Research on inclination monitoring technology of transmission tower based on UAV

Ruhai Liu¹, Huikun Pei¹, Cheng Chen¹, Zhiren Tian¹, Changjin Hao²*

¹ Shenzhen Power Supply Bureau Co., Ltd. China Southern Power Grid, Shen Zhen 518001, Guangdong Province, China
² Institute of Energy Sensing and Information, Sichuan Energy Internet Research Institute, Tsinghua University, Chengdu 610000, China
haochangjin@tsinghua-eiri.org

Abstract. Transmission tower inclination directly affects the reliability of transmission line operation. In order to accurately judge the inclination angle and ensure the safe operation of transmission line, an online monitoring method of transmission tower inclination based on patrol UAV is proposed. The inspection UAV is used to inspect the transmission tower with camera. The transmission tower point cloud data is collected by the inspection UAV combined with the camera. The pyramid grading management is constructed to collect the tower image point cloud data. The grading data is preprocessed to remove the gross error, and the point cloud data is homogenized to get the multi-scale characteristics of the point cloud data. On this basis, a multi-scale classifier is constructed to complete the automatic classification of point cloud data. According to the classification results, the current inclination degree of transmission tower is determined, and the online monitoring of transmission tower inclination is completed. The test results show that this method can effectively monitor the inclination angle of transmission tower under different wind conditions, and the maximum difference between the inclination angle and the actual inclination angle is about 0.3° with better online monitoring effect.

1. Introduction

Transmission lines are widely distributed, and the operation environment is complex. Accidents such as collapse caused by the inclination of transmission tower occur from time to time. Traditional detection method relies on manual inspection, and the inspection efficiency is very low. It is difficult to maintain some key nodes, so it is difficult to detect the tilt fault of transmission tower in time[1, 2]. Therefore, it is urgent to monitor the status of the tower in real time by effective technical methods, detect the fault in time and send out early warning to maintain the safe operation of transmission line.

In view of the above problems, scholars at home and abroad have carried out relevant research. Literature [3] combines high-resolution technology and deep learning to monitor transmission towers. Literature [4] predicts the state of transmission tower under strong wind based on multi-source heterogeneous data. Literature [5] realizes the inclination monitoring of transmission line tower by using optical fiber sensing technology. Reference [6] uses visual navigation to determine the position of transmission line tower and realize fault monitoring at the same time.

Aiming at the problems of low detection accuracy and difficult operation of existing research, this paper proposes an on-line monitoring method of transmission tower inclination angle based on patrol...
UAV, which has the advantages of safety, high efficiency and not limited by geographical conditions, and can effectively realize the transmission tower inclination fault and timely warning.

2. Monitoring method of transmission tower inclination angle based on patrol UAV

The online monitoring process of transmission tower inclination based on patrol UAV is shown in Figure 1.

![Inclination monitoring process of transmission tower](image)

**Figure 1. Inclination monitoring process of transmission tower**

The monitoring steps of transmission tower inclination are as follows:

Step 1: specify the patrol task of patrol UAV, and determine the inclination of transmission tower as the patrol object of patrol UAV.

Step 2: set the flight plan of patrol UAV to meet the work requirements while ensuring its safety.

Step 3: use the camera mounted on the patrol UAV to collect the image information of the transmission tower under different positions and attitudes.

Step 4: manage image point cloud data by point cloud pyramid, and enhance its rendering through point cloud data preprocessing.

Step 5: establish a multi-scale classifier based on the local dimension and multi-scale features of image point cloud data to realize the automatic classification of point cloud data, and study the current inclination of transmission tower according to its classification results.

Step 6: output monitoring results.

2.1. Overall structure of real time warning model for transmission tower inclination

Based on the construction of point cloud pyramid, the collected transmission tower image point cloud data is constrained to enhance its storage and recall. It mainly includes the following steps:

Step 1: obtain the two-dimensional boundary of the point cloud data of the transmission tower image collected by the camera mounted on the patrol UAV, which is the maximum and minimum value of the point cloud coordinates.

Step 2: apply the point cloud homogenization extraction method with fixed size and nearby layers to the unit tile on the first floor of the pyramid.

Step 3: integrate the two-dimensional boundary and parameters of transmission tower image point cloud data\(^7\), calculate the structural parameters of the pyramid and store them in its setting file.

Step 4: Based on the two-dimensional boundary interval of each layer of tiles in the pyramid, the point cloud data at the bottom of the tower is collected by the camera mounted on the patrol UAV, and the point cloud data at layer \(i + 1\) \((i > 0)\) is obtained after the data extraction operation at layer \(i\).

After the construction of point cloud pyramid is realized, the optimal number of layers \(n\) is obtained based on the resolution of point cloud data application. According to the data application interval, it is required to read the tile retrieval interval in the optimal layer \(n\) of the pyramid, calculate the two-dimensional boundary of the data application interval and integrate it with the tile structure to obtain overlapping tiles, read the fully overlapping tile data, make its area as incomplete overlapping tiles, and select the point cloud data in the application interval. The tower information in the images collected by patrol UAV under different pose is extracted and classified into a data set.
2.2. Preprocessing of point cloud data
Because of the rough and almost point cloud data of transmission tower image, the elevation interpolation method is used to remove it[8]. The point around the coarse difference of point cloud data is interpolated to get the elevation of the coarse difference and the difference between the coarse difference and the coarse difference. When the difference value exceeds the set threshold, the data is deleted, and the data is retained on the contrary.

After removing the coarse difference of point cloud data, homogenize and refine the point cloud data. The specific operation process is as follows:

Step 1: set the point cloud data as an octree structure, and store the point attribute queue in the point cloud data that completes the removal of coarse handicap.

Step 2: read all point cloud data, process and group all point cloud data at the boundary around the child nodes of the octree.

Step 3: remove ungrouped child nodes.

Step 4: store 1/N points in the child node and take them as the data points to complete the processing.

Step 5: take the stored data points as the extracted point cloud data, and delete the initial point cloud.

2.3. Classification of point cloud data
By analyzing the local dimension and multi-scale features of transmission tower image point cloud data, a multi-scale classifier is designed to realize the automatic search of optimal scale combination and complete the accurate classification of tower information in the image.

2.3.1. Multiscale feature
The geometric features of point cloud data loss are filled by the eigenvalues of point cloud data near large scale, and the uniform multi-scale dimension features in point cloud data set are obtained.

2.3.2. Design of multiscale classifier
The division formula of point cloud dataset is:

\[ f(x) = \omega \cdot x + b \]  

Where the vector is \( \omega \), \( x \). The real number is \( b \).

When the vector \( x \) is 2, the two-dimensional space \( f(x) \) is obtained, and \( f(x) \) is a straight line. When the vector \( x \) is 3, the three-dimensional space \( f(x) \) is obtained, and \( f(x) \) is a plane. When the vector \( x \) dimension is greater than 3, there is an n-dimensional space \( f(x) \), and \( f(x) \) is an N-1-dimensional hyperplane.

Point clouds with \( N_R \) scales are represented as \((x_i, y_i), i=1, 2, ..., N_R\). The spatial point set of dimension \( i \) is \( x \in R^i \). The straight-line segment features of tower are divided by labeling the point cloud dataset with category label \( y \).

There are two types of linear division point cloud data integration, and the division formula is:

\[ \omega \cdot x + b = 0 \]  

The first type takes the optimal classification hyperplane as the constraint condition, and its formula is as follows:

\[ y_j \left( \omega \cdot x_j + b \right) > 1 \]  

The second is based on the maximum value of the sum of the minimum distance between the two samples of the point cloud dataset and the hyperplane. Then get the vector \( \omega \) and real number \( b \). The saddle point of Lagrange function is obtained by constructing multi-scale classifier. The formula is as follows.

\[ L(\omega, b, a) = \frac{1}{2} \| \phi \| - \sum_{j=1}^{N_R} a_j \left( [\omega \cdot x_j + b] - 1 \right) \]
Where \(a_i\) and \(x_i\) are Lagrange multipliers and support vectors respectively.

When the partial derivative of vector \(\omega\) and real number \(b\) is 0, find the optimal solution and obtain the calculation formula of multi-scale classifier as follows:

\[
f(x) = \text{sgn}\left\{ \sum_{i=1}^{N} a_i^* y_i \langle x, x_i \rangle + b^* \right\}
\]

(5)

Where, \(b^*\) is the classification threshold.

Using the logic function to predict the confidence of the distance \(d\) from the sample to the hyperplane, the following is obtained:

\[
p(d) = q/(1 + \exp(-ad))
\]

(6)

Project the point cloud data set in the hyperplane and solve the distance \(d\) from the sample to the hyperplane. Obtain \(d_1\) and \(d_2\) orthogonal in two directions, and \((d_1, d_2)\) is the maximum separable coordinate of the two-dimensional plane. Straight lines are automatically generated in the plane to realize the accurate classification of tower information in the image.

2.4. On line monitoring of transmission tower inclination

According to the classification results of point cloud data, the transmission tower information in the collected image is extracted, and the current tower inclination is analyzed. According to the classification results of point cloud data, the inclination of the tower in all directions is obtained as the measurement target, and the gravity acceleration on the \(x\), \(y\) and \(z\) axes of the tower is used as the measurement basis. Firstly, the acceleration of the tower is transformed into the inclination. The horizontal direction, the direction perpendicular to the horizontal direction and the direction perpendicular to the horizontal plane are defined as \(x\), \(y\) and \(z\) axes respectively. Based on them, a spatial rectangular coordinate system is constructed, so that the included angle between the tower tilt and the positive direction of \(x\), \(y\) and \(z\) axes is \(\alpha\), \(\beta\) and \(\gamma\).

The calculation formulas of included angles \(\alpha\), \(\beta\) and \(\gamma\) are as follows:

\[
\alpha = \arctan\left( \frac{G_x}{\sqrt{G_y^2 + G_z^2}} \right)
\]

(7)

\[
\beta = \arctan\left( \frac{G_y}{\sqrt{G_x^2 + G_z^2}} \right)
\]

(8)

\[
\gamma = \arctan\left( \frac{\sqrt{G_x^2 + G_y^2}}{G_z} \right)
\]

(9)

Where, \(G_x\), \(G_y\) and \(G_z\) are gravity acceleration components, and their values can be positive or negative. A positive value means that the direction of gravity acceleration is equal to the positive direction of \(X\), \(Y\) and \(Z\) axes, and a negative value is the opposite. Therefore, the value range of \(\alpha\), \(\beta\) and \(\gamma\) is \([-90^\circ, 90^\circ]\).

3. Example test

In this paper, the point cloud data of power transmission poles and towers in a certain area are collected by the patrol UAV equipped camera. The number of poles and towers in this area is 70. The original image collected by the patrol UAV equipped camera and the preprocessed image are shown in Figure 2 and Figure 3.

Figure 2 and Figure 3 are the transmission tower images collected and fed back to the ground station when the patrol UAV patrols along the transmission line under different positions and attitudes. Figure 2 is the original image of the camera sampling. Figure 3 is the preprocessed image after removing the gross error. Figure 2 (a) and Figure 3 (a) are the images without inclination under normal
operation of the transmission tower, and Figure 2 (b) and Figure 3 (b) are the images of inclination of the transmission tower after experiencing grade 7 wind. It can be verified that the remote image fed back by the patrol UAV is intact, which is not affected by the electromagnetic interference of the transmission line. The four images prove that the patrol UAV can accurately collect the image of transmission tower through the camera.

![Original Image](image1)

**Figure 2. Original image captured by camera**

![Reprocessed Image](image2)

**Figure 3. Reprocessed image**

The method in this paper is used to collect the point cloud data of transmission towers in this area and shape a 9-layer pyramid. The point cloud effect of the 9th layer of some transmission towers is shown in Figure 4(a), and the point cloud data and tower superposition effect after hierarchical processing are shown in Figure 4(b).

![Point Cloud Effect](image3)

**Figure 4. Effect drawing of transmission tower point cloud**
Preprocess the data to achieve accurate classification of point cloud data. The classification results are shown in Figure 5. According to the accurate classification results of point cloud data, analyze the current working condition of transmission tower and its inclination under various environmental factors, calculate the inclination angle, and realize the on-line monitoring of transmission tower inclination. The influence of different wind factors on the transmission tower inclination data monitored online by this method is analyzed.

![Figure 5. Accurate classification results of point cloud data](image)

Arbitrarily select a transmission tower, analyze the inclination of the tower under different wind forces by using the method in this paper, and complete the on-line monitoring of the inclination of the transmission tower. The analysis results are shown in Figure 6.

![Figure 6. Inspection results of wind speed and tower inclination](image)

According to Figure 6, under different wind forces, the inclination angle of transmission tower expands with the increase of wind speed. When the wind speed is stable, the inclination angle of tower does not change when the wind speed is lower than 2m/s. After the wind speed exceeds 2 m/s, the inclination angle of tower increases steadily, and there is little difference with the inclination angle of tower, and the maximum difference is about 0.2°. In case of pulsating wind, the inclination angle of the tower does not change when the wind speed is lower than 1 m/s. After the wind speed exceeds 1 m/s, the inclination angle of the tower begins to expand. Because the pulsating wind is relatively strong, the swing of the inclination angle of the tower is more complex and the fluctuation range is...
large. The difference between the inclination angle of the tower obtained by this method and the actual situation is small, and the maximum difference is about 0.3 °. It shows that this method can accurately monitor the inclination of the transmission tower. The greater the wind speed, the greater the inclination of the tower.

Compare the effect of this method before and after practical application, and the results are shown in Figure 7. It can be found from Figure 10 that the method in this paper can effectively strengthen the operation safety of transmission tower and reduce the work intensity of staff.

Figure 7. Comparison of practical application effect

4. Conclusions
Taking advantage of the low risk and high efficiency of patrol UAV, this paper studies the on-line monitoring method of transmission tower inclination based on patrol UAV, uses patrol UAV to patrol near the transmission tower, collects the image related data of transmission tower through the equipped camera, and carries out the hierarchical management of image point cloud data based on the construction of point cloud pyramid. Through the homogenization extraction operation of preprocessing, the rendering of point cloud data is enhanced, and a multi-scale classifier is designed by using the local dimension and multi-scale features of image point cloud data to complete the automatic classification of point cloud data. According to the classification results, the current inclination of transmission tower is studied to realize the on-line monitoring of transmission tower inclination. In the future, based on this method, the risk prediction strategy of vegetation growth can be introduced to further improve the monitoring effect of transmission tower and make the operation situation of transmission line more stable by predicting the risk level of vegetation growth.

References
[1] Xia Y, Song X, Jia Z, et al. Technology Research Status and Prospect of Transmission Line Condition Based Maintenance by Robot[J]. High Voltage Apparatus, 2018, 54(7):53-63.
[2] Pylarinos D. Overhead Transmission Line Maintenance in Crete and Rhodes: 2016-2020[J]. Engineering, Technology and Applied Science Research, 2021, 11(1):6833-7844.
[3] Zeng T, Gao Q, Ding Z, et al. Power Transmission Tower Detection Based on Polar Coordinate Semivariogram in High-Resolution SAR Image[J]. IEEE Geoscience & Remote Sensing Letters, 2017, PP(12):1-5.
[4] Hou H, Yu S, Wang H, et al. Risk Assessment and Its Visualization of Power Tower under Typhoon Disaster Based on Machine Learning Algorithms[J]. Energies, 2019, 12(2).
[5] Ming G, Zhao Z, Li Y, et al. Monitoring and research on tilt of transmission line tower based on optical fiber sensing[J]. Journal of Electronic Measurement and Instrumentation, 2018.
[6] Zuwu W, Jun H, Xiaobin S, et al. Method for Orientation Determination of Transmission Line Tower Based on Visual Navigation[J]. Laser & Optoelectronics Progress, 2019, 56(8).
[7] Seo H, Joo S. Characteristic Analysis of Data Preprocessing for 3D Point Cloud Classification Based on a Deep Neural Network: PointNet[J]. Journal of the Korean Society for Nondestructive Testing, 2021, 41(1): 19-24.

[8] Shi Xiaosong, Cheng Yinglei, Xue Doudou, et al. Object Classification Method for Multi-Source Fusion Point Clouds Based on Point-Net[J]. Laser & Optoelectronics Progress, 2020, 57(8):081019.