Application of UAV aerial survey in Three-Dimensional Design of Transmission Lines

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Abstract: The three-dimensional design of power transmission and transformation engineering is the mainstream trend of current power engineering design work. Based on the three-dimensional image model for power engineering design, path optimization and electrical distance calibration can be carried out more intuitively and conveniently. In this paper, the multi-rotor uav is equipped with sensors to collect image data, and establish a real-time model of the transmission line corridor to provide data support for the three-dimensional design of the transmission project. At the same time, the three-dimensional model is compared with the artificial measured results, and the applicable scope of the uav real-world modeling is summarized.

1. Introduction
Digital 3D design is the foundation of a new generation of intelligent design platform. At present, 3D design technology is widely and deeply applied in all walks of life in our country. Starting in 2017, State Grid Corporation and China Southern Power Grid Corporation will work together to promote the full application of digital three-dimensional design technology in power engineering. In the future, digital design with three-dimensional design as its core will become the main axis throughout the whole process and life cycle of power engineering.

As an important means of spatial data acquisition, UAV mid-altitude and low-altitude data acquisition technology has the advantages of long endurance, low flight cost, high data resolution, flexible scheduling, etc. It can realize real-time data transmission and can enter high-risk areas for detection. It is a powerful supplement to satellite remote sensing and traditional aerial photogrammetry [1].

In this paper, multi-rotor unmanned aerial vehicle (UAV) is used to carry out aerial photography with sensors. Image data of the proposed transmission line corridor are collected, real-life three-dimensional models are made and imported into the three-dimensional design platform [1]. The transmission line design based on the three-dimensional model will greatly improve the visual degree of the design, accurately measure the spatial distance between ground objects and the line, and optimize the line path.

2. UAV aerial survey

2.1. UAV Aerial Survey System
The UAV aerial survey system is composed of aircraft, load module, ground control station, flight control system and other parts, which can realize the autonomous aerial survey of the survey area by UAV according to the route planning procedure [2]. This aerial photography system is composed of DJI Phantom 4 aircraft and UAV flight control software, which can operate in multiple modes of normal shooting, banding, tilting, encircling and panorama. With the technical support of three-dimensional solution, control point measurement, one-key mapping and other technologies, aiming at the optimization algorithm of rotor camera, large-scale precision application is realized, and DSM, real shot, three-dimensional model and other achievements are produced.

2.2. Engineering survey

Xingxi-Linquan-Longquan 220kV line project is located in the hilly area in the eastern part of Taihang Mountain. From the start of the newly-built Longquan 220kV substation to the end of the east and west break points of Xingxi-Linquan 220kV line, Longquan-Xingxi 220kV line and Longquan-Linquan 220kV line are formed.

Table 1. Project Overview

| Voltage class | 220kV |
|--------------|-------|
| Transmission power | 529MVA |
| Line path length | The eastern route is 1.04km long and the western route is 1.22km long. |
| Number of loops | single circuit |
| Wire model | 2*JL/GlA-400/35 |
| Ground wire model | One side uses 24-core OPGW, and the other side uses JLB40-150 aluminum clad steel strand. |
| Design basic wind speed | 27m/s |
| Design icing thickness | Conductor 5mm, ground wire 10mm |
| Pollution level | The whole line is designed according to grade e pollution area. |

2.3. Technology roadmap
3. Work flow

3.1. Route design
According to the route direction of the project, in order to completely cover the corridor area of 100m on both sides of the two lines, the survey area is designed as a polygon, as shown in Figure 1. The lowest elevation is 279m, the highest elevation is 308m, and the average elevation of the survey area is 292m after calculation. According to the specifications, when the aerial photography scale is greater than or equal to 1:7000, the terrain elevation difference in the survey area is generally not greater than 1/6 of the relative aerial height, and the aerial photography design index is shown in Table 1.

Table 2. UAV photogrammetric design

| Indicator item             | Numerical | Indicator item             | Numerical |
|----------------------------|-----------|----------------------------|-----------|
| Resolution                 | 5cm       | Survey area                | 2.011km²  |
| Course overlap             | 80%       | Highest altitude           | 308m      |
| Lateral overlap            | 60%       | Lowest altitude            | 279m      |
| relative flying height     | 183m      | Average altitude           | 292m      |

3.2. Layout design of image control points
As the coordinate system adopted in the design of this project is Xi'an 80, and the coordinate system of UAV aerial photography system is WGS84, it is necessary to set up image control point conversion coordinate system for layout design. The precision and quantity of image control points directly affect the precision of post-processing of aerial survey data, so the layout and selection of image control points should be standardized, strict and accurate as far as possible. This time, 7 image control points are arranged by painting method and GPS is used to collect coordinate data of points (Xi'an 80). The distribution of image control points is shown in Figure 2.

4. Real Scene Modeling of Transmission Line Corridor
Taking aerial image data as data source, adopting image matching color point cloud data technology and three-dimensional grid optimization algorithm, automatic three-dimensional modeling, texture mapping, connection point reconstruction texture and reconstruction constraints are realized, and a three-dimensional model of transmission line corridor is established [3].

4.1. Three-dimensional modeling process
Using aerial photography image processing software, the collected aerial photographs are preprocessed to homogenize and reduce noise. Then, according to the heading and side overlapping data of the image, the photos are spliced into the whole image. Using POS data captured by unmanned aerial vehicle and coordinates of ground image control points, three points in the air are corrected, and
the image coordinate system is converted from WGS84 to Xi’an 80 coordinate system required by the project. Finally, through image matching point cloud, TIN triangle modeling and texture attachment, a three-dimensional image model is generated, as shown in Figure 3.

![Image matching point cloud](image1)

![Building a digital surface model](image2)

![Automatic texture mapping](image3)

Figure 3. Realization modeling process of transmission line corridor

Up to now, the ground objects in the 3D real scene model have only spatial information and no attribute information. Therefore, it is necessary to endow roads, trees, houses, crossing lines and other ground features with attribute information, so that spatial distance calculation can be realized in the process of line selection.

![Cross-land feature information plotting](image4)
4.2. Accuracy analysis of 3D Model
Before the flight, the 5-tower position of the transmission line was collected as the flight accuracy testing point. For image control point correction, the median error is ±0.01 m. By comparing the detection results of the detection points, the in-plane error in the three-dimensional model is between ±0.05 and 0.1 m, and the in-elevation error is between ±0.1 and 0.2 m. According to the requirements of "Technical Regulations for Survey of 220kV and Below Overhead Transmission Lines", the measurement accuracy meets the requirements of initial depth.

| Point number | Accuracy XY/Z[m] | Error X[m] | Error Y[m] | Error Z[m] | Projection error[pixel] |
|--------------|------------------|------------|------------|------------|------------------------|
| 1            | 0.02/0.02        | 0.011      | -0.014     | -0.002     | 0.383                  |
| 2            | 0.02/0.02        | -0.001     | 0.012      | -0.002     | 0.302                  |
| 3            | 0.02/0.02        | -0.026     | -0.003     | 0.014      | 0.445                  |
| 4            | 0.02/0.02        | 0.008      | -0.016     | -0.030     | 0.250                  |
| 5            | 0.02/0.02        | 0.002      | 0.013      | -0.007     | 0.393                  |
| 6            | 0.02/0.02        | 0.002      | 0.006      | 0.004      | 0.687                  |
| 7            | 0.02/0.02        | 0.009      | -0.004     | -0.013     | 0.458                  |

Average value: 0.000798, -0.000647, -0.005207
Root mean squared error: 0.011645, 0.010776, 0.013873

5. Engineering Application

5.1. Comparative analysis of mapping accuracy of ground objects
Due to the completion of the detailed survey of the whole line before the three-dimensional design of this project is carried out. Therefore, by comparing and analyzing the cross-section features such as trees, roads, houses and the like in the manual measurement results with the three-dimensional model, the accuracy of feature plotting in the three-dimensional model can be obtained.

(a) Existing tower base position comparison
Compare the ground features plotted in the 3D model with the measured data, as shown in Figure 5, and the comparison results are shown in Table 5. It can be seen from this that, besides the unrecognized ground objects, considering the factors that the boundary definitions of the ground objects are not completely consistent in the two survey methods, it can be considered that the ground object precision in the three-dimensional model can meet the initial design requirements.

### 5.2 Spatial distance measurement

In the three-dimensional scene, based on BIM technology, the tower, line and string of transmission lines are modeled in three-dimensions, which can truly simulate the corridor scene of transmission lines, just as shown in Figure 6. According to the regulations on the safe distance of 220kV overhead transmission lines in the 110 kv-750kv overhead transmission line design code (table 4), it is possible to measure the spatial distance of crossing objects in the transmission line corridor, accurately measure the spatial distance of crossing objects such as residential areas, buildings, trees and the like in the

| Serial number | Ground object type  | Deviation (Unit: m) |
|---------------|---------------------|---------------------|
| 1             | Highway             | 0.2                 |
| 2             | House               | 0.3                 |
| 3             | Path                | 0.1                 |
| 4             | Tomb                | Unrecognized        |
| 5             | Trees               | 0.2                 |
| 6             | Tower base          | 0.3                 |
| 7             | Greenhouse          | 0.3                 |
| 8             | House               | 0.2                 |
| 9             | 10 kV line          | 0.5                 |
| 10            | Communication line  | Unrecognized        |
transmission line corridor, and give an alarm to the sections that do not meet the safe distance, as shown in Figure 7.

![Figure 6. Tower, line, and string models in a 3D scene](image)

**Table 6. Wire-to-ground distance and cross-over table of 220kV overhead transmission line**

| Name of spanned object         | Distance (m)          |
|--------------------------------|-----------------------|
| Residential area               | 7.5                   |
| Non-residential area           | 6.5                   |
| difficult transport area       | 5.5                   |
| Railway                        | To standard rail top 8.5 |
| Power line                     | 4                     |
| Communication line             | 4                     |
| Motor-pumped well              | 4                     |
| Grade highway                  | 8                     |
| Non-navigable river            | 4 (flood level once every 100 years) 6.5 (to winter ice) |
| Trees (calculated by natural growth height) | 4.5 |
| Fruit tree                     | 3.5                   |

![Figure 7. 3D spatial distance accurate check](image)
6. Conclusion
In this paper, the unmanned aerial vehicle aerial survey system is used to carry out digital three-dimensional modeling of the transmission line corridor and restore the real-life model of the overhead transmission line project, which provides data support for the route optimization of the transmission line and the calculation of the spatial distance across the ground objects. Comparing the research results with the measured results, the advantages and disadvantages of 3D scene modeling can be summarized as follows.

Advantages:
(1) Aerial survey data covers a wide area and has fast data acquisition speed. Even if the route changes, there is no need to re-survey, which is convenient for route optimization.
(2) Plotting surface features based on three-dimensional models can reduce a large part of manual measurement workload.
(3) For trees that need to be cut down or have a high span along the line, aerial survey is more accurate in counting the number of trees because only row spacing and row spacing are marked by manual survey, and aerial photography can clearly identify individual trees.

Disadvantages:
(1) For objects with unclear images such as graves, low-voltage power lines and communication lines, they cannot be plotted based on aerial photography.
(2) Since the elevation data obtained by aerial survey of common unmanned aerial vehicles are surface elevation of ground objects, it is impossible to penetrate vegetation to obtain surface elevation.

Based on the above characteristics, the three-dimensional modeling of transmission line corridor can adopt the operation mode of "unmanned aerial vehicle aerial survey system+manual supplementary survey of small ground objects". In areas with high vegetation coverage, airborne radar can also be selected to generate laser point clouds to obtain the true elevation of the earth's surface.

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