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Original article

Automatic Power Line Reconstruction from Multiple Drone Images Based on the Epipolarity

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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 power lines that are installed with a proper sag by loosening the cable to lower the tension and to secure the sufficient clearance from the ground or nearby objects. The power line sag may extend over the tolerance due to the weather such as strong winds, temperature changes, and a heavy snowfall. Therefore the periodical mapping of the power lines is required but the poor accessibility to the power lines limit the work because most power lines are placed at the mountain area. In addition, the manual mapping of the power lines is also time-consuming either using the terrestrial surveying or the aerial surveying. Therefore we utilized multiple overlapping images acquired from a low-cost drone to automatically reconstruct the power lines in the object space. Two overlapping images are selected for epipolar image resampling, followed by the line extraction for the resampled images and the redundant images. The extracted lines from the epipolar images are matched together and reconstructed for the power lines primitive that are noisy because of the multiple line matches. They are filtered using the extracted line information from the redundant images for final power lines points. The experiment result showed that the proposed method successfully generated parabolic curves of power lines by interpolating the power lines points though the line extraction and reconstruction were not complete in some part due to the lack of the image contrast.

Keywords : Power Lines, Epipolar, Drone, Transmission Tower, Photogrammetry

1. Introduction

Electric transmission towers and power 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.

It is important to periodically monitor the power lines. High cable tension is not good for safety though it provides with good clearance from the ground by lowering the cable sag. In contrast, the excessive sagging can decrease the cable tension for safety, but it degrades the durability of the power lines and decreases the clearance from the ground. In addition, weather conditions such as strong winds, temperature changes, and a heavy snowfall make the power lines not only to expand or contract, but to swing to touch the nearby objects.

The monitoring of the power lines has been limited. The poor accessibility to the power lines limit the monitoring work because most power lines are placed at the mountain area. For the reason, it is favored to use remote sensors such as LiDAR (Light Detection And Ranging) or aerial sensors

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mounted on an aircraft. But it is costly and limited due to the aviation regulations to operate an aircraft along the power lines, even though it can cover large area of interests. Another limitation for the power lines monitoring is that the manual operation is time-consuming either using the terrestrial surveying or the aerial surveying.

We utilized multiple overlapping images acquired from a low-cost drone to automatically reconstruct the power lines points in the object space. Researches have been carried out to extract power line information in 2-D space from aerial photos (Yan *et al*., 2007; Li *et al*., 2010; Yang *et al*., 2012; Sharma *et al*., 2014). Hough transform, a morphological filter, and a fuzzy C-mean clustering are used to extract power lines by suppressing noises from the background geographic features. Some researches focused on the 3D reconstruction of power lines based on the stereo photogrammetry. Jozkow *et al*. (2015) generated a point cloud of power lines using a dense image matching. Zhang *et al*. (2017) proposed a semi-patch matching algorithm for the power line inspection using stereo images. Experiments of the researches are limited to the some part of the power line, not for whole 3D line extraction between a span. Oh and Lee (2017) generated the cubic grid point of a whole span in the object space and filtered them with help of the power line primitives in the image space. The method requires the parameter to bound the region of power lines in the object space for the cubic grid points generation.

The basic idea of this research is to utilize multiple aerial images more than two to extract and reconstruct power lines points by suppressing noise points. Two overlapping images are used to reconstruct power lines primitive in the ground based on the epipolar geometry. The rest of images are used to filter the primitives for the final power lines points. The proposed method shows the difference to Oh and Lee (2017) in the perspective of using epipolarity and not using the cubic grid points generation that requires the boundary of region of power lines.

The paper is structured as follows: In Section 2, the proposed method is explained including the flowchart, the epipolar resampling, the line extraction in image space, and the reconstruction and filtering. The experimental results are presented in Section 3, followed by conclusions in Section 4.

2. Method

The proposed method is depicted in Fig. 1. Among the acquired images using a drone, two overlapping images are selected for epipolar image resampling. The line extraction is carried out for the epipolar resampled images and redundant images. The extracted lines from the epipolar images are matched together for primitive ground reconstruction. Those primitive points should have a lot of noise components because there are multiple power lines in the images resulting in a lot of mismatches. Therefore they are filtered using the extracted line information from the redundant images for final power lines points.

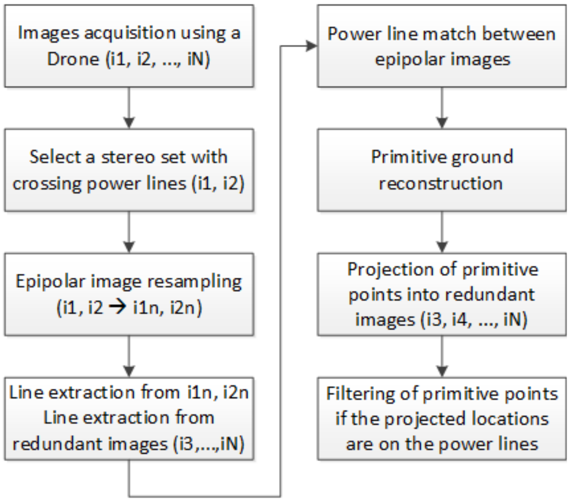


Fig. 1. Flowchart of the study

2.1 Epipolar image resampling

Two overlapping images are selected from the acquired aerial images for the epipolar image generation.

Given the exterior and interior orientation parameters, the epipolar image resampling can be carried out without image matching processes and the fundamental matrix estimation. The orientation angles of the epipolar image plane are determined as Eq. (1) from the orientation angles of input images that are estimated in the bundle adjustment process. The epipolar image resampling is to project the each image pixel of the input images into the epipolar image plane.

$$
\begin{aligned}
\omega_n &= \frac{\omega_1 + \omega_2}{2}, \\
\phi_n &= \tan^{-1}\left(\frac{Z_{L_1} - Z_{L_2}}{\sqrt{(X_{L_1} - X_{L_2})^2 + (Y_{L_1} - Y_{L_2})^2}}\right), \\
\kappa_n &= \tan^{-1}\left(\frac{Y_{L_1} - Y_{L_2}}{X_{L_1} - X_{L_2}}\right),
\end{aligned}
\tag{1}
$$

where, (X_L, Y_L, Z_L) represent the perspective center of the image, ω, ϕ, κ are the orientation angles (roll, pitch, and yaw), and the subscripts '1' and '2' indicate the left and right images, respectively. The subscript 'n' indicates the epipolar image plane.

The two images should be across the power lines such that power lines show distinct x-parallax in the images. As a result, the power lines should be aligned in the vertical direction in the epipolar image space. Note that if input images are selected along the power lines, the power lines and the epipolar line may align nearly parallel. In the case, we cannot pinpoint the conjugate location in another image for one power line point.

The line extraction performance highly depends on the image contrast. Power lines with good image contrast to the background should be relatively easy to be extracted. Fig. 3 shows two image samples that Fig. 3(a) with bare soil background shows poor contrast but Fig. 3(b) shows better contrast with vegetation background. In the experiment of study, the line extraction results for different image contrasts will be present.

(a) (b)

Fig. 3. Comparison of power lines image contrasts depending on the backgrounds. (a) bare soil, (b) vegetation

2.2 Power line extraction

The line extraction is carried out in the epipolar image space using a simple line extraction template. Since power lines show very smooth curve in the image, a long line extraction template can be used. For the case that the power lines are aligned vertically in the epipolar 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, power line pixels that show high contrasts with the background can be easily extracted. If the lines are not vertically aligned, the template can be modified using different angles.

-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

2.3 Primitive ground reconstruction and filtering using redundant images

For each pixel of line component in one of the epipolar image, we searched the match point along the same image line in the other epipolar image as depicted in Fig. 4. Note that the power lines are aligned vertically in the epipolar images. Since there are multiple power lines along the same image line, it is not easy to pinpoint one line. Therefore multiple points are selected and they are used for the ground reconstruction. Note that only one of the points should be correct and the others are wrong. These reconstructed points are called 'power lines primitives' in the study.

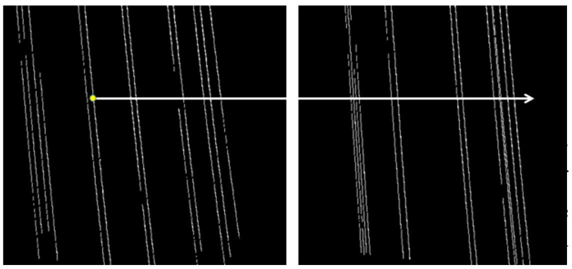


Fig. 4. Match point search along the same line of the epipolar images

equation. Then if the projected location is on the line component in the redundant images, the point is kept. Otherwise the point should be removed. This process was carried out for all primitive points.

3. Experiment

3.1 Data acquisition and preprocessing

Test images were acquired using a low-cost drone (DJI Phantom 4) for one span of power lines in Gwangju, Korea. Table 1 shows the specification of the drone and the camera. The focal length of the installed camera is about 3.6 mm and the camera produces 12.4 mega pixels images. The power lines carry 154 kV electric power and the span between the double-circuit power towers is about 100 m. The flying height of the drone was at about 40~50 m above the power lines and the GSD (Ground Sampling Distance) of the power lines was estimated to about 2 cm. The images of this site show different backgrounds such as the green vegetation, road, and bare soil as samples are shown in Fig. 5(a). Total four strips of images with 80 % overlap were acquired and pre-processed including the bundle adjustment in a commercial software (Pix4D Mapper).

Table 1. Specification of the drone and camera

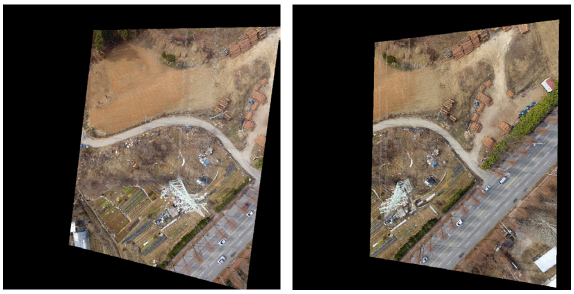
Drone		Camera	
			
Weight	1380 g	Focal length	3.6 mm
Max speed	20 m/s	Pixel pitch	0.00158 mm
Flight time	28 mins	FOV (Field Of View)	94 deg
Global Navigation Satellite System	GPS (Global Positioning System) GLONASS (GLObal NAvigation Satellite System)	Sensor size	4000×3000

3.2 Epipolar image resampling

For each image strip, we selected two overlapping images from the multiple images for the epipolar image resampling. If images acquired parallel to the power lines are used, epipolar lines should be almost parallel to the image line in the resampled image. In the case, it would not be easy to observe x-parallax. The overlapping images are across the power lines such that distinct x-parallax of the lines is observable in both images. Since the bundle adjustment produced the exterior and interior orientation parameters, the information enabled the direct epipolar image resampling without further image matching processes and the fundamental matrix estimation. In the resampling process, the lens distortions such as radial distortions and decentering distortions are corrected.

Fig. 5(b) shows an example of epipolar images. Note that the power lines that are stretched horizontally in the input images are now aligned vertically. The resampled images help us to search the conjugate point by reducing the search space to one image line. In other words, the conjugate point can be searched along the same image line for a power line point in one image, However, it is still not easy to pick the conjugate point because there are multiple power lines along the same image line.

(a)



(b)

Fig. 5. Epipolar image resampling that aligns the power lines along the vertical direction. (a) input images, (b) resampled images

3.3 Line extraction

We used a simple line extraction template. We applied the vertical template of 9 pixels long to the epipolar resampled images considering power lines are smooth curve in the image. The template produces a binary image that contain '1' along the line component and '0' else where. We labeled each extracted line component by analyzing 4-direction connectivity. Then we suppressed line components that has shorter length than 100 pixels assuming those short components are noises.

Fig. 6 show some results of line extraction and noise suppression. Vegetations under the power line show good contrast though the color is not green in Fig. 6(a). The road in Fig. 6(b) creates poor contrast to the power line. We can clearly observe that an image with good contrast to the background produces much better line extraction results.

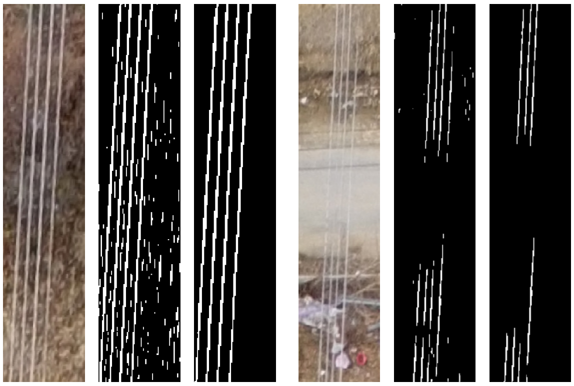


Fig. 6. The line extraction and noise suppression. (a) an image with good contrast, (b) an image with poor contrast

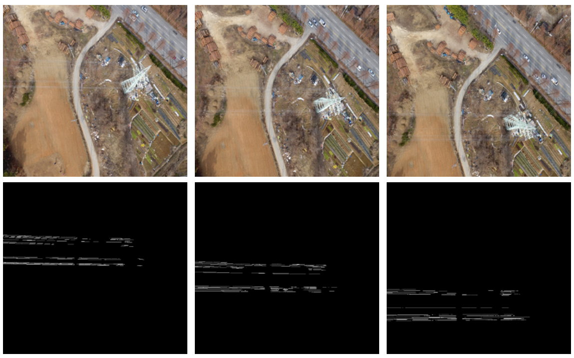


Fig. 7. Lines extracted from redundant images

We also applied the line extraction template for redundant images as results are shown in Fig. 7. But in this case, the line extraction template is designed to extract horizontal lines because those images are not epipolar resampled.

3.4 Primitive ground reconstruction

Lines from epipolar resampled images produce the power lines primitives as a sample is shown in Fig. 8. A lot of power lines primitives are created in the object space because the multiple lines with different x-parallaxes were matched together in the resampled images. Some of the points should be true and the others are wrong. Therefore the next step should be filtering them.

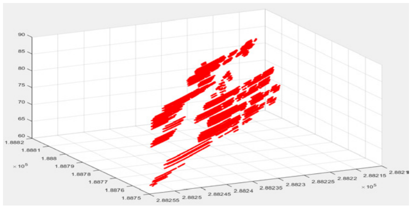


Fig. 8. Reconstructed power line primitive points

3.5 Filtering in the image space

In this stage, we use redundant images to filter the power line primitives. Each primitive point is projected into the redundant images that were not used for the epipolar resampling. If the primitive point is correct, the projected location should be on a line component in the all of the redundant images. Fig. 9 shows a part of a redundant image that shows the extracted power lines in white color. Dots(·) and 'X'symbols indicate the projected primitive point locations.'X'symbols mean that the points are incorrect because they are outside the power lines.

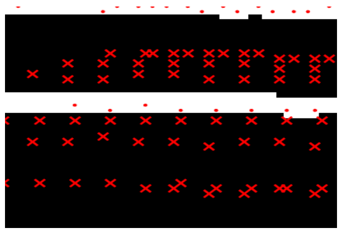


Fig. 9. Projected locations of power line primitive points on a redundant image

In the study that we have three redundant images, we kept the primitive point only if the projected location is on the line component in all of three images.

The process was carried out for four strips of images and the reconstructed power line points are shown in Fig. 10. Each color indicates different image strips. Line extraction seems not complete in some parts due to poor image contrast to the background in the images. But we can clearly identify the shape and linearity of power lines.

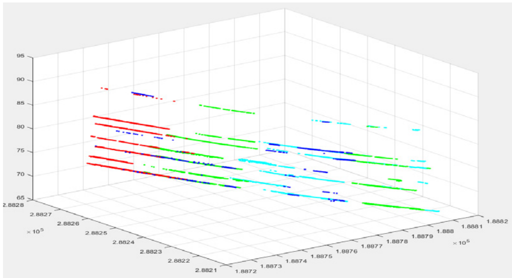
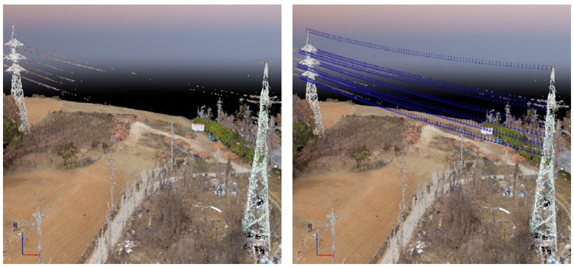


Fig. 10. Filtered power lines points

3.6 Interpolation and display

The filtered power lines points are interpolated using the parabola equation and imported into the commercial software (Pix4D Mapper) for the display as presented in Fig. 11. Fig. 11(a) shows the dense match result of the commercial software where point cloud void along the power lines is observable. We already observed that the proposed method extracted dense power lines points though they are not complete in Fig. 10. However, the interpolated points better describe the parabolic shape of power lines in Fig. 11(b).



(a) (b)

Fig. 11. Reconstructed power lines. (a) commercial software result, (b) proposed method

4. Conclusion

We utilized multiple aerial images more than two acquired from a low-cost drone to automatically reconstruct 3D power lines points. Among multiple images, two images crossing the power lines were selected and directly epipolar resampled using the interior and exterior orientation parameters from the bundle adjustment. Line extraction was carried out for the epipolar resampled images and the rest of images using a simple template with different directions. Line extraction performance was highly affected by the image contrast between the power lines and the background. The line information from the epipolar images was used for the reconstruction of power lines primitives in the ground. But the primitives contain a lot of noises because multiple power lines exist in each image. Therefore the line information from the rest of images was required to suppress the noise primitives. Though the line extraction and reconstruction were not complete in some part due to the lack of the image contrast, the process successfully generated parabolic curves of power lines by interpolating the power lines points. In the future, we plan to carry out the spatial analysis of power lines and hazard mapping. We also plan to study the automation of the whole process including the selection of optimal images among the multiple images.

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