Airborne LIDAR point cloud tower inclination judgment

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Abstract. Inclined transmission line towers for the safe operation of the line caused a great threat, how to effectively, quickly and accurately perform inclined judgment tower of power supply company safety and security of supply has played a key role. In recent years, with the development of unmanned aerial vehicles, unmanned aerial vehicles equipped with a laser scanner, GPS, inertial navigation is one of the high-precision 3D Remote Sensing System in the electricity sector more and more. By airborne radar scan point cloud to visually show the whole picture of the three-dimensional spatial information of the power line corridors, such as the line facilities and equipment, terrain and trees. Currently, LIDAR point cloud research in the field has not yet formed an algorithm to determine tower inclination, the paper through the existing power line corridor on the tower base extraction, through their own tower shape characteristic analysis, a vertical stratification the method of combining convex hull algorithm for point cloud tower scarce two cases using two different methods for the tower was Inclined to judge, and the results with high reliability.

1. Introduction.

Towers entire power system is a vital part of the accord is possible in a variety of complex weather conditions frequency between the wire and overhead transmission lines and towers with magneto telluric and electrical insulation safety requirements\cite{1}. In the electrical inspection operations, inclined tower, tower base, and other parts of the state judgment is an important content.

Among them, the tower tilted factors are mainly the following aspects: when in the role of external damage or special meteorological environment, on both sides of the tower wire discontinuity, Both sides of the tower to create tension differential, transmission line pole Tower base will force imbalance due to its inclined slip and other phenomena, in this case the event will affect the normal operation of the transmission line. Therefore, to ensure the normal operation of the company's power grid, power lines should be checked regularly in order to detect the presence of hidden dangers and defects tower to prevent accidents. As China's power equipment intelligent upgrading and deepening of industrialization mature, intelligent power grid and gradually shift to the business model, transmission line towers inclined more and more serious harm, how do the Inclined tower measurement, high-voltage transmission line tower inclined state to take preventive measures we need to explore and become the subject of in-depth study \cite{2}.

At present, the power line tower inclination measurement methods mainly vertical corridor method\cite{3-7}, a method theodolite, plane mirror method, a terrestrial laser measurement and online monitoring inclined tower. Development of UAV technology for the development of the grid inspection technology provides a new tool for development. UAV power line inspection apparatus having a small investment, relatively low cost of inspection, automation, intelligent features, with significant technical and economic advantages and electrical inspection characteristics, and can be avoided manned patrol and complicated geographical conditions under manual inspection of security issues. From airborne radar scan point
cloud power line corridor, based on the existing tower automated extraction algorithm, based on the
tower elevation data and projection plane fitting algorithm for point cloud tower inclination judgment[8-
9].

2. Analyzing inclined tower principle

Tower formula inclination

\[ q = \frac{SH \times 1000}{mm} \%
\]

The formula \( q \) -- inclination; \( S \) -- tilt value, mm; \( H \) -- tower top or measurement points to the ground
height, mm.

Normal tower Inclined the maximum allowed value (see table1) \(^{[10]}\)

| category | Reinforced concrete pole | Iron tower |
|----------|--------------------------|------------|
| Inclination tower (Including the deflection) | 1.5% | 0.5% (It applies to more than 50m high Iron tower and) |
| | 1.0% | 1.0% (The following applies to 50m height Iron tower) |
| Cross arm skewness | | 1% |

Iron tower adjacent contacts between the curvature of the main material >0.2%

3. Characteristics of laser point cloud tower

There are many drawbacks to explore the use of spatial information technology to solve artificial
transmission line power line inspection method, Chinese Academy of Surveying and Mapping, the PLA
General Staff 60th Institute, Beijing University of Guangdong Power Grid Corporation Electric Power
Research Institute, aerospace joint Wuhan University conducted a large-scale application of the use of
the UAV power line inspection. Data source of this article a number of areas from Guangdong 110KV-
500KV high-voltage transmission line inspection sweep the surface of the laser point cloud data. As
shown in figure 1) tower cloud point coordinates.

![Figure 1. Schematic point cloud tower](image)

Figure 2 by the analysis of various types of towers, towers are generally divided into tower head, tower
body, the tower legs of three parts, tower head from the tower legs up tower sectional dramatic changes
(broken line appears) over part of the tower head, If there are no dramatic changes in cross-section, the
lower cross arm above the lower chord part of tower head, the tower head contains insulators, ornaments,
etc., the whole point cloud tower head irregular distribution. Basis of the above in the first paragraph of
the tower called the tower legs. Section of the tower and the tower between the legs called tower body,
tower body extracted by setting a threshold value, extraction tower cloud point above the lowest point
between 2m to 15m tower body is the point cloud point cloud, (according tower Depth freely set) tower
body is generally shown as a rectangular table rules are as follows.
4. Overall inclined tower monitoring processes and methods

4.1. Experimental data
In the lidar data, first, from a large number of the original point cloud point cloud isolated tower. Point cloud tower separation method is to use Liu Zhengjun like patent "an airborne LIDAR data extraction and power lines fast reconstruction method" (patent number: ZL201210002838.5) used in the method. Secondly, the point clouds extracted tower tower body has a regular shape, head to the adoption of the rules of the point cloud tower body extracted tower was straight lateral edges, tower body will be projected onto a two-dimensional point cloud in all directions each perpendicular to the horizontal plane plane, the final calculation of the point cloud projecting tower body inclined to the side edge of each of two-dimensional direction of the plane, to determine the effect of tilting tower. Concrete tower tilt determination flow chart shown in figure 3.

![Figure 3. Tower of the flow chart](image)

4.2. Projection
Laser point cloud data itself is three-dimensional data, since the tower body has a rectangular point cloud data table structure is very regular, and the side edge in a straight line, if tower body is extracted four side edge in the three-dimensional situation is very difficult, with respect to the three-dimensional space dimensional planar side edge extraction is relatively simple and accurate, so tower body will be a three-
dimensional projection [44] in all directions perpendicular to the geoid (in all directions: in this paper between 0° to 180° every 10° as a unit 18 projection angle can be selected in this direction, if the guarantee greater precision, you can select a smaller angle) as shown in figure 4.

![Figure 4. Two dimensional plane point cloud tower tower](image)

4.3. Extraction side ribs
UAV mounted laser radar scanning power line corridor, due to machine vibration, weather, sweep the laser surface scanner hardware and other reasons can lead to a power line tower scanning incomplete, incomplete. Aiming point cloud density in both cases using the two methods is projected onto a two-dimensional plane left and right side of the ribs on both sides of tower body linearly cloud point extraction.

1) Point cloud density is relatively normal
Shown in figure 5, when the original tower normal point cloud data-intensive, projected onto a two-dimensional plane of the presentation rules similar isosceles trapezoid side edge and dense point cloud rendering linear fitting point of the line, Fitting line points the better, So the use of vertical stratification.

![Figure 5. Tower body good point cloud diagram](image)

Vertical stratification: the approximate isosceles trapezoid rule than the two-dimensional plane to the horizontal center line about hierarchical, left and right point cloud rendering right angle trapezoidal, hierarchical set threshold, according to a threshold to identify the left and right sides of the leftmost and rightmost coordinate point cloud abscissa corresponding to the minimum and maximum values, to the right and left side edge extraction.

As shown in figure 6, will be projected onto a two-dimensional plane data-intensive vertical stratification reached renderings, to achieve the effect of the extraction side of the ribs, lateral ribs for straight after fitting.
Figure 6. Schematic diagram of the structure of vertical stratification

2) Point cloud density is relatively sparse case

Shown in figure 7, the right of the original point cloud tower missing chunks of data, projected onto a two-dimensional plane is still the case of missing data, since part of the point cloud can not extract the missing tower body side edge all point clouds, and it is difficult fitted to complete the tower side of the trunk edge, so the use of convex hull algorithms.

Figure 7. Schematic diagram of tower body loss

Convex hull Definition: Let $S$ be the intersection of a plane, closed $s$ all minimum convex polygon vertices, called $s$ convex hull, expressed as $CH(S)$. Vertex $CH(S)$ on, sometimes also called the $S$ pole. Define the convex hull of planar point set point set that contains the smallest convex set that point as a point of focus part of convex polygon vertices, any one of the convex polygon edges, not all of the points are concentrated in the edge of the point side on the same side [45].

Shown in figure 8,9, will be projected onto a two-dimensional convex hull of the scarce data presented renderings, achieved little cloud of scattered peripheral contour extraction.

Figure 8. Schematic diagram of constructing convex hull
4.4. Extraction side ribs
We usually ask when the general slope of the line obtained by plotting the manner determined linear equation \( y = ax + b \) of a slope and intercept \( b \), but more in the measurement data and scattered when the same data to different people handle the results are not the same, so that the calculated \( a \) and \( b \) is relatively large errors. Using least squares fitting line solution to the large amount of data, and obtain a slope and intercept \( b \) is unique. Least squares fit to the scarcity and dense point cloud above two cases have reached the edge extraction side effects, by bilateral side edge least squares linear fit to determine its lateral edge inclined slope.

4.5. Analyzing inclined tower
Tower tilted inclination value divided by the tower top or measurement points to ground level, as shown below for the calculation principle tower tilt, \( \triangle ac \) tower in a vertical plane normal position, \( \triangle cb \) segment for the tower tilted position, \( ab \) to tower angled horizontal length, the inclination of the tower \( \tan \angle c = \frac{ab}{ac} \), \( \angle c \) is the desired angle of inclination.

For peripheral side edge contour extraction point cloud is still using the vertical stratification method, illustrated as below figure 10.

![Figure 10. Sketch map of tangent angle theory](image)

By defining judgment can be converted to point cloud tower inclination, that tower to find the inclination angle of the point cloud can be. As shown below(see figure 11) there are two flat, horizontal surface normal level 1, level 2 is a tower which was inclined plane, can draw a horizontal plane through the 1,2 angle of inclination angle of the tower, according to the geometric relationship between the availability of \( a = ((b + a) - (b-a)) / 2 \).

![Figure 11. Schematic diagram of tower inclination theory](image)
As shown below is projected onto a two-dimensional plane towers tower schematic point cloud using the least squares method can be determined slope tower tower AB and DC two side edges, AB side edge slope \( \tan \angle B \), CD side edge slope \( \tan \angle C \) turn can be obtained \( \angle B \) and \( \angle C \) angle size. Through the above analysis, the difference between the figure 12 and \( \angle C \) \( \angle B \) half of the absolute value of the tangent of the inclination the tower is, it is judged that the tower tilted formula \( \tan \left( \frac{\angle B - \angle C}{2} \right) \).

\[
\text{Inclination} = \tan \left( \frac{\angle B - \angle C}{2} \right)
\]

Figure 12. Tower inclination transformation diagram

4.6. Achievements Exhibition

Table 2: Results show schematic diagram

| No. | XOY vertical projection plane angle (degrees) | The inclination angle (degrees) |
|-----|---------------------------------------------|---------------------------------|
| 1   | 0                                           | 0.113521                        |
| 2   | 10                                          | 0.146535                        |
| 3   | 20                                          | 0.091209                        |
| 4   | 30                                          | 0.092416                        |
| 5   | 40                                          | 0.054037                        |
| 6   | 50                                          | 0.016442                        |
| 7   | 60                                          | 0.167541                        |
| 8   | 70                                          | 0.08295                         |
| 9   | 80                                          | 0.005290                        |
| 10  | 90                                          | 0.065680                        |
| 11  | 100                                         | 0.012954                        |
| 12  | 110                                         | 0.049968                        |
| 13  | 120                                         | 0.199206                        |
| 14  | 130                                         | 0.056920                        |
| 15  | 140                                         | 0.035524                        |
| 16  | 150                                         | 0.085106                        |
| 17  | 160                                         | 0.031889                        |
| 18  | 170                                         | 0.168842                        |
| 18 projection plane of maximum tilt angle (degrees) | 0.199206 |
50m or less tilt the tower is less than 0.01 0.003477

Whether Inclined tower No

As shown above (see table 2) is a point in an area of the test tower in Guangzhou cloud of output achievement, achievement in the form of txt text output, text output is included in each of the inclination angle with the horizontal plane of the projection angle and the corresponding projection, the projection plane 18 is inclined angle the maximum inclination of the tower and the tower tilted whether information. Judging by the principle known tower tilt tower tilt less than 50m less than 0.01, known tower tilt angle 0.199206, can be obtained inclination \( \tan(0.199206) = 0.003477 < 0.01 \), therefore not inclined tower.

More than a single tower tilt measurement, for practicality, optimized and improved for more than one tower tilt judgment, the raw point cloud data into a plurality of towers and tower center position coordinates, the results of its output, as shown below (see table 3), one for each tower inclination information, location coordinates tower Center, 18 projection plane and the inclination angle of maximum inclination and judgment basis (examples include five towers, the tower may be more inclined to judge).

**Table 3** Results show schematic diagram

| Tower Center position (X, Y, Z) | Maximum 18 projection plane inclination angle | 0.01 tower tilt angle, the tilt tower | Whether Inclined tower |
|---------------------------------|-----------------------------------------------|--------------------------------------|------------------------|
| 10795.080000 7702.760000 40.23 | 3.907276                                       | 0.068301                             | Yes                    |
| 10501.690000 7641.690000 45.60 | 0.118568                                       | 0.002068                             | No                     |
| 10154.970000 7566.350000 41.10 | 0.375367                                       | 0.006551                             | No                     |
| 9881.050000 7505.010000 39.50  | 0.287791                                       | 0.005023                             | No                     |
| 9591.460000 7445.540000 47.00  | 0.331600                                       | 0.005788                             | No                     |

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