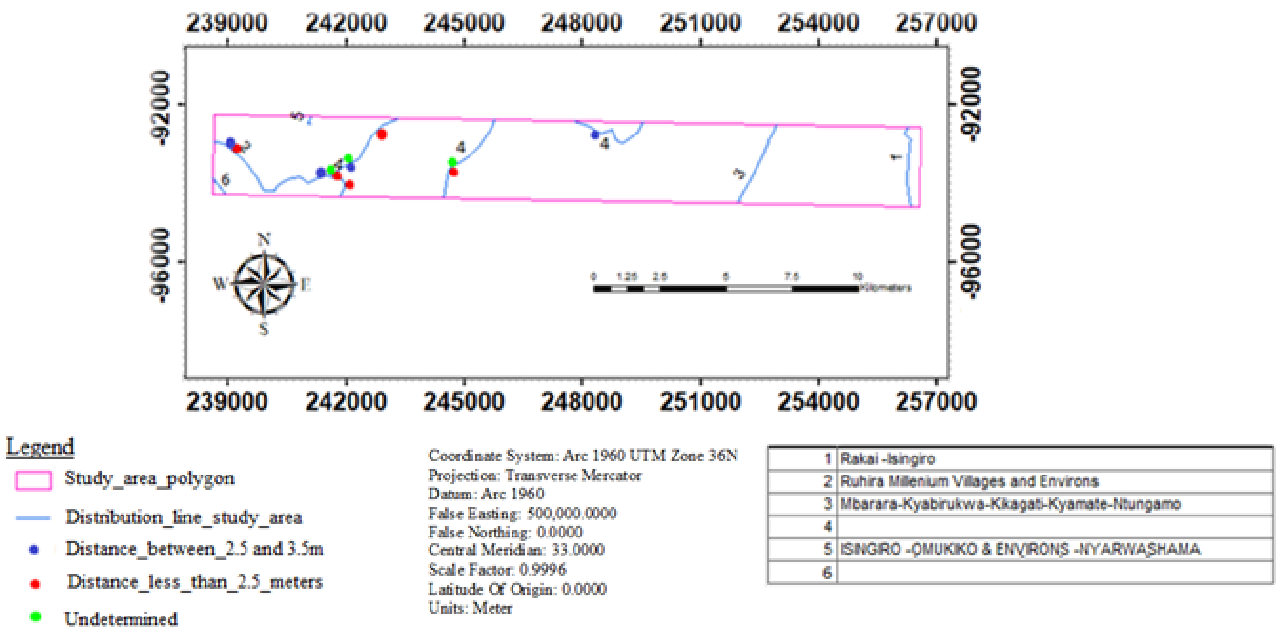

Figure 6. Degree of vegetation encroachment

On investigating the credibility of the claims shown in Table 1 visually, it was found that some trees had their canopies in zones higher than the ones stated. Other trees, especially those with canopies within the growth limit zone, had been trimmed. Because data validation had been carried out 17 months subsequent to the date of the Pléiades 1A image capture, these variations were to be expected. However, it should be noted that visual inspection is subjective.

Table 1. Degree of vegetation encroachment

			Vegetation Limit Zone in DSM							Cordinates (Arc 1960	
Code	Line_Name	Line type	Growth Limit Zone	Dist(m)	Notice	Dist(m)	Professional only	Dist(m)	Undertermined	X_Cord	Y_Cord
1	Rakai-Isingiro	33kv-Distribution	—		—		—				
2	Ruhira Millenium Villages and Environs	33 Kv-Distribution	•	1,253						238864,209	-93002,794
										239093,063	-93129,935
3	Mbarara-Kyabirukwa-Kitagati-kyamate-Ntungamo	33 kv-Distrubution	—		•	3,487					
4	4_Unnamed	33kv-Distribution	•	2,452	—		—			241635,884	-93740,212
			•	2,321						244610,984	-93689,356
			•	2,152						241864,739	-93867,353
			•	1,243						243009,007	-92545,086
					•	2,736				248577,784	-92646,779
					•	2,985				241737,596	-93765,64
					•	3,254				241279,889	-93816,497
									•	241483,314	93816,497
									•	241864,738	93536,497
									•	244636,412	-93587,643
5	Isingiro- Omukiko & Environs-Nyarwashama	33kv-Distribution	—		—		—				
6	6_Unnamed	33kv-Distribution	—		—		—				

5. Conclusions and Recommendations

5.1. Conclusions

The RMSE of 17.3 cm in the vertical heights of the DSM shows the potential of using satellite imagery to model the spatial relationship between vegetation and high-voltage powerlines. However, this depends on the accuracy of the stereo matching algorithm used to create the DSM and the spatial resolution of the stereo pair used. A high-resolution stereo pair is preferable.

Using satellite stereo images cannot be a complete replacement to ground inspection methods since in certain scenarios in this research it was impossible to determine the degree of vegetation encroachment on the powerlines. These instances are indicative of cases where the tree canopy obscured the powerlines. Since large-sized images and high computing power levels are required, satellite stereoscopy cannot be used to monitor powerlines for vegetation over wide areas. Out of the six lines in our study area, only Line 4 and Line 2 had scenarios of vegetation encroaching on the power lines. Nearly 66% of the places identified in the corridor of Line 4 had vegetation reaching the danger zone (growth limit zone).

5.2. Recommendations

Considering the accuracy levels obtained in validating the DSM, it is high time electricity distribution and transmission authorities complemented their ground inspection techniques with satellite stereo image techniques to monitor the density of the vegetation in their powerline corridors.

Tree canopies located in the corridor of Line 4, to the west of the study area, need trimming. Further research needs to be conducted into the process of incorporating shadows in the tall vegetation detection algorithms to eliminate false positives in the tall vegetation dataset if this vegetation monitoring procedure is to be less time-consuming.

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