Method for Measuring the Separation between Transmission Lines and Forests Using UAV Data

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Abstract

For safe transmission of electricity, it is necessary to determine the separation between transmission lines and forests around steel transmission towers. Unmanned aerial vehicles (UAVs) have low operational costs, and UAV image data are of high resolution that can be acquired at any arbitrary time. Therefore, to reduce the cost of determining the separation between transmission lines and forests, UAV data can be utilized for three-dimensional (3D) reconstruction of the transmission lines and forests. In this study, we developed a method for measuring the separation between transmission lines and forests using such a 3D reconstruction.

Keywords: transmission lines, forests, UAV, SfM, separation measurement

1. Introduction

Electricity is an important utility in our daily life. Power transmission lines for transporting electricity have the following characteristics: (i) high voltages of 11.2 kV or more, (ii) supported by steel transmission towers, and (iii) several of them are placed in mountainous areas. On August 14, 2003, a major blackout occurred across parts of Canada and the United States⁽¹⁾. The blackout reached 61,800 MW and affected approximately 50 million people. Complete recovery took more than a week in some areas. The blackout was caused by tree branches touching transmission lines. Therefore, it is necessary to determine the separation between transmission lines and forests around steel transmission tower to transmit electricity safely.

Currently, separation measurements are done with a helicopter⁽²⁾. However, such a method is expensive in terms of fuel and facility maintenance, and therefore cannot be frequently used. Unmanned aerial vehicles (UAVs) have low operational costs, and UAV image data has high resolution that can be acquired at any arbitrary time. In recent years, the use of three-dimensional (3D) reconstruction data by structure from motion (SfM) has become widespread. Determining the separation between transmission lines and forests by 3D reconstruction obtained from UAV data can help reduce these costs. Therefore, in this study, we developed a method for estimating the separation between transmission lines and forests using 3D reconstruction based on UAV data.

2. Study Area and Data Used

2.1 Study Area

The Akita trunk line in Daisen city, Akita Prefecture is targeted in this study. The transmission voltage of this trunk line is 275 kV, and maintenance is necessary when the distance from the forests is less than 7.0 m. The structure of the target power transmission instrument is illustrated in Fig. 1. It is composed of a 2-conductor transmission line with two electric wires per phase and a single line called the overhead ground line, and these lines are supported by steel transmission towers. Most power transmission methods use 3 phases per circuit, and this is called the three-phase alternating current transmission method⁽³⁾. This line is composed of three phases on both the left and right (2-circuit).

In addition, the distance between transmission lines and

Fig. 1. Structure of transmission instrument.

Fig. 2. UAV data example (90 m altitude).

forests is short, and regular observation and maintenance work are necessary.

2.2 Data Used

The UAV used in this study is the Phantom 4 Pro V2.0 manufactured by DJI⁽⁴⁾. Still image data were acquired on November 12, 2018 using the UAV's inbuilt visible light camera. The UAV flight altitudes were 90 m and 120 m. The UAV was flown obliquely above the transmission lines, and the capturing angle was set to the direction of the transmission instruments. In addition, still images, which were later captured, overlap by 80% or more for 3D reconstruction⁽⁵⁾. At flight altitudes of 90 m and 120 m, the UAV data covered approximately 3 cm and 4 cm, respectively, on the ground just below the transmission lines. Fig. 2 shows an example of the captured UAV data.

3. Proposed Method

In this paper, we propose a method for calculating the separation between the transmission lines and forest by performing 3D reconstruction from the acquired UAV data. First, to perform 3D reconstruction of transmission lines from the acquired UAV data, transmission line definition and

Fig. 3. Transmission line enhanced image.

enhancement pre-processing was performed to create an enhanced image of the transmission lines. Thereafter, 3D reconstruction was performed using SfM from the transmission line enhanced image. Finally, the separation distance between transmission lines and forests was calculated from 3D reconstruction.

3.1 Transmission Line Definition

In addition to the fact that the width of the transmission line is as thin as approximately 3 pixels, it has been recognized that the visibility of this line decreases due to the surrounding environment. Therefore, the transmission line was extracted from the UAV data by defining it manually.

First, with the image end and the steel tower as the end, both ends of each transmission line and several points on the transmission line were selected. Next, a Catmull-Rom spline curve⁽⁶⁾ is created from the selected points. This curve is defined as a transmission line, and subsequently, enhancement processing of transmission line is performed, as described in Section 3.2.

3.2 Transmission Line Enhancement Processing

An enhanced image of the transmission line was created for its 3D reconstruction using SfM. First, the result of dilating⁽⁷⁾ the thickness of the spline curve defined in Section 3.1 up and down by 6 pixels is extracted. Next, interpolation of the transmission line phases was performed. Specifically, in each phase, the upper transmission line was dilated downward only, and the lower transmission line was dilated upward only. Finally, the enhanced transmission line area was divided into colors for each phase and drawn on the original image to create a transmission line enhanced image. In addition, to prioritize the reconstruction of the transmission lines below, using magenta, yellow, cyan, and red for coloring, transmission line enhancement processing was applied to only the lower four phases. Fig. 3 shows the results of enhancing the transmission lines shown in Fig. 2.

Fig. 4. Result of building dense point cloud.

3.3 3D Reconstruction

Reconstructing the transmission instrument and its surrounding environment in a 3D space is beneficial for visually determining the separation distance. Therefore, based on the UAV data, 3D reconstruction of the transmission instrument and its surrounding environment was performed by SfM, which is a technique for estimating the position and orientation of a camera and the shape of an object from points having common features (i.e., tie points) among multiple images^(8,9). The 3D data created by SfM can be measured in various ways by setting a coordinate system. In this study, Agisoft PhotoScan Professional Version 1.4.3 manufactured by Agisoft⁽⁵⁾, was used as the SfM software. In 3D reconstruction, the camera position and orientation were first estimated from the tie point matching results and the camera's internal information, such as focal length. Subsequently, a dense point cloud was built based on the estimated camera position. Fig. 4 shows the results of a dense point cloud that was built.

3.4 Separation Measurement

In this section, we propose a method for measuring the distance based on the reconstructed 3D point cloud information. Specifically, the cross section perpendicular to the transmission line is extracted from the 3D reconstruction data, and the shortest distance between the transmission line and the forest is estimated.

(1) Voxel Conversion

The 3D point cloud is converted into a voxel model⁽⁷⁾ with a resolution of $10\text{ cm} \times 10\text{ cm} \times 10\text{ cm}$ to determine the measurement error in the separation measurement within 30 cm or 50 cm. An orthographic projection of the converted model from the Z-axis direction (XY plane orthographic voxel model) is shown in Fig. 5 (a).

(2) Rotation Processing

First, focusing on the color of the transmission lines, the transmission line area is detected. Next, the angle of the

(a) Before rotation.

(b) After rotation.

Fig. 5. XY plane orthographic voxel model.

transmission lines on the XY plane orthographic voxel model is calculated using a Hough transformation⁽⁷⁾, and the point cloud before voxel conversion is rotated. The point cloud subjected to the rotation processing is converted again into a voxel model with the same resolution. The model after rotation is shown in Fig. 5 (b).

(3) Transmission Line Area Specification and Classification

In the separation measurement, the cross section obtained by cutting the voxel model perpendicularly to the Z-axis direction (XZ cross section) is used, as shown in Fig. 6. First, as shown in Fig. 7, the upper left start point (X_0, Y_0) , width (w), and height (h) of the area surrounding all transmission lines are manually specified. This process is performed only on the one XZ cross section where the lowest phase transmission line is reconstructed. Next, the transmission lines are automatically classified into each phase using positional information of the transmission line continuously between adjacent cross sections. This process produces a magenta grid, as shown in Fig. 8. The specific flow of this process is shown in Fig. 9. At the same time, the area of the steel tower is defined by the brown rectangle shown in Fig. 8 and excluded from the scanning targets of the transmission line voxels.

(4) Shortest Distance Calculation

Based on the classification result of the transmission lines, the shortest distance between the transmission lines and the forest is calculated for each cross section at arbitrary coordinates.

4. Reconstruction Result

4.1 Reconstruction of Transmission Lines

The results for the reconstruction status of transmission lines are evaluated. In addition, the reconstruction rate is calculated as the ratio of the number of XZ cross sections in which the transmission line voxel exists in each phase to the total number of XZ cross sections in the red frame shown in Fig. 10. The definition of phase number is given in Fig. 11. Phase numbers 1 to 6 are transmission lines, and phase numbers 7 and 8 are overhead ground lines. Phase numbers 1 and 2 are close to the ground surface, and phase numbers 3 and 4 are the transmission lines most distant from the steel tower, where the distance to the forest tends to be close. Therefore, distance measurement in transmission lines of phase numbers 1 to 4 are of the highest priority. Therefore, in addition to the recovery rates of phase numbers 1 to 4, the average recovery rates of phase numbers 1 and 2 and phase numbers 1 to 4 were calculated. The obtained results are listed in Table 1. By enhancing the transmission lines, they were reconstructed by 80% or more on average. In particular, a high reconstruction rate of 90% or more was obtained for phase numbers 1 and 2.

Fig. 6. XZ cross section.

Fig. 7. Transmission line area specification.

Fig. 8. Transmission line classification and tower area exclusion.

Additionally, to determine how continuous the reconstructed transmission line is from the 3D reconstruction result of the enhanced image, a distribution chart showing the presence or absence of transmission line reconstruction for each phase at every coordinate is shown in Fig. 12. In this chart, the Y coordinate is taken as the horizontal axis, and each phase number is taken as a point on the vertical axis. Therefore, the points plotted in the distribution map indicate transmission line voxels. It is observed from Fig. 12 that the transmission line was extensively reconstructed. In particular, in phase numbers 1, 2, and 4, the transmission line was continuously reconstructed in the range of 200 m or more.

The above results suggest that transmission line enhanced images are useful for 3D reconstruction of transmission lines.

Fig. 9. Flow chart of transmission line area classification.

Fig. 10. Transmission line reconstruction rate calculation target range (red frame) and separation measurement example coordinates (orange line, Section 4.3).

Fig. 11. Definition of phase number.

Table 1. Reconstruction rate of transmission lines.

Phase No.	Rate
1	95.75%
2	94.11%
3	48.44%
4	83.08%
Average of 1 and 2	94.92%
Average of 1 to 4	80.34%

Fig. 12. Distribution chart of transmission line reconstruction.

4.2 Evaluation of Reconstruction Accuracy

To evaluate the accuracy of 3D reconstruction based on actual dimensions, the accuracies of the tower structure, forest height, and building height were verified. To determine the accuracy of the steel tower structure, we compare the steel tower structure diagram provided by Tohoku Electric Power Co., Inc. with the transmission line enhanced rotation model (Fig. 5 (b)). For the heights of the forests and buildings, we compare the measurement results of a laser range finder (TruPulse 200 manufactured by Laser Technology Inc.⁽¹⁰⁾) with the wide area original image model (Fig. 13). The target range of the error is within 0.5 m for the forests and 0.3 m for the buildings.

The measurement results for the steel towers are shown in Table 2. All obtained results reconstructed the steel tower in 3D within the target error range. In addition, the measurement objects in the forests and buildings are shown in Fig. 13, and the measurement results at the height of the measurement objects are shown in Table 3. For the buildings, we obtained a 3D reconstruction within the target error range. However, in the case of the forests, they were outside the target error range. This is because it is difficult to determine the position of the root of the forest in 3D reconstruction. Therefore, it is necessary to set a clear reference point separately from the root of the forest and to measure the height difference between it and the top of the forest.

4.3 Results of Separation Measurement

As an example of separation measurement, Fig. 14 shows the result in the XZ cross section of the orange line shown in Fig. 10. By making the transmission line parallel to the Y axis, it is possible to calculate the separation distance at any position along the transmission line. Moreover, as a result of classifying the transmission line by each phase, it is possible to measure the separation distance between the transmission line and the forest for each phase on a one-to-one basis.

5. Conclusions

In this study, we analyzed a method for measuring the separation distance between transmission lines and forests using 3D reconstruction from UAV data. The results obtained are summarized below.

- (1) Using a transmission line enhanced image, it is possible to reconstruct the transmission line around a forest, in a wide range and continuously

Fig. 13. Wide area original image model and measurement target.

Table 2. Measurement results for steel tower.

Between phase No.	Voxel model	Correct value	Error
1 and 3	7.2m	7.0m	0.2m
3 and 5	8.5m	8.4m	0.1m
1 and 2	14.9m	14.6m	0.3m
3 and 4	18.9m	18.6m	0.3m

Table 3. Measurement result for height of forests and buildings.

Measurement target	Voxel model	Measured value	Error
Forest 1	32.4m	33.3m	-0.9m
Forest 2	31.0m	30.3m	0.7m
Building 1	5.7m	5.8m	-0.1m
Building 2	8.3m	8.1m	0.2m

Fig. 14. Separation measurement result example (Y=81.3).

in 3D.

- (2) 3D reconstruction by SfM can reconstruct steel towers and structures having dimensions close to the measured values.
- (3) With the 3D reconstruction data, it is possible to calculate the separation distance for each cross section by making the transmission line parallel to an arbitrary axis.
- (4) By classifying the transmission line according to each phase, it is possible to calculate the distance of separation between the transmission line and forest as the shortest distance on a one-to-one basis.

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