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Original article

# Transmission Lines Rights-of-Way Mapping Using a Low-cost Drone Photogrammetry

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**Abstract**

Electric transmission towers are facilities to transport electrical power from a plant to an electrical substation. The towers are connected using wires considering the wire tension and the clearance from the ground or nearby objects. The wires are installed on a rights-of-way that is a strip of land used by electrical utilities to maintain the transmission line facilities. Trees and plants around transmission lines must be managed to keep the operation of these lines safe and reliable. This study proposed the use of a low-cost drone photogrammetry for the transmission line rights-of-way mapping. Aerial photogrammetry is carried out to generate a dense point cloud around the transmission lines from which a DSM (Digital Surface Model) and DTM (Digital Terrain Model) are created. The lines and nearby objects are separated using nDSM (normalized Digital Surface Model) and the noises are suppressed in the multiple image space for the geospatial analysis. The experimental result with drone images over two spans of transmission lines on a mountain area showed that the proposed method successfully generate the rights-of-way map with hazard nearby objects.

Keywords : Transmission Tower, Power Lines, Rights-of-way, Drone, Photogrammetry

## 1. Introduction

Electric transmission towers and lines are used to transport electrical power from a plant to an electrical substation. The interval between towers is determined considering the construction cost and the safety. Note that the interval should be optimal to reduce the number of towers and to secure the proper cable tension and safe clearance from the ground. Transmission lines carry high voltages of electricity over long distances. They are supported by large steel lattice structures installed on property called a rights-of-way.

An electric transmission line rights-of-way is a strip of land used by electrical utilities to construct, operate, maintain and repair the transmission line facilities. The width of a rights-of-way depends on the voltage of the line and the height of the structures. Most transmission towers and lines are installed on mountain areas so that trees and plants around the lines must be managed to keep the operation of these lines safe and reliable.

Trees are a major cause of electrical outages through tree contact with conductors during storms (Huff, 2006; Poulos and Camp, 2011). Tree contact with transmission lines is a leading cause of electric power outages and a common cause of past regional blackouts, including the

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August 2003 blackout that affected 50 million people in the Northeast United States and Canada. In Korea, an accident was reported in 2018 because of the contact of a tree and the wire in Changwon. Trees in the rights-of-way that can grow tall enough to jeopardize safety and reliability and side trees located off the rights-of-way, but with branches that reach into the rights-of-way should be monitored.

The rights-of-way monitoring must be conducted but the poor accessibility to the lines limit the monitoring work because most transmission lines are placed at the mountain area. Therefore the study using a terrestrial 3D laser scanner for transmission tower monitoring (Kim, 2014) is limited. Remote sensors such as LiDAR (Light Detection And Ranging), aerial sensors mounted on an aircraft, and recently popular drones are favored for the work. Pfifer (2008) presented the transmission line mapping using helicopter-mounted LiDAR. They processed the point cloud using a morphological filtering and the Hough transform for the transmission line estimation. Kremer (2011) used a multi-sensor platform of LiDAR and optical sensors for the transmission line mapping and Im *et al.* (2015) studied monitoring the transmission lines and towers using a drone-mounted LIDAR. The focus of these studies is to investigate the data acquisition and geospatial accuracy analysis, not the feature extraction.

In this study, we used a low-cost drone for transmission wires rights-of-way monitoring. Aerial photogrammetric processing of multiple overlapping images produces a dense point cloud around the transmission lines and towers. Then the point cloud is used for DSM (Digital Surface Model) DTM (Digital Terrain Model) creation, and followed by nDSM (normalized Digital Surface Model) generation. The point cloud is further classified into wires and nearby objects for the rights-of-way mapping and the geospatial analysis.

The paper is structured as follows: In Section 2, the proposed method is explained including the flowchart, transmission line extraction and filtering, and the rights-of-way mapping. The experimental results are presented in Section 3, followed by conclusions in Section 4.

## 2. Method

The proposed method is depicted in Fig. 1. Aerial images are acquired along the transmission wire with an overlap for the bundle adjustment. The adjusted images are used for the point cloud generation through the dense image matching. First, the point cloud is classified into three categories in the object space. In the step, the height information from the ground is used. The classification is further processed in the multiple image space for more precise transmission line extraction. Finally, the point cloud of transmission line are used for the rights-of-way mapping.

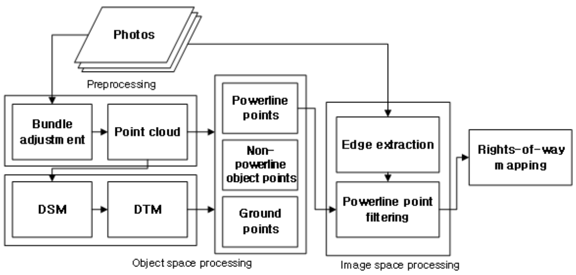



**Fig. 1. Flowchart of the study**

### 2.1 Data acquisition and preprocessing

For transmission line mapping application using a low-cost drone, the safety and GSD (Ground Sampling Distance) of images are taken into account to determine the flying height. The GSD depends on the flying height, the focal length and the pixel pitch of the camera. A lower flying height, a longer focal length, and the smaller pixel pitch increase the resolution of the acquired images (small GSD). Secondly, the overlap between the images are planned. For aerial photogrammetry, the conventional overlaps range 60~80%. A higher overlap gives more options to select images for mapping while it causes more time to acquire more number of images.

The acquired images are bundle-adjusted to estimate the accurate position and attitude of each image. The image are matched to one another to extract tie points (keypoints) that are used for the bundle adjustment. For a low-cost drone, the adjustment is carried out in a way of the self-calibration for the better focal length and lens distortion parameter estimations.

## 2.2 Transmission line extraction

The separation between transmission line and non-transmission line is carried out in two spaces; object and image spaces. First, the dense point cloud of the target area is processed in the object space for the terrain extraction. DSM is created from the point cloud and the morphological opening filtering is applied to generate DTM. The morphological opening filtering is a basic noise removal processing that removes small objects from an image as shown in Eq. (1). In other words, erosion operation removes objects that are smaller than structuring element B and dilation operation restores the shape of remaining objects.

$$A \circ B = (A \ominus B) \oplus B \tag{1}$$

where $A$ denotes the target data, $B$ is the morphological operator, and $\ominus$, $\oplus$ denotes erosion and dilation, respectively.

The point cloud can be separated by the simple difference with the DTM. The height difference can be used for the classification criteria. As the result, we can obtain three point clouds, namely transmission line points, non-transmission line points, and ground points, respectively. Note that they may contain much noise due to the simple approach. For example, the transmission line points contain some other points, and vice versa.

Following the object space processing, we move to the image space processing to suppress the noise. Transmission line and points are projected using the collinearity equation into each image to check whether they are properly classified. To prepare the image space processing, the line extraction is carried out in the image space using a simple line extraction template. Since transmission lines show very smooth curve in the image, a long line extraction template can be used (Oh and Lee, 2018). For the case that the transmission lines are aligned vertically in the image space, the vertical template is used as shown in Fig. 2. The template has 2 in the middle and –1 in the edge to impose higher weight in the middle. Therefore, transmission line pixels that show high contrasts with the background can be easily extracted. However, the line extraction produce not only transmission line feature but noises that should be suppressed. Therefore, we suppressed line components that has shorter length than a threshold assuming those short components are noises.

| | | |
|---|---|---|
| -1 | 2 | -1 |
| -1 | 2 | -1 |
| -1 | 2 | -1 |
| … | … | … |
| … | … | … |
| -1 | 2 | -1 |
| -1 | 2 | -1 |
| -1 | 2 | -1 |

**Fig. 2. Line extraction template for vertical lines**

Fig. 3 depicts the projection of points into the image space to check the points are on the transmission lines in multiple images. A point in object space is projected into the multiple images and classified if the point is located on the line features in the image space.

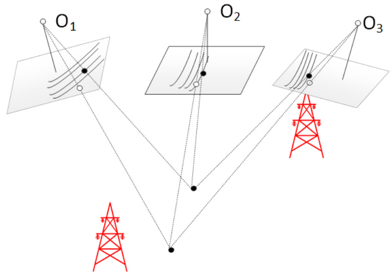



**Fig. 3. Transmission line point filtering in image space**

## 2.3 Rights-of-way mapping

Fig. 4 depicts a clearance guideline that shows the wire zone and the border zone with the potential hazard tree. It is a site explicit way of dividing the rights-of-way width into three distinct management zones from edge to edge: the border zone, the wire zone, and another border zone. Some very short woody shrubs are promoted in the wire zone; whereas shrub–short tree cover types (taller woody vegetation) are allowed to grow in the border zones (Ballard *et al.*, 2004). Note that not all of the rights-of-way area under the conductors needs to be treated as ‘wire zone’. But, management needs and objectives might still warrant that some or all of the area under the wires in an “effective border zone” (noncritical wire zones) be kept free of most woody vegetation.

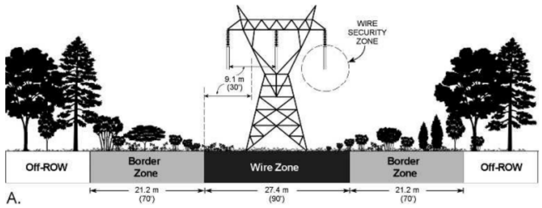



**Fig. 4. Tree-trimming clearance guidelines (Ballard *et al.,* 2007)**

Regarding the wire security zone, federal standards in United Sates mandate that utilities have a transmission vegetation management program to prevent outages on the transmission system as Table 1.

**Table 1. Minimum vegetation clearance distances for alternating current voltages (meters)**

| ( AC ) Nominal System Voltage (KV)+ | ( AC ) Maximum System Voltage (kV)[21] | MVCD meters Over sea level up to 153 m | MVCD meters Over 153m up to 305m | MVCD meters Over 305m up to 610m | MVCD meters Over 610m up to 915m |
|---|---|---|---|---|---|
| 765 | 800 | 3.6m | 3.6m | 3.6m | 3.7m |
| 500 | 550 | 2.1m | 2.2m | 2.2m | 2.3m |
| 345 | 362[22] | 1.3m | 1.3m | 1.3m | 1.4m |
| 287 | 302 | 1.6m | 1.6m | 1.7m | 1.7m |
| 230 | 242 | 1.2m | 1.3m | 1.3m | 1.3m |
| 161* | 169 | 0.8m | 0.8m | 0.9m | 0.9m |
| 138* | 145 | 0.7m | 0.7m | 0.7m | 0.7m |
| 115* | 121 | 0.6m | 0.6m | 0.6m | 0.6m |
| 88* | 100 | 0.4m | 0.4m | 0.5m | 0.5m |
| 69* | 72 | 0.3m | 0.3m | 0.3m | 0.4m |

In Korea, the guideline on the wire height from the ground is defined as Table 2 according to Korea Electric Association. The guideline presents the height from the ground for different vegetations.

**Table 2. Wire height from the ground (Korea Electric Association, 2012)**

| Voltage | 154kV | 345kV |
|---|---|---|
| pine tree | 21 m | 24 m |
| larch | 24 m | 26 m |
| other trees | 19 m | 22 m |

The rights-of-way mapping requires the information on the center of the transmission lines to define the wire and border zones. The extracted transmission line point cloud is used for the center line estimation in this study. The 3D center line can be estimated by computing SVD (Singular Value Decomposition) of the transmission line point cloud as Eq. (2) for orthogonal axis of the point cloud. The columns of contains the information of the center line vector. The boundary of the wire and border zones can be derived by applying 2D buffering to the center line.

$$A = U\Sigma V^T \quad (2)$$

where $A$ contains normalized transmission line points coordinates, $V$ consists of orthogonal vectors of the input point cloud (the columns $V$ of are the eigenvectors of $A^TA$), $U$ is also orthogonal matrix, $\sum$ contains the singular values.

In addition, given the classified transmission line point cloud, hazardous vegetations along the rights-of-way can be monitored. In this case, the 3D buffering can be used for the feature monitoring near the wire zone and the border zones. Fig. 5 shows an example of 3D buffered area of a transmission line point using the sphere.

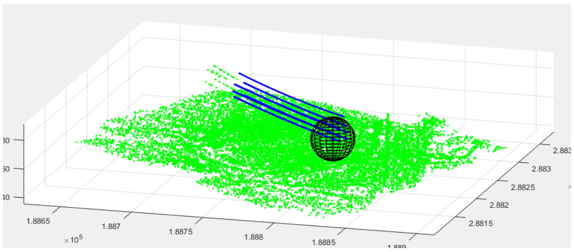


**Fig. 5. 3D buffering of each transmission line point for near feature detection**

# 3. Experiment

## 3.1 Data acquisition and preprocessing

Test images were acquired using a low-cost drone (DJI Phantom 4 Pro v2.0) for two spans of transmission lines in a mountainous area in Busan, Korea as shown in Fig. 6. Transmission tower B is located on the ridge of the mountain and the other two are on the slope. The spans between the transmission towers are about 360m and 180m. Table 3 shows the specification of the drone and the camera. The focal length of the installed camera is about 8.5 mm and the camera produces 20 mega pixels images. The flying height of the drone was at about 40~50m above the power lines and the GSD of the transmission lines was estimated to better than 3cm. Each span data were acquired in separate mission with total four strips of images with 80 % overlap. The two spans data were pre-processed including the bundle adjustment in a commercial software (Pix4D Mapper). In this experiment, GCPs (Ground Control Points) were not used because this application does not require high absolute positional accuracy.

**Table 3. Specification of the drone and camera**

| Drone | | Camera | |
|---|---|---|---|
|  | |  | |
| Weight | 1375 g | Focal length | 8.5 mm |
| Max speed | 72 km/h | Pixel pitch | 0.00234 mm |
| GNSS | GPS/GLONASS | Sensor size | 5472x3648 |

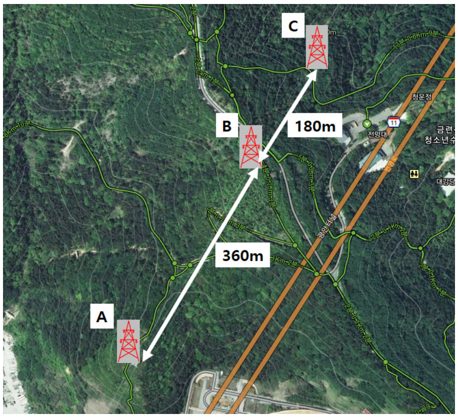



**Fig. 6. Test area (two spans)**

## 3.2 Point cloud processing in object space

The point cloud is generated with the density of 55 points per $m^3$ as shown in Fig. 7. Note that the point cloud is not classified yet.

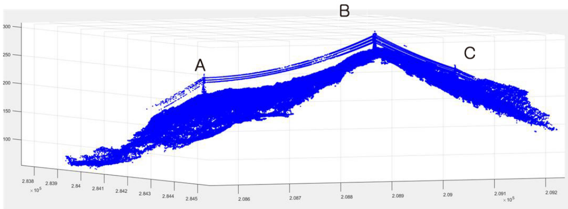
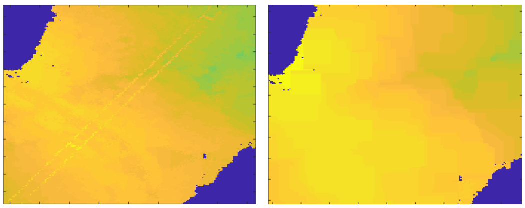



**Fig. 7. Generated point cloud (before classification)**

The point cloud is interpolated for the DSM of one-meter spatial resolution(Fig. 8(a)). Then we applied the morphological opening process using 30 meters square structure to generate DTM in Fig. 8(b). The parameter 30 meters was chosen considering the width of the transmission tower and vegetation widths. The objects with smaller widths than the parameter are removed from DSM for DTM.



(a) (b)

**Fig. 8. Rasterized elevation model (a)DSM and (b)DTM**

In the next step, we subtracted the DTM from the point cloud to compute the height information from the ground(terrain) because the DTM serves as the ground height. Applying thresholds to the object height, we obtained the resulted point cloud as shown in Fig. 9 that colors show each class. The red color shows the transmission line, green is for non-transmission line, and the blue is the ground. We tested different thresholds 10, 15, and 20 meters for the transmission line point classification. As shown in Fig. 10, lower thresholds tend to classify more non-transmission line points to transmission line points.

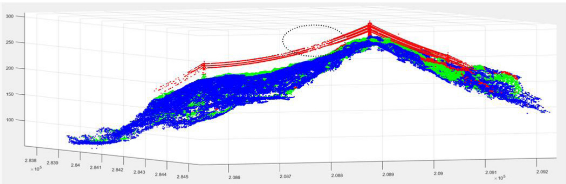


**Fig. 9. Classified point cloud using height information (red: transmission line, green: non-transmission line, blue: the ground)**

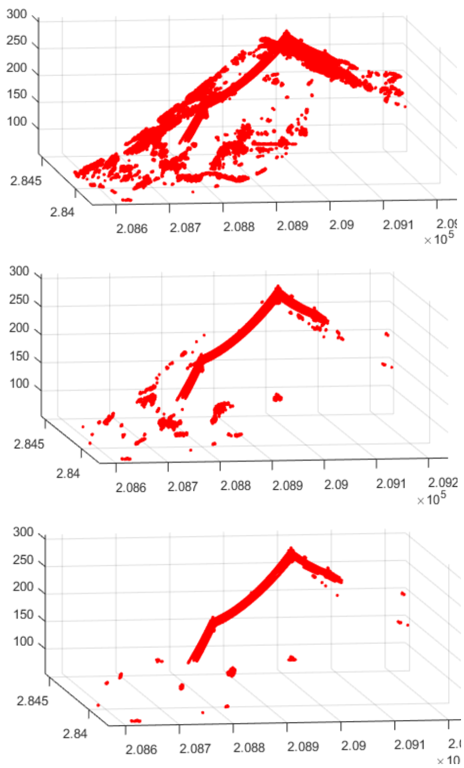



**Fig. 10. Transmission line extraction using different height thresholds (from left: 10m, 15m, 20m)**

Note that a raster processing approach using nDSM was not used for feature classification because the interpolated DSM may lose transmission line information over low point density as highlighted in Fig. 11.

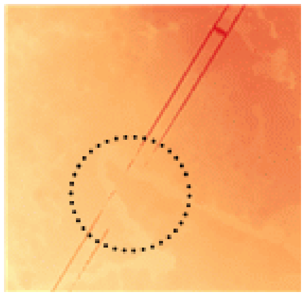
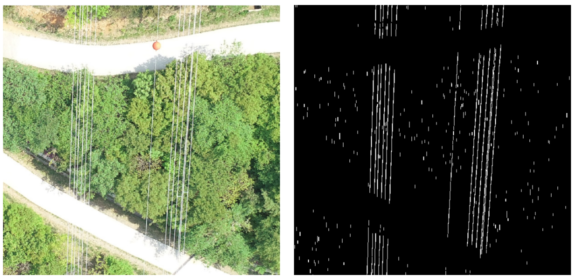


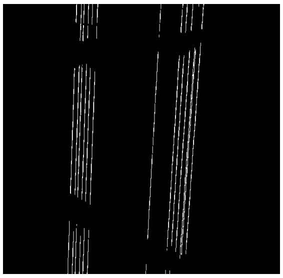
**Fig. 11. Information loss of transmission lines in raster processing**

### 3.3 Point cloud filtering in image space

As can be seen in Fig. 9, the point cloud classification is not accurate and noisy. For example, many non-transmission line points on the right side are classified into the transmission line points. Therefore, we performed the point filtering in the image space. First, we extracted transmission line location in each image as a sample is shown in Fig. 12(a). Fig. 12(b) shows the result of the morphological opening and Fig. 12(c) shows the noise-removed result. The 9x2 pixels of structure was used for the morphological process and the feature length less than 100 pixels was considered as non-transmission lines.



(a) (b)



(c)

**Fig. 12. Line extraction example (a) drone image (b) morphological opening (c) noise removal**

Fig. 13 shows the result of image space filtering with a threshold of 6 photos. Compared to Fig. 10, most of non-transmission line points are removed while a few noisy points are observable near transmission lines.

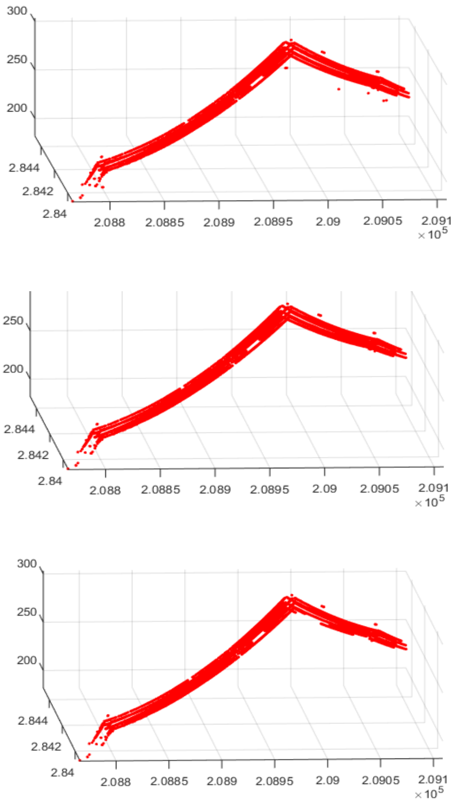



**Fig. 13. Transmission line filtering in the image space for different height thresholds (from left: 10m, 15m, 20m)**

## 3.4 Rights-of-way mapping

Given the transmission line points, the centerline of the transmission lines is estimated before the rights-of-way mapping. In Fig. 14, the classified transmission line points in red are used to derive the center line in black line.

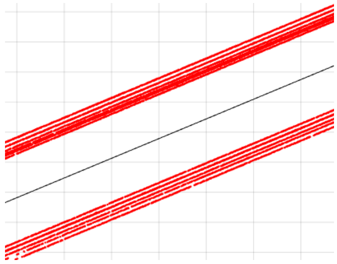


**Fig. 14. Estimated center line of transmission line points (top view)**

Then we applied the geospatial buffering to the center line to extract the wire and border zones using the widths of 27.4m and 21.2m of Fig. 4. The experimental result is shown in Fig. 15 with the color difference. The geographic features or vegetations in this zone should be periodically monitored.

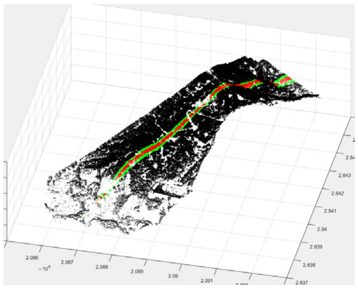


**Fig. 15. Estimated zones along the transmission line (red color, width 27.4m) and border zone(green color, 21.2m from the wire zone)**

In addition, the extracted transmission line point cloud is used to monitor the adjacent vegetation using 3D buffering. As an experiment, we applied 3 meters to define the wire security zone as described in Fig. 4, but no feature was detected for the test site. Therefore, we simulated the data by increasing the elevation of the features by 10 meters and continued the analysis. Fig. 16 shows the result of the analysis where features in red color are detected within the wire security zone.

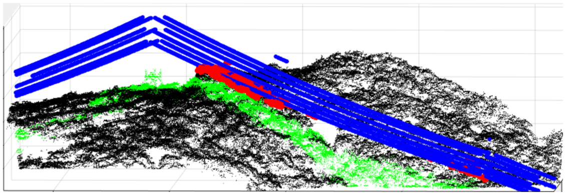


**Fig. 16. 3D buffering for feature detection in security wire zone (simulated) (blue color: transmission line, green: rights-of-way, red: hazardous objects)**

## 4. Conclusion

The application of a low-cost drone was studied for transmission wire rights-of-way monitoring. Aerial photogrammetry was carried out to generated the point cloud of the target area, and the transmission line points were extracted both in the object and multiple image spaces. The use of multiple images was helpful to filter out noises in the object space classification result. The extracted transmission line points were used to estimate the center line of transmission lines which define the wire and border zones. In addition, the transmission line points was helpful to monitor adjacent geographic features and vegetations by applying 3D buffering and geospatial analysis. Future study will include the use of multispectral camera for better detection of the vegetation information around the transmission wire. In addition, the ground truth data will be acquired and compared with the result for the quantitative evaluation.

## Acknowledgements

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