The Utilization of Satellite Images to Identify Trees Endangering Transmission Lines

Y. Kobayashi, G. G. Karady, G. T. Heydt, R. G. Olsen

***Abstract*—** This paper introduces an innovative concept for the use of multispectral stereo pair of satellite images to identify dangerous trees and plants along overhead transmission rights of way. Multispectral satellite images of the right of way are scanned automatically and the color (wavelength) of each pixel is analyzed. This scanning identifies healthy vegetation which may contain trees that endanger the line. Using multispectral stereo images, the height of each pixel is determined and the distance from the conductor is calculated. When this distance is less than the danger zone surrounding the conductors, the identified object or tree is assumed to endanger the line. Case studies using satellite images in the vicinity of Scottsdale, AZ and San Diego, CA demonstrate the feasibility of the proposed method. Details are given for prototype software development for satellite image scanning to determine tree interference with overhead transmission lines.

***Index Terms*— satellite images, tree trimming, transmission engineering, overhead conductors, power transmission.**

I. BACKGROUND

OVERGROWN trees under a transmission lines may interfere with circuit operation and may produce short circuits. As a typical example, the 2006 blackout in the Western United States and Canada was initiated by a combination of inadequate tree trimming and high conductor sag, caused by a high conductor temperature, caused by high load current and low wind conditions. The National Electrical Safety Code [1] requires *periodic tree trimming* in the vicinity of the lines. Tree trimming is needed when a tree penetrates a danger zone, which is a region that envelopes the transmission line and is dependent on the voltage rating. The present practice is to identify dangerous trees by visual observation from helicopters/airplanes and driving along the right of way [2]. Such visual inspection is labor intensive and costly. This paper presents a computerized method that uses high resolution *satellite images* to identify the location of trees penetrating the danger zone and endangering transmission line operation.

The objective of vegetation management in the right of way is to maintain healthy low-growing plants (e.g., shrubs, grasses, and native ferns), and to remove trees that are determined to be a present or future hazard to the transmission line. Flashover occurs when the distance between the tree and the line is less than a minimum value (i.e., 1 foot for a typical distribution line and 24 feet for a 500 kV line). While wind may move trees closer to the line and this can produce flashover, maximum sag and maximum wind generally do not occur at the same time because the maximum wind condition cools the conductors and hence reduces sag. By drawing circles around the energized conductors, a danger zone can be determined. A tree must be cut or trimmed when it penetrates this danger zone. The height and width of the danger zone depends on the line configuration and the assumed maximum wind. Conductor swing also reduces the distance: consequently, the danger zone is calculated using the maximum sag and maximum wind conditions.

A common method for the estimation of vegetation height is the analysis of analog and digitized aerial photos by means of image stereoscopy. In practice, most cases still require human estimation with direct visual observations. The right of way tree trimming identification is commonly based on LiDAR (Light Detection and Ranging) technology. For example, Morsdorf [7] makes use of LiDAR technology to extract the vegetation structure for fire management. In [8], Clode classifies trees and transmission lines using LiDAR data. Turton and Jonas [9] show the possibility of extracting transmission lines and towers directly using LiDAR.

Typically, the LiDAR systems are flown from modified ski carriers on the side of a helicopter. The helicopter flies, as slowly as possible, down one side of the line and then back up the other. Differential GPS has been used to obtain vertical precision of better than 0.05 m since 2003, and results have improved since that time. Differentiation of conductors from vegetation and tower structures is automated in the LIDAR signal processing and the results are output to standard transmission line design programs such as PLS-CAD. The LiDAR method is a mature technology with many commercial providers for transmission line surveys. It provides highly accurate data. Unfortunately, the cost of carrying out a LIDAR survey can be high, because of both the rental fee for the helicopter ($1000/h) and the LIDAR data processing fees. Further, the technology is best suited for the evaluation of one line at a time thus necessitating a large number of studies and data gathering exercises to cover a large geographical region.

LiDAR technology is based on an active laser pulse signal, which is emitted from the aircraft, directed towards the Earth's surface. A special sensor records the reflected signal. The distance between the aircraft and the surface can then be calculated from the time lapse between the send / receive pulses. Figure 1 shows the concept of acquiring LiDAR data.

Another method to extract the height of trees from images is to estimate the height from the ratio of the radius of the crown. Borgefors and Hyyppä show that the trunk diameter is correlated with the height and the radius of the crown [10]. Pollock [11] proposed a generic model to represent the size of tree with a formula, called a generalized ellipsoid of revolution (GER). Straub and Heipke demonstrated an application to extract trees using aerial color infrared images and a dense digital surface model [12]. A series of research projects by Yasuoka [13] shows techniques to estimate the number of trees from satellite images and LiDAR data.

In this paper, a different approach from the aforementioned ground and air based methods is taken. Satellite images are used to identify trees that penetrate the danger zone, and an automated, image processing concept is presented for the wide-scale processing of images for transmission engineering applications.

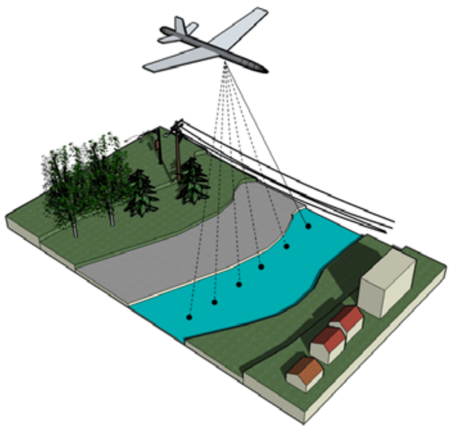

Fig. 1 An illustration of LiDAR technology. Note: helicopters are usually used in power transmission applications.

Vegetation management is estimated at 7-10 billion dollars business annually in the United States alone [3]. Additional references on vegetation management appear in [4, 5, 6]. The advantage of moving to satellite imagery for this application relates to the widespread coverage of such images, and the inspection reduced need for expensive direct observation methods.

The concept of the utilization of satellite images for the cited task offers potential improvements over direct visual inspection and airplane based (e.g., LiDAR) technologies:

- wide area of coverage
- frequent overhead passes
- areas with restricted access may be viewed
- potentially lower cost because of processing a large geographical area at one time in an automated workflow.

An important issue relating to the use of satellite images for the identification of any ground features relates to the utilization of *stereo pair images*. Processing of stereo images allows the user to extract height information for the observed terrain. Because the satellite is effectively infinitely far from the ground features, it is necessary to access two separate images recorded utilizing slightly different angles. Figure 2 shows the concept. In direct visual observation of transmission rights of way, the relative position of trees and other objects to the transmission line is resolved by the interpreter's observation. However, it appears that the wide area coverage of satellite images (e.g., in comparison with direct visual observation) may more than compensate for the need for stereo images. The cost to achieve acceptable level of resolution is an unresolved issue, because of the high cost of stereo, multispectral satellite images. However, the wide coverage, the fast processing of the satellite images and the expected decrease of image cost by the increase of demand offers the potential of lower overall cost – especially in large volume purchase of images.

II. Satellite Images

At present, there are several main civilian sources and types of satellite images. For extracting ground features in remote sensing, the accuracy depends on the ground sample distance (GSD) value. GSD is the spatial resolution of imagery and represented as a distance of meter per pixel. According to [14, 15], the images of one meter GSD are suitable for extracting ground feature, and IKONOS, QuickBird and OrbView satellites produce images commercially. According to [16], the IKONOS satellite is the world's first commercial satellite to collect panchromatic images with one meter GSD and multispectral imagery with 4 meter GSD. IKONOS was launched in September 1999 and started providing imagery in January, 2000. The images are taken at the satellite altitude of 680 km. The accuracy of the orthorectified image is ±1.75 m. It takes 11 days to return to the same location (revisit cycle).

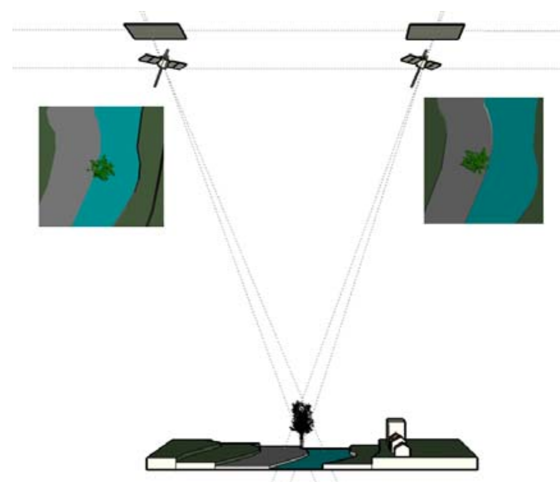

Fig. 2 Pictorial of stereo satellite imagery

QuickBird is a high-resolution satellite owned and operated by DigitalGlobe. Using state-of-the-art technology, Ball's Global Imaging System 2000 sensor, QuickBird uses remote sensing to 0.61 m GSD resolution. QuickBird was launched in October 2001, and acquires images at the satellite altitude of 450 km. The satellite returns in 1.0 to ~3.5 days. Additional information on the QuickBird satellite capability is available at [17]. According to [18, 19], a stereo pair of QuickBird images is readily used to extract height of buildings.

OrbView also offers one of the high-resolution satellite images. The original OrbView-1 was launched in 1995, and the satellite was placed in service in 2000. OrbView-2 and OrbView-3 were launched in 1997 and in 2001. The OrbView-3 takes 1 m panchromatic and 4 m multispectral images. The next generation, OrbView-5 was launched in 2008, and it offers unprecedented special resolution by simultaneously acquiring 0.41 m panchromatic and 1.64 m multispectral imagery [20]. The OrbView-5 images are the highest resolution satellite images available to civilians.

There are many formats for digital images such as JPG, GIF, TIFF, and RAW. Remote sensing techniques especially for the detection of vegetation commonly use TIFF format (Tagged Image File Format) because it is able to save four bands: red (R), green (G), blue (B), and near infrared (NIR) bands in one file. The R, G, B, (RGB) and NIR bands are wavelengths of the electromagnetic spectrum / energy. The R band has a wavelength in the range of about 0.6 to 0.7 µm; the G band from 0.5 to 0.6 µm, the B band from 0.4 to 0.5 µm, and the NIR band from 0.7 to 1.2 µm. The RGB bands are visible for the human eye, but the NIR is invisible. The intensity of the spectrum at each point of the TIFF image is represented as a set of four band values. The values are usually digitized as an 8 bit integer value in the range 0 to 255, and this representation is denominated as the digital number (DN). The satellite image providers offer TIFF image file with R, G, B, and NIR bands as a multispectral satellite image.

III. SOFTWARE FRAMEWORK

Attention now turns to the development of digital software that is suitable for the identification of the relative placement of objects in general, and suitable for the determination of the distance between trees and conductors of a transmission line in particular. The objective is to apply this software tool to satellite images for the automatic detection of the distance between overhead transmission circuits and trees. The work is divided into three stages. The first stage detects areas with healthy vegetation and trees using commercially available multispectral satellite images. The second stage is to estimate height of trees or vegetation close to the transmission line.

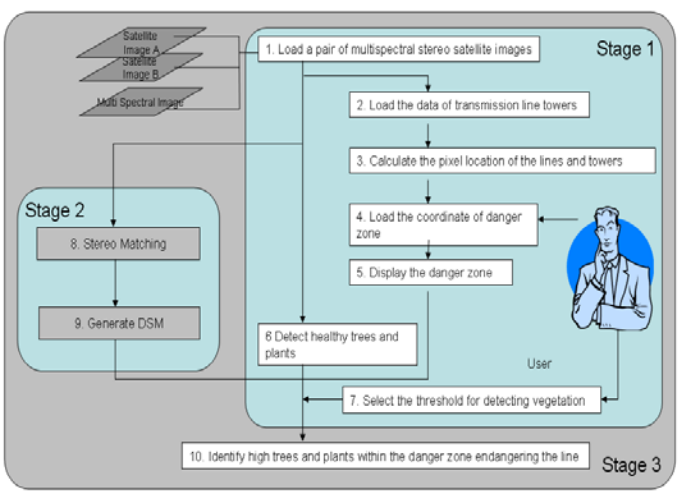

Fig. 3 Software framework for the scanning and analysis of satellite images

The height of the location is calculated for each pixel using a technique called, "stereo-matching" from a stereo pair of satellite images. Stereo-matching is used to calculate the distance between each pixel in the first image and the corresponding pixel (with the maximum correlation) in the second image. This results in a three dimensional 'picture' of the area, called Digital Surface Model (DSM). The height of trees is then estimated using this DSM. The final stage is to integrate the developed two computer tools for a practical code which is appropriate for power transmission engineering applications.

The framework is divided into ten main steps. Fig. 3 shows the software framework and the pipeline of these steps:

1. Load a pair of multispectral stereo satellite images
2. Load transmission tower data
3. Calculate the pixel location of the lines and towers on the image
4. Load the coordinates of the danger zone
5. Display the danger zone
6. Detect the healthy trees and plants within the danger zone
7. Select the threshold value for detecting vegetation
8. Calculate stereo matching for each pixel within the danger zone
9. Generate three dimensional Digital Surface Model
10. Identify high trees and plants within the danger zone endangering the line.

The software developed as outlined above was implemented using Java, an object-oriented programming language, and JAI (Java Advanced Imaging), which is one of the Application Programming Interfaces for image processing in Java. This approach permits transferring and displaying large scale satellite images.

IV. SOFTWARE DETAILS

Like most other software packages used in power engineering, the software tool utilizes graphical user interfaces (GUIs) which are intended to interface the user with the actual satellite imagery. Figure 4 shows the generalized configuration of the GUI. The main-panel, sub-panel, control-panel, and info-panel are the developed GUI components for this program.

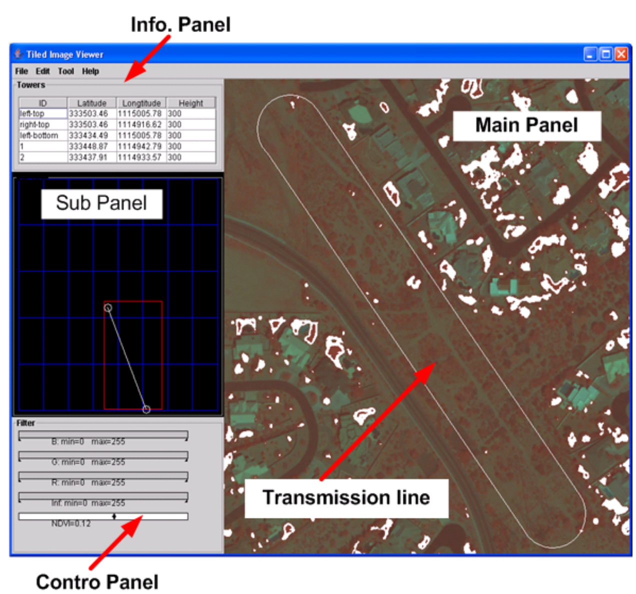

Fig. 4 Graphical User Interface of the developed software tool

The main panel shows a satellite image and overlays some results of analysis. The sub-panel displays transmission towers as a small circles and the transmission line as a line. The control panel gives index numbers which are used to interactively identify land type such as bare land, trees, and buildings. The 'info-panel' displays a table of geographical coordinates of the transmission towers. The following sections explain the details of each step.

1) Loading and displaying a multispectral satellite images

A multispectral satellite image file is loaded by selecting the data source in a file browser. The loaded image is not displayed directly but subdivided into tiled images with smaller pixels such as 256 x 256 in order to display the image in real time. Otherwise it is not feasible to handle large scale satellite images in regular PCs because of the limitation of memory size. The size of satellite image is usually bigger than that of the computer screen, and therefore only a small part of loaded image is displayed in the main panel. The visible small area on the main panel is projected in the sub-panel as a boundary box. The user may scroll the image and change the visible site by dragging a mouse in the main panel.

In the software development, the *x, y* coordinates in an image is measured by pixels. Consequently the pixel coordinates must be transferred to corresponding longitude and latitude values. The transfer from the pixel coordinate to geographical coordinates can be achieved by using an affine transformation. This procedure utilizes a transformation matrix which is defined by any three reference points in the image. The geographical coordinates of the points are obtained using the popular Google Earth software. Once the information matrix is defined, any pixel position in the image can be transferred to the corresponding latitude and longitude.

(2) Load transmission line tower data

A text file that contains the tower data, which are the tower index number and the latitude and longitude that determines the tower location, is loaded to a file browser. In the file, the towers are simply numbered starting from one end of the line. These data are obtained from the utility supplied plan and profile drawings of the transmission line.

(3) Calculate the pixel location of the lines and towers on the image

After loading both the satellite image file and the transmission line tower data, the geographical coordinate of each tower must be transferred to the corresponding pixel position in the image in order to get the *x, y* position in the image. This is the inverse function of the affine transformation from the pixel coordinate to the geographical coordinate.

(4) Displaying the danger zone

The danger zone maximum width is calculated by analyzing the transmission line data [2, 3]. A circle around each tower is drawn using the half width of the danger zone. Two lines tangentially touching the circles determine the boundary of danger zone. These boundaries are displayed as white lines in the main panel.

(5) Detect the healthy trees and plants within the danger zone

Once the danger zone boundary is identified, the software scans only the limited number of pixels within the zone. During the scanning each pixel is analyzed by calculating the normalized differenced vegetation index (*NDVI*) defined as,

$$NDVI = (NIR - R) / (NIR + R)$$

where *NIR* is the near infrared red digital number and *R* is the red digital number.

For the detection of vegetation, the ratio of red (*R*) and near infrared red (*NIR*) digital numbers (*DN*) is used. The phenomenon is termed a 'red edge' because the reflected signal from healthy vegetation shows a very strong increase and steep slope in the red portion of the electromagnetic spectrum. In other words, the parameter *NDVI* represents the intensity of the signal in the spectrum corresponding to the amount of healthy vegetation present in a specific pixel. The value range is normalized for programming convenience between -1 and +1. The *NDVI* value for each pixel is displayed in the red channel instead of the red value so that the healthy vegetation is shown in strong red.

(6) Select the threshold value for detecting vegetation

In order to determine the healthy vegetation area properly, the best threshold value needs to be defined. In the software implementations tested, the *NDVI* value is defined experimentally by the user because this parameter varies from image to image depending on the sensor, the actual conditions when the image is taken such as weather, and the sensor features such as the focal length. The point whose *NDVI* value is beyond the threshold value defined in the control panel is depicted in white instead of strong red. These color codes are found to be useful and user friendly for rapid identification of tree location. In practice, a practical value for the *NDVI* threshold is about 0.1~ 0.3.

(7) Stereo matching and DSM generation

Stereo matching includes several steps: panchromatic high resolution satellite stereo imagery has to be loaded as a stereo pair. For each pixel in one image of the stereo pair, a pixel with the maximum cross-correlation value in another is searched. The cross-correlation is calculated as,

$$C(I_1(i_1, j_1), I_2(i_2, j_2)) = \sum (V_1(i_1, j_i) * V_2(i_2, j_2) - U_1 * U_2) / (O_1 * O_2),$$

where $C(I_1(i_1, j_1), I_2(i_2, j_2))$ is the cross correlation value of the pixel position (i_1, j_1) in the first image; I_1 and the pixel position (i_2, j_2) in the second image I_2. The parameter $V_k(i_k, j_k)$ is the template matrix around the position of (i_k, j_k) in the image; I_k. U_k is the mean value of template matrix $V_k(i_k, j_k)$; and O_k is the standard deviation of template matrix $V_k(i_k, j_k)$. The distance between the pixels is scaled to define the height of the position. Finally, a three dimensional image is calculated providing *z* value of height in addition to the *x, y* coordinate for each pixel. The *z* value for each pixel is represented as a 16 bit floating point number.

(8) Identify high trees and plants within the danger zone endangering the line

The final step is to show the results in 2D and 3D views by integrating the data: NDVI image, DSM, and the danger zone. The danger zone is displayed on the NDVI image, and the height of each pixel position on the cross-section line is shown in the cross-section diagram. The height data are from the DSM image file generated by stereo matching.

The user can investigate the height of any point within the danger zone interactively in the cross-section diagrams. The vertical and horizontal cross-section data of a specific point are displayed. For convenient identification by the user, the cross-section data are painted with three colors: gray, light gray and white. The points inside and outside the danger zone are represented in light gray and gray respectively. Only the points with high *NDVI* value in the danger zone are in white as shown in Figure 5.

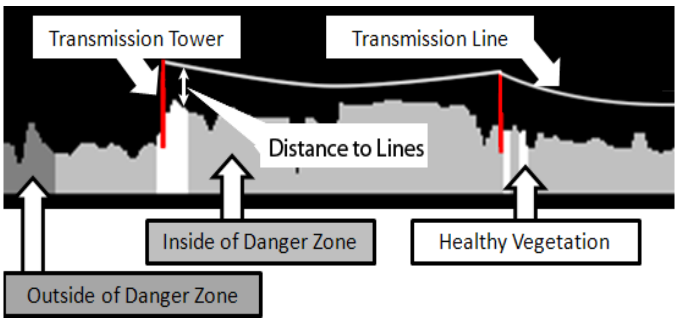

Fig. 5 'Paint rule' of cross section, actual profile obtained for a test bed in San Diego, CA

Note that Figure 5 is a flat representation of a three dimensional image: only the vertical component of the distance between the vegetation and the transmission line is depicted in this figure. In a practical application the actual three dimensional distances are calculated.

Table. 1 The location of several exemplary extracted trees, San Diego site test bed. The distances listed are shortest distances to the conductor.

ID	Latitude (N) (deg)	Longitude (W) (deg)	Distance to lines (m)
0	32.75925	117.19985	40.78
1	32.75928	117.19983	42.65
2	32.75953	117.19974	32.10
3	32.75919	117.19980	38.71
4	32.75934	117.19972	42.47
5	32.75957	117.19963	31.19
6	32.75927	117.19960	47.05
7	32.75930	117.19955	48.57
8	32.75939	117.19950	26.23
9	32.75946	117.19942	32.37
10	32.75944	117.19935	32.37
11	32.75933	117.19931	24.45
12	32.75924	117.19920	54.78

Finally, the program generates a list of trees in the danger zone. A tree is defined as a set of healthy vegetation pixels. The list is displayed as a table with the information of latitude, longitude, and the distance to transmission lines for each extracted tree. Table 1 shows a part of the tree list generated in a typical application. For Table 1, a test bed in the vicinity of San Diego CA was used

V. Results / Case Study

Fig. 6 gives an illustration of a case study using a 0.61 m GSD multispectral QuickBird satellite images in Scottsdale, AZ. The *NDVI* threshold value is set as 0.12 in this application. Since the stereo pair is not available for this site, the DSM is not generated.

Another case study uses a one meter GSD multispectral stereo pair of IKONOS satellite images in San Diego, California. The transmission towers are located in the opposite side of a freeway, and the lines cross the freeway. There is a vegetation covered area to the north of freeway.

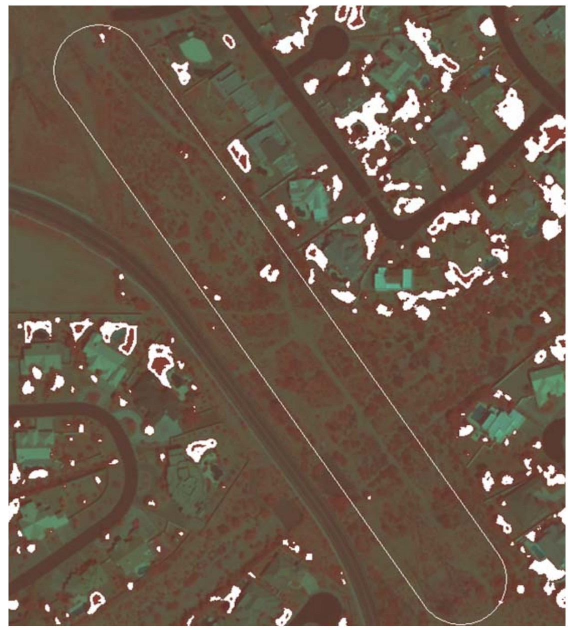

Fig. 6 Screen shot of the developed software showing an actual right of way in Scottsdale AZ. North is upward.

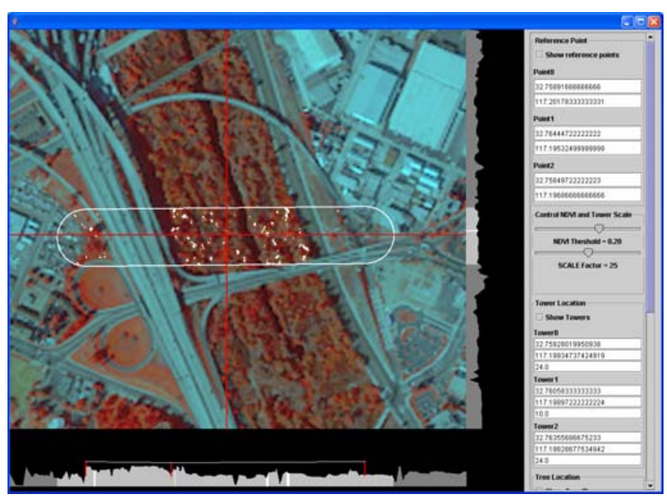

Fig. 7 Screen capture of the case using a stereo pair for a test bed in San Diego CA. The freeway discussed in the text is visible at the left of the image. North is to the right.

When a stereo pair of images is used, the additional GUI appears to the user (see Figure 7). Through the interfaces, the user can investigate the trees in the danger zone by changing the *NDVI* threshold values and generating the cross-section diagrams. Figure 8 shows the result images with different *NDVI* threshold values in this case. An initial cross-section point is set as the center of dangerous zone. The cross-section diagram parallel to the *x* direction (horizontal cross-section) is shown in the bottom of image, and the one parallel to the *y* direction (vertical cross-section) is in the right sides as shown in Figure 7.

For the San Diego test bed depicted in Figs. 7 – 9, when the *NDVI* threshold value was set as 0.20, 95 trees were extracted. When *NDVI* was 0.15, 37 trees were extracted. When *NDVI* was 0.24, 104 trees were extracted. When *NDVI* = 0.15, the extracted regions were too small to recognize. When *NDVI* = 0.24, the regions were too numerous to identify the locations of vegetation clearly. As the result, in this application, it was decided to investigate the extracted trees utilizing *NDVI* = 0.20. Figure 10 shows the locations of five closest trees to the transmission lines, and Table 2 shows the geographical information of these trees. In Figure 10, only the closest trees are labeled with white numbers in a black circle; for example tree 39 is under the line but not high enough to cause interference.

The height data are extracted from the DSM image shown in Figure 9. The intensity of each pixel represents the height of the position in the image. The higher elevation is marked with the whiter color and the lower is marked as darker. The trees are considered to have a priority for tree trimming if they are endangering the transmission lines.

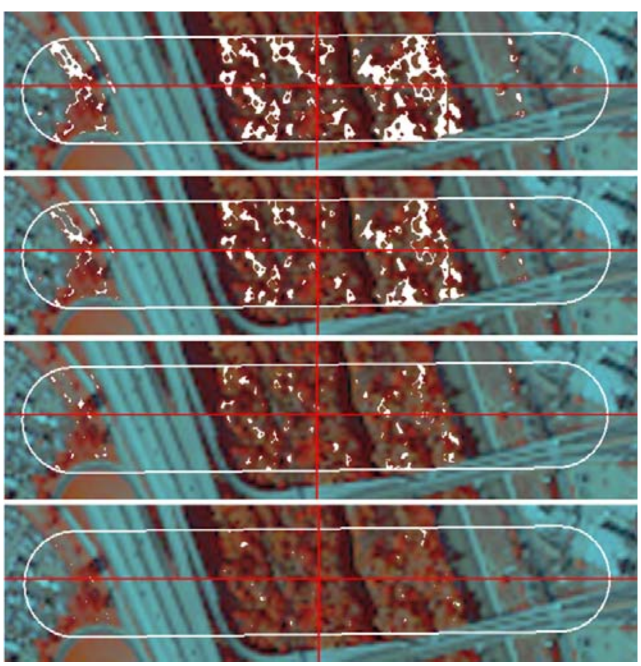

Fig. 8 Effect of *NDVI* threshold on an IKONOS multispectral satellite image: from top to bottom, a) *NDVI* = 0.1, b) *NDVI* = 0.25, c) *NDVI* = 0.20, and d) *NDVI* = 0.25. These four images are for the San Diego test bed. North is to the right.

Table 2 Information of five closest trees (i.e., perpendicular distance) to transmission lines, San Diego test bed

ID	Latitude (N) (deg)	Longitude (W) (deg)	Distance to lines (m)
26	32.76076	117.19942	24.29
11	32.75933	117.19931	24.45
8	32.75939	117.19950	26.23
21	32.76072	117.19948	29.15
40	32.76071	117.19930	30.11

Fig. 9 Digital Surface Model generated by stereo matching, San Diego test bed, North is upward.

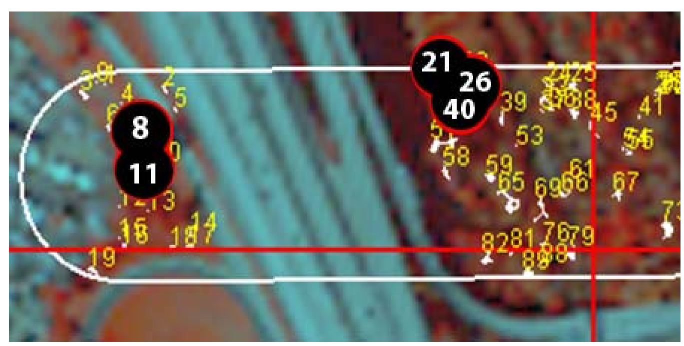

Fig. 10 Five closest trees to transmission lines in the extracted tree list, San Diego test bed. The multilane freeway under the line is at the left-center. North is to the right. The closest trees are highlighted as a white number in a black circle in this diagram.

VI. CONCLUSIONS

This paper presents an innovative new computerized method to identify dangerous trees and plants on transmission rights of way using multispectral stereo pair of satellite images. The location of healthy vegetation was identified by calculating *NDVI* value using the red and the near infrared red bands in a multispectral image. The height of vegetation was calculated using stereo matching technique. The method has been implemented in a computer code written using the Java language.

The practical use of the program was demonstrated by analyzing a short section of a transmission line in Scottsdale, AZ using QuickBird satellite image and a line in San Diego, CA using a multispectral stereo pair of IKONOS satellite images. Details on the development of the computer software are given.

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IX. Biographies

Yoshihiro Kobayashi received the Ph.D. degree majoring in Architecture from University of California, Los Angles, and B. Arch and M. Arch degrees from Waseda University, Japan. He is a leader of Digital Phoenix Project aiming at developing 3D city models for decision making on urban and city issues at Arizona State University, Tempe, AZ where he is a faculty research associate.

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