Application of Visible Image and LiDAR Point Cloud Fusion Technology in Distribution Network Tree Barrier Inspection

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Abstract. Aiming at the problems of poor visual effect and low accuracy of single use of LiDAR or visible light camera for tree barriers inspection in distribution corridors, the LiDAR point cloud data and visible light image data are obtained simultaneously through UAV carrying integrated system. First, the LiDAR point cloud data are de-noised, filtered and classified, and the ground and non-ground laser point clouds are separated. Then, the laser point cloud data and visible image data are set up in the same coordinate system by coordinate conversion. Then, the spectral information of visible image is assigned to the corresponding point cloud, and the 3D real scene image of point cloud is reproduced to realize the function of identifying and analyzing the hidden trouble of distribution corridor tree barrier. It greatly improves the accuracy and efficiency of tree barriers hidden trouble inspection, and the visual effect is intuitive.

1. Introduction
Vegetation, such as shrubs and tree species, is the largest corridor feature that affects the safe operation of power distribution lines. Most of the power distribution network failures are caused by hidden dangers of tree barriers. When the safe distance between the tress and the wires is insufficient, it will cause tripping, discharge and other accidents. Inspection and analysis of tree barrier’s hidden dangers has become an important task of the power transmission department. The traditional inspection method of tree barrier is that inspectors carry professional height measuring poles, theodolites and other heavy instruments to calculate whether the distance from the wire sag to the tree top meets the requirements of specifications and safe operation. Due to the personal status of the inspectors and the different measurement angles, large measurement errors are often caused, and deforestation, destruction of vegetation and hidden dangers of tree barriers sometimes occur [1-2]. Traditional inspection method of tree barrier are often affected by natural disasters, such as ice, snow, floods and landslides. The inspection efficiency is low and the accuracy is not high, which can no longer meet the needs of modernized operation of power distribution network with growing scale. As a new inspection method of power lines, Unmanned Aerial Vehicle (UAV) are usually equipped with digital camcorders and cameras to obtain visible light image data of the line corridors. This operation method has the advantages of high inspection efficiency without geographical influence. However, the visible light image data is two-dimensional data, which can not truly reflect the three-dimensional information of the electric wire corridor. In addition, its spatial positioning accuracy is low, which is difficult to measure the distance between trees, bamboo and other objects to the electric wire. It is also
impossible to identify hidden dangers of tree barriers. With the technological development of light detection and ranging (LIDAR) and cost deduction, a new and effective inspection method for power line is provided. LIDAR technology has the advantages of accurate spatial positioning and clearance distance measurement, and fast tree-dimensional modeling. However, because the LIDAR point cloud data has no color characteristics, its visualization effect is poor, which is not conductive to interpreting the information of ground objects and non-ground objects. In summary, visible light image and LIDAR have their own advantages and disadvantages. A complete three-dimensional real-world model can’t be obtained by a single measurement method.

There are many domestic and foreign research on the application of LIDAR measurement technology or visible light images on power grids, but the combined application of the two is relatively rare. In this paper, the LiDAR point cloud data and visible light image data of are obtained simultaneously through UAV carrying integrated system for tree barriers inspection in distribution corridors. It avoids the problems of poor visual effect and low accuracy of single use of LiDAR or visible light camera. It greatly improves the accuracy and efficiency of tree barriers hidden trouble inspection.

2. Principles of Airborne LIDAR Measurement

LIDAR is a detection technology that quickly obtains three-dimensional information on the ground and ground objects by transmitting laser pulses, receiving the returned pulse signals, and processing the system. The airborne LIDAR system usually consists of a flight platform, a laser scanner, a positioning and inertial measurement unit, and a control unit. The flight platform can be rotorcraft, fixed-wing aircraft or unmanned helicopter. Laser scanner includes pulse ranging scanner and phase ranging scanner. Positioning and inertial measurement unit is based on differential global positioning system (DGPS), and inertial measurement unit (IMU) [3-6]. When the UAV scans along the wire corridor, the airborne LIDAR system sends a laser pulse signal to the surface through the laser scanner, and determines the distance between the center of the scanner and the laser spot on the surface according to the time from the signal transmission to the return to the laser scanner. Using DGPS to determine the center coordinates of the scanner (x0, y0, z0) and the spatial attitude parameters determined by the IMU, and then according to the spatial geometric relationship, the three-dimensional coordinates (x, y, z) of the ground laser point can be determined. LIDAR point cloud data not only includes three-dimensional coordinates in space, but also contains information such as the number of echoes and echo intensity. Using these data, high-precision digital elevation models (DEM) and digital surface models can be generated [7-10].

The UAV airborne LIDAR system is used for power inspection operations. When the laser pulse encounters trees, wires or towers, the laser pulse is reflected back to the detector to determine the spatial position of the scanned object. Because the high-density LIDAR data is very suitable for restoring the shape of the tree canopy, by extracting and processing the information of different laser echoes, three-dimensional modeling of visible light camera electric wire corridor is carried out, and the distance between the ground object and the electric wire is measured in the three-dimensional model to ensure the trees, buildings, crossovers, and other pairs of lines are in line with operating specifications and meeting operating requirements.

3. Data Fusion Method

Fusion of LIDAR point cloud data and visible light image data can give full play to their respective advantages. The fusion of LIDAR point cloud and visible light image requires three processes of point cloud data processing, registration and coloring. The method flow is shown in Figure 1.

3.1. Point Cloud Data Processing

Point cloud data processing includes point cloud denoising, filtering and classification. The processing flow is shown in Figure 2. Due to the different surface roughness of the scanned object and the influence of various noises of the external environment, the point cloud data will have small pieces of
point cloud and discrete points that are different from the main point cloud, which are not conductive
to the extraction and matching of the point cloud. It uses Gaussian distribution filtering method to
denoise the original point cloud data, with the principle to perform statistical analysis on the field of
each point, determine the threshold value by the mean and standard deviation of the Gaussian
distribution, and eliminate the points outside the threshold as noise points to improve the accuracy of
subsequent laser point cloud and visible light image registration [11].

LIDAR

2D Image
data

Point cloud and pixel
registration

Point cloud coloring

3D scene of
point cloud

Figure 1. The process of data fusion. Figure 2. The process of LIDAR point cloud data processing.

The point cloud data collected by the LIDAR system contains complex information, including not
only the three-dimensional coordinates (x, y, z) of the target point, but also the intensity of the object's
reflection. Among these laser points, some points are located on the real terrain surface, and some are
located on artificial buildings such as houses, towers, power lines, or natural vegetation such as trees,
 bamboos, and grass. The ground echo points of the laser point cloud data are removed, and the original
point cloud is divided into ground points and non-ground points. The ground points are interpolated to
obtain the DEM of the distribution corridor, which is called point cloud data filtering. The
classification of point cloud data is to distinguish branches, houses, roads and other different features
from the point cloud data [12]. In the extraction of power line points in tree barrier analysis, ground
points and ground object points are first separated by filtering, and then the vegetation points and
power line points are separated via classification methods.

3.2. Point Cloud and Pixel Registration

The laser point cloud data and the visible light image data must be registered in the same coordinate
system. The laser point cloud data is acquired based on the World Geodetic System 1984 (WGS-84).
The point cloud data is used as the reference coordinate system of the visible light image, and then
covert the visible light image data to the WGS-84 coordinate system. The collinear equation of visible
light image measurement is as follows:

\[
\begin{align*}
X - X_c &= (Z - Z_c) \frac{a_1 x + a_2 y - a_3 f}{c_1 x + c_2 y - c_3 f} \\
Y - Y_c &= (Z - Z_c) \frac{b_1 x + b_2 y - b_3 f}{c_1 x + c_2 y - c_3 f}
\end{align*}
\]

(1)

Make
In the formula, R is the rotation matrix. (x, y) are the coordinates of the image point in the image plane coordinate system. (Xc, Yc, Zc) are the coordinates of the projection center in the object space coordinate system. f is the focal length. The coordinates of the rotation matrix and the projection center point are obtained by the position and orientation system (POS) [13].

In order to realize the conversion from the two-dimension visible light image coordinates (x, y) to the LIDAR three-dimensional space coordinates (x, y, z), first assume a two-dimensional coordinate value z0. Using bilinear interpolation, the value z1 of point z with coordinates (x1, y1) from the LIDAR data. After repeating the calculation, the value of (xn-1, yn-1, zn-1) and (xn, yn, zn) can be obtained. When the corresponding difference between the last two coordinates is less than the set threshold, the calculation stops. The three-dimensional space of the point corresponding to the visible light image position (x, y) is coordinates (x, y, z):

\[
\begin{align*}
X &= \frac{X_n + X_{n-1}}{2} \\
Y &= \frac{Y_n + Y_{n-1}}{2} \\
Z &= \frac{Z_n + Z_{n-1}}{2}
\end{align*}
\]  

Repeat the above steps, and then add three-dimensional coordinate information to each pixel in the visible light image.

3.3. Point Cloud Coloring

Another way to express the collinear equation of visible light image measurement:

\[
y = -f \frac{a_3(X - X_c) + b_3(Y - Y_c) + c_3(Z - Z_c)}{a_3(X - X_c) + b_3(Y - Y_c) + c_3(Z - Z_c)}
\]

\[
x = -f \frac{a_3(X - X_c) + b_3(Y - Y_c) + c_3(Z - Z_c)}{a_3(X - X_c) + b_3(Y - Y_c) + c_3(Z - Z_c)}
\]  

The point cloud data corresponding to the pixel in the image plane coordinate system (x, y) can be obtained via the three-dimensional coordinates (X, Y, Z) of each LIDAR point, high-precision POS data and camera parameters through using formula (3). Then it is important to assign the hue, saturation, lightness and HSL to the corresponding laser point [14-17]. The point cloud data not only contains its own three-dimensional coordinates (x, y, z), echo intensity, echo frequency and other information, but also contains the HSL spectral information given by the visible light image. That is, the LIDAR point cloud and the visible light image are fused, which is shown in Figure 3.
Figure 3. The process of LIDAR point cloud data processing.

Figure 4. The system of UAV LiDAR

4. Equipment Selection
This project uses HDL-64E laser radar, with 64 lines of laser beam, which can output 2.2 million high-density pulse points per second. The laser wavelength is 905 nanometers with strong penetrating ability, which can completely penetrate leaves to reach the surface plane. It is very suitable for restoring shapes of wires and tree crown. Taking DJI S900 multi-rotor UAV as the carrier, it integrates high-density LIDAR point cloud scanner, visible light HD camera, DGPS, IMU and other sensors. The airborne fusion system is shown in Figure 4, with the characteristics of light weight, convenient carrying, simple operation and use, high flight reliability, high positioning accuracy and high image resolution, which meets the requirements of synchronous acquisition of 3D laser point clouds and visible light images. Through professional functional software, it can identify hidden dangers of tree barriers.

5. Functions

5.1. Real-time Tree Barrier Analysis
Inspectors can use UAV fusion system to collect data on the distribution network corridor, so as to determine the distance between trees under current working conditions quickly, accurately and in real time, judge whether the distance between trees and wires meets the requirements of safe operation, and realize the integrated maintenance mode of real-time inspections and discovering defects immediately [18].

5.2. Early Warning Analysis of Tree Growth
The average growth rate of the trees can be calculated through periodically obtain the laser point cloud data of the trees in the distribution network corridor. Using the software to simulate the growth of trees in the future, it is important to identify potential danger points in advance, so as to prevent them, and to realize the early warning of tree barriers for future working conditions [18].

5.3. Tree Falling Analysis
Most tree-barrier power outages are caused by trees outside the power corridor falling into the corridor, due to insufficient safety distance between the tree and the wire during the fall process. The best cutting amount of trees can be determined via calculating the dangerous area of tree falling and analyzing tree falling with color point cloud data and software, considering factors such as tree height and tree growth rate.

5.4. Tree Barrier Simulation Analysis under Comprehensive Conditions
Distribution lines with wide laying area and long lines, complex terrain and various weather conditions will change the spatial distance between wires and trees, which will affect the safe operation of power lines. Using color point cloud data and professional software to simulate the
distance between the maximum sag and maximum wind deviation and surrounding trees under comprehensive working conditions such as maximum temperature, icing or maximum wind speed, timely warning of insufficient safety distance can be given.

6. Conclusion
Based on the real-time fusion technology of LIDAR point cloud and visible light image, the ground feature information of the power distribution corridor is obtained and the three-dimensional real scene of the laser point cloud is reproduced. It gives real-time working condition tree barrier analysis, tree growth warning analysis, tree falling analysis and tree barrier simulation analysis under comprehensive conditions. This technology improves the work efficiency of the tree barrier inspection of the power distribution corridor and the accuracy of the tree barrier identification, and the visualization effect is intuitive. It also reduces the workload and work intensity of the tree barrier inspection of the power transmission department, and realizes the visualization and intelligence management of operation and maintenance of the distribution line, which is worthy of promotion and application.

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