Power line monitoring using optical satellite data

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Abstract

In this paper we present a feasibility study for using high resolution and very high resolution satellite imagery for high and medium voltage power line monitoring. The main objective is to evaluate the potential of utilizing satellite data in power line maintenance in forested areas. The study suggests that satellite imagery can be used to (1) identify individual trees growing near the power lines, which pose a threat to the stability of the distribution lines, (2) evaluate the height of vegetation in high voltage power line corridors and (3) detect changes in the corridors and surrounding areas. The results indicate that satellite monitoring could become an important maintenance planning tool for electricity distribution companies in the near future.

1 Introduction

Disturbances in electricity distribution networks can inflict substantial costs to the distribution system operator. Efficient maintenance of the areas around power lines is essential to minimize these costs. In forested areas, all trees within a specific distance from the power lines need to be cut down to decrease the possibility of disturbances caused by falling trees, for example, in case of storm or heavy snow load. In addition, the height of vegetation in the power line corridors needs to be controlled in order to prevent contact between the vegetation and the power lines.

In this paper we present a case study for Elenia Oy, an electricity distribution system operator operating 1000 km of high voltage and 23 000 km of medium voltage power lines in Finland. Currently, the power lines are inspected using aerial imaging taken from the helicopter every fourth year. However, there is a need for a more frequent supervision of tree clearing and automated inspections in order to maintain the power lines safe and reliable. For complementing the laser scanning and optical data obtained by helicopter, we study the possibilities of using 6 m and 0.5 m resolution optical satellite data in four different *monitoring tasks* related to the maintenance of power lines in forested areas, summarized in Table 1.

The *risk detection* task consists of identifying parts of the distribution network in which the width of the power line corridor is less than a specific threshold value. Trees growing near a power line should be cut down in advance in order to prevent them from falling over the power line uncontrollably, for example, in case of storm or heavy snow load. The goal in *vegetation height analysis* is to evaluate the average height of vegetation in the power line corridors below the power lines. If the average height exceeds a specific threshold in a part of the distribution network, that part should be cleared to prevent the vegetation from interfering with the power lines from below. *Clearance quality verification* is performed to check if the clearance of power line corridors is executed appropriately, that is, according to the maintenance program of the electricity distribution company. Finally, *clear-cut detection* is executed to recognize changes in the neighborhood of the power line corridors. The main reason for detecting clear-cuts is that individual trees left after the clear-cut, for example, seed trees or trees between the clear-cut and the power line corridor, are potential risks to the power lines.

Table 1: Monitoring tasks related to the maintenance of power lines in forested areas.

Task	**Goal**
Risk detection	Identify trees that pose a threat to the stability of the distribution network
Vegetation height analysis	Evaluate the height of the vegetation in the power line corridors
Clearance quality verification	Verify that clearance has been executed appropriately
Clear-cut detection	Locate new clear-cuts near power lines

Literature review

Satellite and UAV imagery have been studied in many recent publications related to power line monitoring.

Reference [10] discusses a monitoring method based on the analysis of multi-spectral and stereoscopic very high resolution satellite imagery. Reference [13] proposes an algorithm for automatically identifying power lines from aerial images acquired by an aerial digital camera on board a helicopter. The experimental results demonstrate that the algorithm can successfully extract the power lines from aerial images regardless of background complexity. The applicability of several tree crown delineation techniques for complex environments in power line corridors is studied in [6]. A review of vegetation management approaches in power line corridors based on aerial remote sensing techniques is presented in reference [8]. Reference [7] proposes a method for power line detection from UAV images based on Hough transform. The presented experiment on real image data demonstrates that the approach can be used to efficiently detect the locations of power lines. Reference [9] presents an evaluation of airborne sensors for use in vegetation management in power line corridors. The authors address three integral stages in the management process, namely the detection of trees, relative positioning with respect to the nearest power line, and vegetation height estimation. Multispectral and high resolution image data are analyzed along with LiDAR data. The accuracy and reliability of the sensors are verified by using ground truth data. The tested tree detection method was shown to achieve a detection rate of 96% in the performed experiments. A new concept utilizing multi-spectral satellite stereo images to find out the 3D depth of vegetation endangering transmission lines is proposed in [1]. The authors of [5] propose an object recognition algorithm by fusing information from multisensor (LiDAR and imagery) data and multiple visual feature descriptors. In references [11] and [12], novel methods based on estimating the height of vegetation near transmission lines using satellite stereo imagery are proposed. Local methods of stereo matching using Quickbird Satellite images are compared.

2 Materials and methods

2.1 Data

The area of interest of the case study is located in Southern Finland and contains 40 kilometers of medium voltage power lines and 130 kilometers of high voltage power lines. Satellite images with 0.5 m and 6 m resolution from 2013, 2014 and 2015 were used for analysis.

The 0.5 m very high resolution (VHR) satellite data was obtained from the Pléiades constellation, which provides the coverage of Earths surface with a repeat cycle of 26 days. The 6 m high resolution (HR) satellite imagery was obtained from the SPOT Earth observation system (Satellite Pour l'Observation de la Terre), operated by CNES (Centre National d'Etudes Spatiales). Four spectral channels were used for analysis, namely, the blue, green, red and near infrared (NIR) channels.

2.2 Methods

The methods used in this study are based on the *Probability* and *AutoChange* algorithms ([2],[3] and [4]) designed for forest evaluation and change detection. The algorithmic ideas were elaborated to better fit the needs of power line monitoring, which focuses on narrow corridors of land.

The method used in risk detection is based on locating the power line corridor, by analyzing texture and the values of different spectral channels in the satellite data pixel by pixel. By classifying the image into two classes (full grown forest and low vegetation) we obtain an estimate of the width of the power line corridor in different parts of the network. Risks are detected by identifying parts of the network in which the estimated width is less than the specified threshold (7.5 m for 20 kV power lines and 26 m for 110 kV power lines). The height of vegetation was analyzed by executing a more accurate image classification for the power line corridors. Each pixel of the satellite data was classified into one of the following height classes: 0...1 m, 1...4 m, 4...7 m, >7 m. Three vegetation height samples obtained by laser scanning were used to calibrate the classification algorithm. The shares of different height classes were calculated for all segments between adjacent poles. The clearance quality was verified and the clear-cuts were detected by using the vegetation height classification method described above. The classification of the archive images from 2013 and 2014 were compared to the classification of the images from 2015.

Fig. 1: Risk detection example, 0.5 m resolution, false color. The image shows a 20 kV power line segment, whose end-points are marked with white markers. The red square points a location in which the width of the power line corridor is less than the specified limit, 7.5 m.

Both 0.5 m and 6 m resolution satellite data were used to study the applicability of the image types for the monitoring tasks.

3 Results

Table 2 shows a summary of the applicability of 0.5 m resolution and 6 m resolution optical satellite data for the purposes of power line monitoring.

By using the risk detection method described in Section 2.2, 18 risk locations were detected from the area of study by using the 0.5 m satellite data. The detected risk locations were verified visually from the images. In addition, a single risk location was verified from the aerial images taken from a helicopter. In most cases, the reason for the narrowing of the power line corridor was due to a single tree, whose branches were partially grown over the corridor. An example of a detected risk is presented in

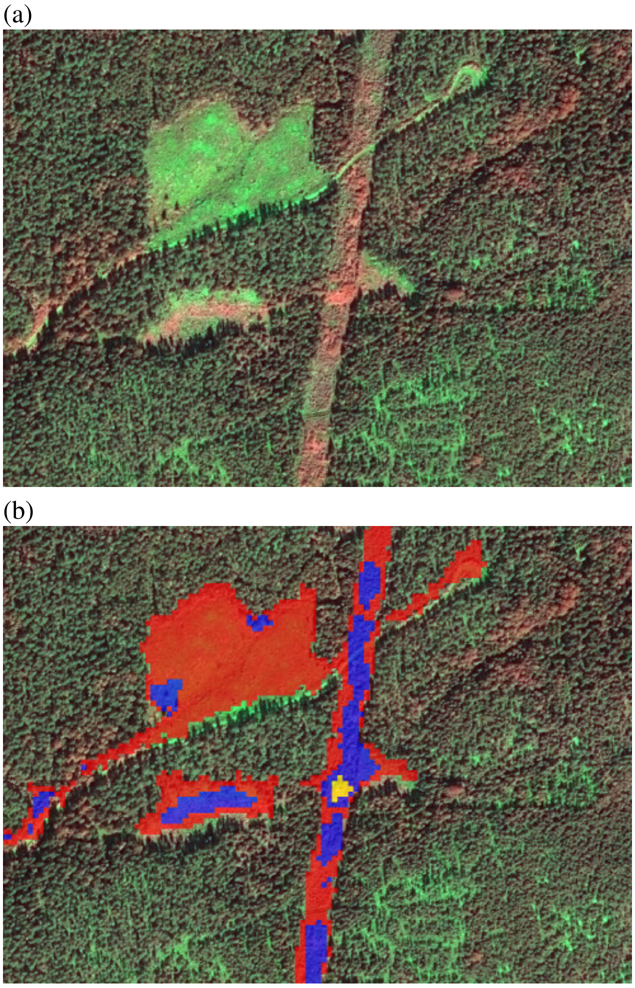

Fig. 2: Vegetation height analysis example, false color. Figure (a) shows a 0.5 m resolution satellite image of a 110 kV power line segment. Figure (b) shows a vegetation height classification obtained by using a 6 m resolution satellite image. The red, blue and yellow areas represent 0. . .1 m, 1. . .4 m and 4. . .7 m height classes, respectively.

Figure 1[1]. Since the risk detection task requires the detection of single trees, the 6 m resolution was seen to be inadequate for this purpose.

A vegetation height classification for the study area was executed by using the height analysis method described in Section 2.2. Figure 2 shows an example of the results of the height classification for a single power line segment using the 6 m resolution. By comparing the height classifications produced by using the two different resolutions, the difference appeared to be relatively small.

By studying the 0.5 m resolution satellite data it was concluded that the data is not applicable for an accurate analysis of the vegetation in the 20 kV power line corridors. The analysis of vegetation is challenging due to the shadows of the trees surrounding the power line corridor, which darken the corridor either partly or entirely depending on the geographical orientation of the power line corridor and the acquisition time of the satellite image. By looking at the 0.5 m resolution image of the 110 kV power lines, it was noted that the clearance quality could be readily verified both algorithmically and visually (see Figure 3).

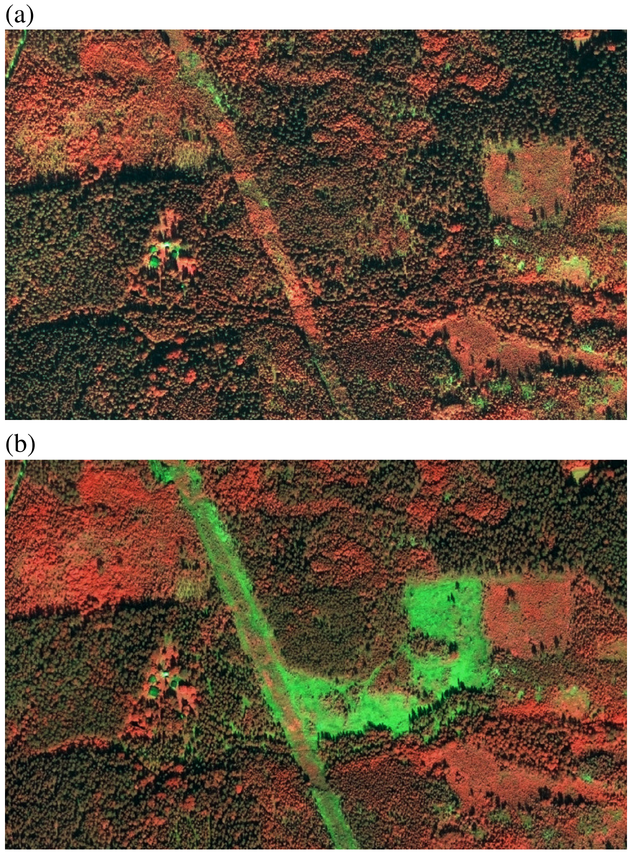

Fig. 3: Clearance quality verification and clear-cut detection example. A false color 0.5 m resolution satellite image of a 110 kV power line segment in 2013 is presented in Figure (a). Figure (b) shows the same segment in 2015. The near infrared channel which can be used to visually evaluate vegetation is shown in red. Areas in which the infrared reflection is small are rendered green and represent areas in which the amount of vegetation is small.

The detection of clear-cuts was executed for the entire study area by using the classification method described in Section 2.2. From the neighborhood of 110 kV and 20 kV power lines, 8 and 1 new clear-cut areas were detected, respectively. By comparing the results obtained by the 0.5 m data and the 6 m data, we concluded that the detection of clear-cut areas was equally accurate with the two resolutions.

4 Conclusions

The results of the study show that 0.5 m very high resolution (VHR) satellite images can be used to analyze the width of

[1] The images in this paper have been compressed and the resolution has been reduced to meet publication requirements.

Table 2: Applicability of 0.5 m and 6 m resolution satellite data for the studied monitoring tasks.

Task	20 kV power lines	110 kV power lines
Risk detection	0.5 m	0.5 m
Vegetation height analysis	-	0.5 m, 6 m
Clearance quality verification	-	0.5 m
Clear-cut detection	0.5 m, 6 m	0.5 m, 6 m

medium voltage power line corridors and to identify individual trees growing near the power lines, which pose a threat to the stability of the distribution lines. The second main result of the project is that 6 m high resolution (HR) satellite imagery can be used to evaluate the height of vegetation in high voltage power line corridors and to detect changes in the corridors and surrounding areas. In order to improve the performance of the vegetation height analysis, future work calls for a more systematic and thorough calibration of the algorithm by using laser scanning or manually obtained field observation data.

The proposed methods can provide valuable information for clearing and maintenance operations. In terms of cost efficiency, the use of HR images seems currently more viable due to the high cost of VHR images. However, the availability of satellite data is constantly increasing and the costs are decreasing. Thus, as a final conclusion, the results suggest that satellite monitoring could become an important maintenance planning tool for electricity distribution companies in the near future.

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