PHOTOGRAMMETRIC TECHNIQUES FOR POWER LINE RANGING

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ABSTRACT:

This paper presents a photogrammetric method for power line inspection, which is more informational, automatic and intelligent. The main task in the research is to extract the power line automatically during the flight, and then reconstruct the model of the electricity line through forward intersection. The objects below the power line are matched through VLL (Vertical Line Locus) algorithm. Finally, calculate the distance between the power line and the objects. Experiments were carried out, in which rapid data processing was performed during the flight, and the results proved that photogrammetric method is prior to the traditional method which is time-consuming and less efficient.

1. INTRODUCTION

Power line ranging is a fundamental work to ensure the lines work normally so as to transfer electricity safely. If the distance between the lines and buildings, vegetable go beyond the limit of safety requirement, it would not only bring a plethora of troubles to the citizens around, but also do harm to the whole society. Traditional manual inspection of power lines is subjective, hardly manageable, and error-prone. Recent years, with the development of information technology, how to use the information tools to enhance the power of inspection work has become one of the significant problems to solve.

Current PDA-based power line inspection system allows workers to do the inspection with handheld GPS, which is a kind of intelligence systems. However, the PDA-based inspection can not reach high accuracy with the use of GPS. Besides, PDA-based power line inspection system is labor-intensive, inefficient, and dangerous to some extent [Hongqiao, 2008].

LiDAR technology, with the advantages of fast speed, few out-work, precise and high automation, has seen remarkable development in recent years. Specifically, the accuracy of the laser ranging has reached the few cm level for hard surfaces, which is close to the static survey performance. Although LiDAR technology can provide excellent results, its use is somewhat limited by economic factors, so it is not widely applicable in China [Zujian, 2008].

In the late nineties, especially since the new century, with the rapid development of GPS technology and computer technology, digital photogrammetry theory, technology and equipment have become more mature, which made the power exploration sector attach importance to the photogrammetric method used in power lines ranging. Based on its advantages of acquiring relatively high precise digital images, highly automatic processing and generating accurate surface characterization, photogrammetric technology has made power line inspection more convenient than the PDA method and relatively cheaper than LiDAR method. However, the conventional photogrammetric method based on DSM or DEM, which is time-consuming and lack of efficiency. At this point, how to quickly check the long power lines is an imperative problem. In this paper, an on-line photogrammetric method is proposed to overcome the weakness in off-line procedures for ranging.

2. POWER LINE EXTRACTING

In order to calculate the coordinates of the power line, it is necessary to extract the power line from the image. However, to extract the power line from the image is a non-trivial task for three main reasons. To start with, the width of the power line in the image so fine that it is difficult to be detected by most edge operators. Moreover, in the image, the grey value of the objects' edges in the background is similar to that of power line thus adding a plethora of interference information during the detection of power line. Finally, the result of extraction is often break-lines so the connection is needed in the next process.

2.1 Determination of Initial Point

Before tracing the power line in the image, it is necessary to determine one initial point in the power line. By using the initial point, the search space of the tracing is largely shorten for the reason that it do not need to search every point in the image, so the speed of extraction can be greatly promoted, and tracing with the initial point in the power line can increase the reliability of the results.

The initial point can be calculated by collinearity equations with the object coordinates of the power tower and the elements of exterior orientation by POS:

$$x_0 = -f\frac{a_1(X-Xs)+b_1(Y-Ys)+c_1(Z-Zs)}{a_3(X-Xs)+b_3(Y-Ys)+c_3(Z-Zs)} \qquad (1)$$
$$y_0 = -f\frac{a_2(X-Xs)+b_2(Y-Ys)+c_2(Z-Zs)}{a_3(X-Xs)+b_3(Y-Ys)+c_3(Z-Zs)}$$

Where f=focal length

(x_0, y_0)=image coordinates

(X, Y, Z) =object coordinates of the power line

$(a_1 ... c_3, Xs, Ys, Xs)$ =elements of orientation

2.2 Tracing the Power Line

The tracing of power line in the image starts from the initial point calculated before. The whole process of tracing is shown in Figure 1. The extraction of the power line is based on the typically significant difference in the gray value between the power line and the surroundings. If the grey value of the current point is similar to the previous one, then consider the current point to be the interest point. As it shown in the Figure 1, three direction gradient operators have been chosen, which is widely used in edge detection, to extract the power line in the image. The three directions are 0 degree, 45 degree and -45 degree.

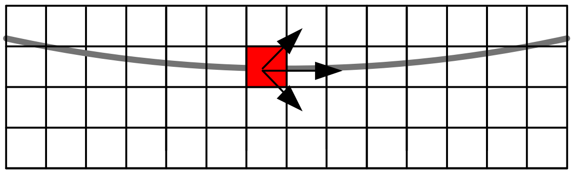


Figure 1. three direction gradient operators

The values of the gradient operators are calculated according to the equations:

$$\begin{aligned} G_{0^\circ} &= \left|g(i,j)-g(i+1,j)\right| \\ G_{45^\circ} &= \left|g(i,j)-g(i+1,j+1)\right| \\ G_{-45^\circ} &= \left|g(i,j)-g(i+1,j-1)\right| \end{aligned} \quad (2)$$

Then select the minimum one among the three values of the gradient operators, so the interest points have been selected according to k.

$$G_k = Min\{G_{0^\circ}, G_{45^\circ}, G_{-45^\circ}\}(k=0^\circ, 45^\circ, -45^\circ) \quad (3)$$

Search the next point according to the same rule until search at the boundary of the image, so that a serial of interest points along the power line have been extracted.

2.3 Searching Direction Constrain

Errors are happened when the power line break in the image, so the gradient operators may trace at wrong direction. In the case, constrain of the searching direction is needed. The direction constrain is synchronous with the tracing for interest points. The processing procedure is below:

First, calculate the slope k between the current point (x_i, y_i) and the initial point (x_0, y_0):

$$k_i = \frac{x_i - x_0}{y_i - y_0} \quad (4)$$

Then, determine whether the direction constrain is needed according to the condition:

$$k - k_0 < threshold \quad (5)$$

Where k_0 is the slope of initial point.

If the current point met the condition, tit will be directly selected as interest point, else the slopes of every directions should be calculated according to the equation:

$$k_{ij} = \frac{x_{ij} - x_0}{y_{ij} - y_0}(j = 0^\circ, 45^\circ, -45^\circ) \quad (6)$$

Select the direction which is minimum difference to k_0:

$$Min\{k_{ij} - k_0\}(j = 0^\circ, 45^\circ, -45^\circ) \quad (7)$$

and the point is chosen as interest points.

2.4 Curve Fitting

The extracted power line points are discrete and sometimes contain errors, and thus, curve fitting is needed. The purpose of curve fitting is twofold: firstly, it can remove errors to some degrees, thus provides a validity check for the extraction of power line point, and secondly, it allows for modeling the power line descriptions as linear features.

The power lines in the image are curves with regular shape and certain trend, so the a conic polynomial is appropriate for the curve fitting:

$$y = ax^2 + bx + c \quad (8)$$

Where (x, y) = coordinate of the extracted points

(a, b, c) = polynomial parameters

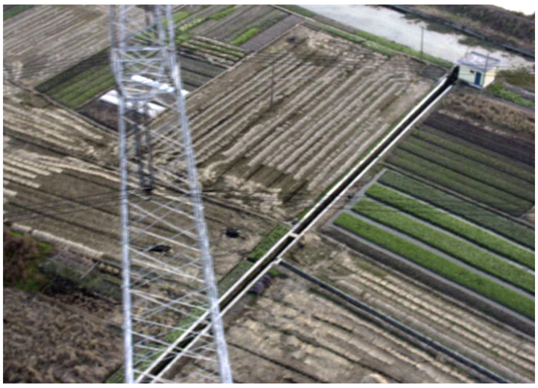
For the reason that the number of extracted points are far beyond the number of polynomial parameters in the conic equation, the least squares adjustment is needed in the calculation.

In order to check the algorithm of power line extraction, the experiment carried out with analog images and the real images. Figure 3 shows the result of analog data and Figure 4 shows the result of real data. In the experiments, the k_0 is set as 0, for the reason that in the real case, the power line traverse the whole image. The threshold is set as 0.05.

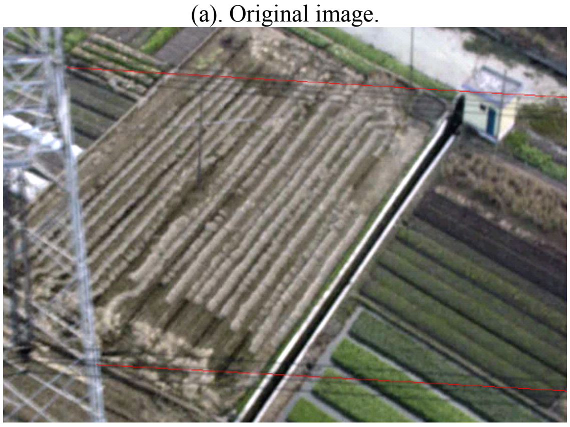
(a). Original image.

(b). power line extraction result

Figure 4. experiment with analog data



(a). Original image.



(b) power line extraction result

Figure 5. experiment with real data

3. VLL MATCHING

After the power line has been extracted from the image, the next step is to calculate the ground coordinates of the objects below the power line. In this processing, VLL (Vertical Line Locus) has been chosen as the matching method. There are several reasons to select the VLL method: To begin with, this method only searches the vertical direction in the object space thus promoting the speed of matching. Likewise, VLL matching is a kind of object-based matching method which has a higher accuracy of point positioning for the reason that it avoids the errors caused by forward intersection.

3.1 VLL Algorithm

The VLL algorithm, being an object-based method for image matching using vertical line locus, can transfer area-based matching to line-based matching, thus greatly enhancing the efficiency of image matching. Gyer (1981) proposed the Vertical Line Locus (VLL) approach. Matching is performed by correlating selected windows centered on points along the projection of a vertical line, and the pair of windows with the highest correlation is selected as the correct match. This approach was implemented on the Kern DSR11 Image Correlator. Grun and Baltsavias (1987) based their method of geometrically constrained least squares matching on the vertical line approach. The planimetric location of an object point is fixed and its elevation is found by moving along a vertical line, using a classical LSM, constrained by the collinearity equations [Annon, 1994]. The processing is shown in Figure 6.

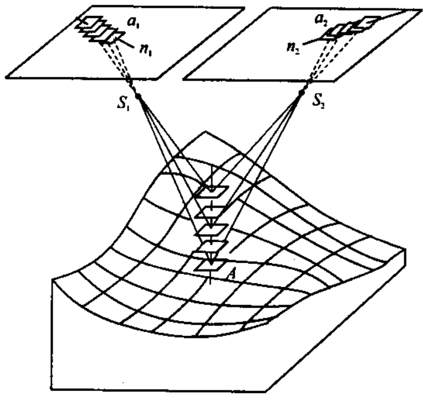


Figure 6. VLL matching

The main steps of the VLL processing are discussed below:

(1)Suppose the plane coordinates (X,Y) of an object and the approximate elevation of the point Z_0. In this case, the (X,Y) is calculated by the coordinates of two power towers (X_1,Y_1) and (X_2,Y_2). The Z_0 is calculated by the height coordinates Z_1 of the first power tower and the height of the tower :

$$Z_0 = Z_1 - h \tag{8}$$

(2)Define the elevation of the point according to the equation:

$$Z_i = Z_0 + i \cdot \Delta Z (i = 0,1,2\cdots) \tag{9}$$

Define the search step ΔZ according to the required accuracy. For example, if the required accuracy is cm level, then choose 0.01m or more small number as search step.

(3)Calculate the photographic coordinates of the left images (x'_i, y'_i) and the right image (x''_i, y''_i) according to the collinearity equation and the elements of exterior orientation acquired by POS.

$$\begin{aligned}
x_i' &= -f\frac{a_1'(X-X's)+b_1'(Y-Y's)+c_1'(Z-Z's)}{a_3'(X-X's)+b_3'(Y-Y's)+c_3'(Z-Z's)} \\
y_i' &= -f\frac{a_2'(X-X's)+b_2'(Y-Y's)+c_2'(Z-Z's)}{a_3'(X-X's)+b_3'(Y-Y's)+c_3'(Z-Z's)} \\
x_i'' &= -f\frac{a_1''(X-X''s)+b_1''(Y-Y''s)+c_1''(Z-Z''s)}{a_3''(X-X''s)+b_3''(Y-Y''s)+c_3''(Z-Z''s)} \\
y_i'' &= -f\frac{a_2''(X-X''s)+b_2''(Y-Y''s)+c_2''(Z-Z''s)}{a_3''(X-X''s)+b_3''(Y-Y''s)+c_3''(Z-Z''s)}
\end{aligned} \tag{10}$$

Where f=focal length

x'_i, y'_i, x''_i, y''_i=image coordinates

X_i, Y_i, Z_i=object coordinates in ground

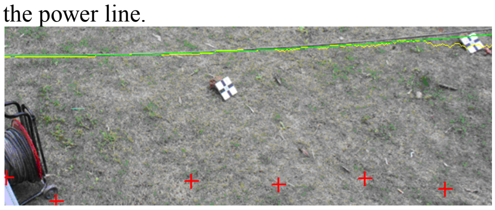
$a'_1 \dots c'_3, a''_1 \dots c'_3, X''s, Y''s, Z''s, X's, Y's, Z's$=elements of exterior orientation

(4)Establish the basic window and the reference window according to (x'_i, y'_i) and (x''_i, y''_i) as center point. Then, calculate the correlation coefficient ρ_i between the two image windows.

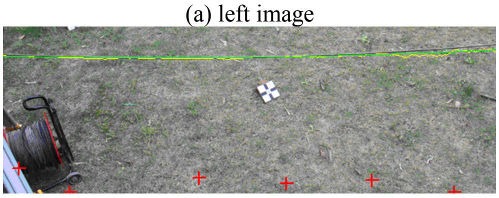
(5)Change the value of i and repeat the step(2),(3),(4), so that a serial of correlation coefficients were calculated. Select the points which have the max ρ_k to be considered as conjugated points and corresponding Z_k would be considered as the elevation of the object.

$$\rho_k = \max\{\rho_0, \rho_1 \cdots \rho_n\} \tag{11}$$

Thus the entire calculation is an iterative processing [Jianqing, 2003]. The matching results are shown in Figure 7, which the red crosses represent the corresponding points of the objects below the power line.



(a) left image



(b) right image

Figure 7. VLL matching result

3.2 Important Factors in Matching

The initial elevation is crucial in VLL algorithm. If the initial value is not relatively correct, it will lead to the situation that the iteration does not converge, thus resulting in wrong points. The experiment carried out with different initial elevation which varied from -0.5m to 1.1m, and the number of correct matching point has been counted. Figure 8 shows the variation of distribution between correct rate and initial elevation. The experiment shows that the variation has a peak around the -0.3m and -0.1m, so that -0.1m has been chosen as the initial elevation. The search distance is another important factor. The experiment carried out with different search distance which varied from 0.2m to 2.2, and the number of correct matching point has been counted. Figure 9 shows the variation of distribution between correct rate and search distance. In the case that the search distance is too long, say longer than 1.5m, the rate of correct point will drop greatly. So did the case with the search distance is too short, for instance shorter than 0.8. As a result, the search distance is set as 0.7meter.

The third factor, which also has effect on the result, is the search interval. Figure 10 shows the variation of distribution between correct rate and search interval. From the figure, the smaller the search interval is, the more accuracy in matching. However, if the search interval was too small, the speed of matching will slow down. Weighed between the accuracy and speed, 0.04m has been selected as the search interval.

The final factor is the size of matching window. Figure 11 shows the variation of distribution between correct rate and search interval. After experiments, it is found out that the smaller window has a more accurate result but more easily lead to mistake, while the larger window has more robustness in matching. The window size in matching is set as 31*31.

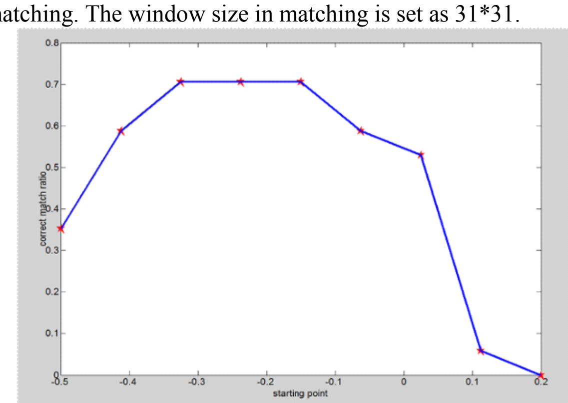


Figure 8. Variation between correct rate and intial elevation. x-axis: initial elevation; y-axix:correct rate

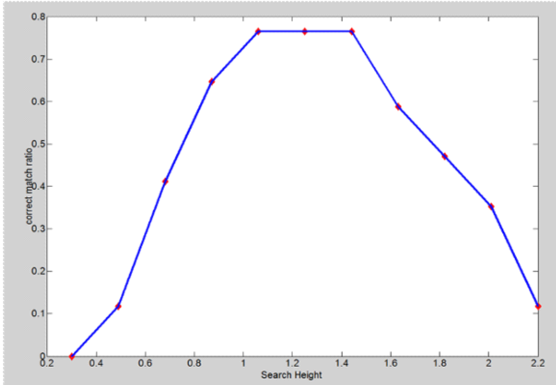


Figure 9. Variation between correct rate and search distance. x-axis: search distance; y-axis:correct rate

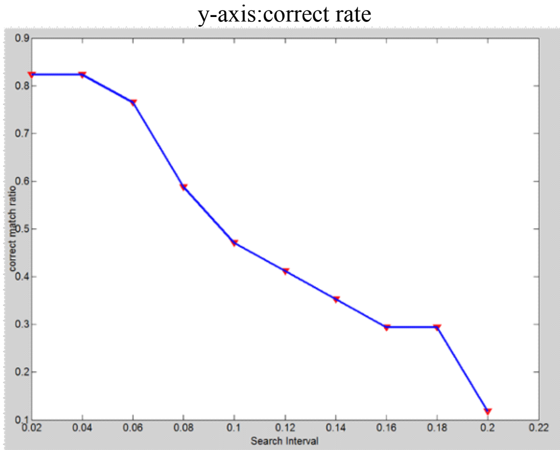


Figure 10. Variation between correct rate and search interval. x-axis: search interval; y-axix:correct rate

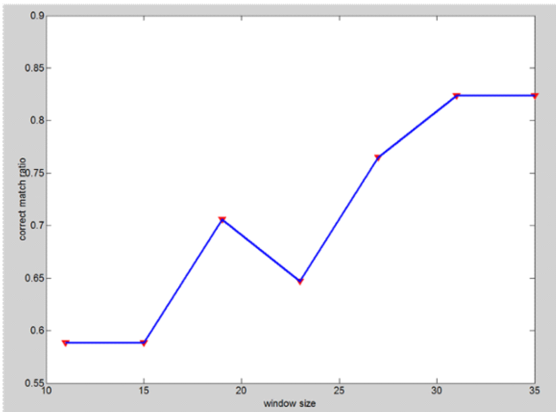


Figure 11. Variation between correct rate and window size. x-axis: window size; y-axix:correct rate

4. POWER LINE 3D RECONSTRUCTION

In order to get the distance between the object and the power line, the ground coordinates of power line should also be known. In the first step, the power lines have already been extracted from the images, however, the extracted two power lines could not directly be used in forward intersection for the reason that the equation of forward intersection is based on point. Consequently, corresponding point in the power lines should be found in the first place, and then, the ground coordinates of the power line could be calculated through forward intersection.

Figure 12 shows the processing of 3D construction of power line. Solid line represents the power lines which are extracted before, while dotted line represents corresponding vertical lines which get from the matching route with VLL. Solid lines and dotted lines intersect at the red points, which considered being the corresponding points of the power line.

Now the image coordinates of the corresponding point in the power line have been calculated, through forward intersection, which is also based on collinearity equation, 3D construction of power line has been accomplished. Table1 show the ground coordinates of the power line after forward intersection.

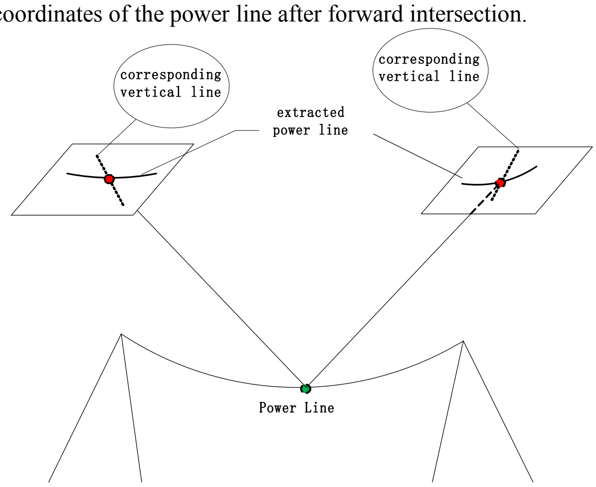


Figure 12. 3D Construction of Power Line

Num	X	Y	Z
P1	2.680485	2.532142	50.526376
P2	3.592669	2.568315	50.187939
P3	4.768225	2.673931	48.538054
P4	5.691482	2.701983	48.379236
P5	6.583491	2.724834	48.217209
P6	7.578928	2.752790	48.038259

Table 1 Coordinates of Power Line(unit: m)

5. EXPERIMENT

Experimental data are real aerial photogrammetric data from helicopter. Using AVT STINGRAY Series IEEE 1394b industry camera, which focal length is 12mm, image size is 1600x1200 pixels and pixel size is 0.0044mm, the helicopter inspect the power lines in Shaoxing, Zhejiang province of China. Elements of exterior orientation are acquired from airborne POS. The first step is pre-processing, including histogram equalization of initial image and the coordinate transformation of the POS data. Next, extract the power lines in the image. Moreover, calculate the coordinates of the objects below the power line by VLL matching. Then, through forward intersection, construct the 3D of power line with the intersection of extracted power line and corresponding vertical line from VLL. The final step is to calculate the distance between the power line and the objects using their ground coordinates. The processing system is developed on Visual C++. The running interface is shown in Figure 13, where the blue lines represent the extracted power line and the red crosses represent the objects below the power lines.

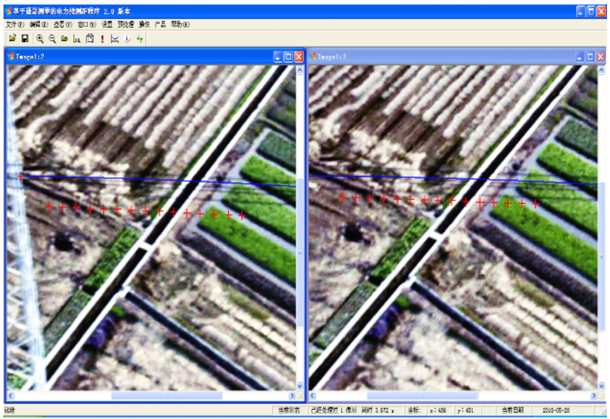


Figure 13. running interface

Figure14 shows the drawing of power lines and the ground objects below, which allows users to visually observe the inspection result of power line. Table2 shows the report of deviation, which contains the coordinates of the objects and their deviation from the power line. That will make it easy to position the dangerous point during the inspection.

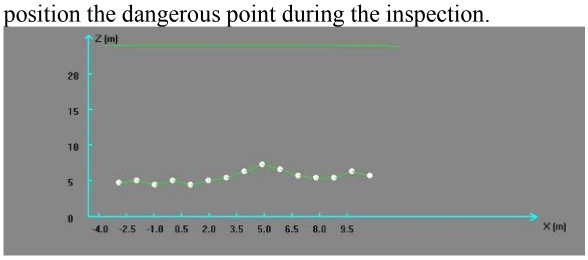


Figure 14. Cross-section of objects below the power line.

	X	Y	Z	deviation
P1	2.761	2.603	12.200	38.326
P2	3.761	2.622	12.800	37.388
P3	4.761	2.640	13.400	35.138
P4	5.761	2.659	13.000	35.379
P5	6.760	2.677	12.400	35.817
P6	7.760	2.696	12.200	35.838
P7	8.760	2.715	12.200	33.844
P8	9.760	2.733	12.800	37.170

Table 2. Deviation report(unit: m)

6. CONCLUSION

The practice of photogrammetric method in power line ranging acquired encouraging initial results. Instead of complex and time-consuming old method in off-line way, the whole data processing of the new method can be automatically completed during the flight, thus greatly reduce the labor intensity and time. More importantly, the dangerous points can be detected quickly, and therefore, the risk can be avoided.

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