Chapter 12
Application of Lidar Technology in Power Engineering Surveying and Mapping

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Abstract Airborne lidar technology provides high-precision and real-time data support for power grid planning, survey, design, construction and operation management with its digital, high-precision and 3D characteristics, and comprehensively improves the efficiency of power grid construction and management. This paper analyzes the composition and principle of airborne lidar technology as a fundamental breakthrough point, and discusses the application of airborne lidar technology in power engineering surveying and mapping. 30 inspection points were collected evenly in this survey area, and the results showed that the median error in the plane was 0.15 m, the maximum error was 0.7 m, the median error in elevation was 0.16 m and the maximum error was 0.12 m, which met the requirements of making 1:2000 Digital Elevation Model (DEM) and Digital Orthophoto Map (DOM) from point cloud data. After the route selection, the height of crossing the point line is analyzed by using the point cloud data, which can be used by the tower arrangement of line electrical specialty. Compared with the previous projects that need to go to the site to measure the line height, it saves time and improves the operation efficiency.

12.1 Introduction

In recent years, with the rapid development of the economy and society, the increasing demand for electricity has brought a severe test to the State Grid. How to build power lines quickly and efficiently, manage the completed lines scientifically, ensure the normal operation of the power grid and ensure the safe transmission of power are particularly important. Power grid engineering has the characteristics of a wide coverage area and a complex geographical environment, so it is necessary to use a measurement method that is not limited by geographical conditions and can efficiently and accurately obtain large-scale 3D spatial coordinate information of the

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surface to realize fast and accurate survey and design of transmission lines [1]. Airborne lidar technology is one of the revolutionary achievements in photogrammetry and remote sensing in recent years, and it is the most advanced 3D aerial remote sensing technology at present. At present, airborne lidar measurement technology is mainly used to quickly obtain large-area 3D topographic data and quickly generate digital products such as DEM, especially the real topographic maps of forest-covered areas and mountainous areas, including strip-shaped target topographic maps. As capillaries of electric systems, transmission lines play an irreplaceable role in transmitting electric energy [2, 3]. With its unique characteristics of penetrating trees, bamboos and vegetation, 3D lidar can obtain information such as fine topography, landforms and the height of trees and bamboos in vegetation areas, which plays an irreplaceable role in other data acquisition methods and brings a brand-new technical trend to transmission line survey [4]. Thanks to the emergence and development of 3D lidar technology, the problems of spatial positioning and measurement accuracy can be well solved, and the problems of route selection and daily operation and maintenance can also be effectively solved. Airborne lidar technology provides high-precision and real-time data support for power grid planning, survey, design, construction and operation management with its digital, high-precision and 3D characteristics, and comprehensively improves the efficiency of power grid construction and management [5, 6]. Compared with the traditional photogrammetry technology, using airborne lidar to design transmission lines is not restricted by weather, light, vegetation and other conditions, and can quickly, cheaply and accurately obtain 3D topography, aerial digital images and other spatial geographic information data. This paper analyzes the composition and principle of airborne lidar technology as a fundamental breakthrough point, and discusses the application of airborne lidar technology in power engineering surveying and mapping.

12.2 Airborne Lidar Technology

12.2.1 Composition of Airborne Lidar System

There are many kinds and structures of lidar, and the form, volume and weight of the whole machine are also very different. All lidars are composed of three main parts: transmitting, receiving and signal processing. According to its structure, lidar can be divided into monostable and bistable. In the bistable system, the transmitting part and the receiving part are placed in different places to improve the spatial resolution. The laser power supply is used to drive the laser to generate a pulsed laser, and the function of the emission optical system is to collimate the laser output by the laser. The receiver is mainly composed of a receiving optical system, photodetector and receiver circuit. The function of the photodetector is to convert the laser light collected by the receiving optical system into a current signal, which is amplified, filtered, amplitude detected and frequency detected by the receiver circuit.

The airborne lidar measurement system takes the plane as the observation platform and the laser scanning ranging system as the sensor, and obtains the 3D spatial information of the earth's surface in real time [7]. The airborne lidar measurement system mainly consists of five parts: lidar ranging system, dynamic differential GPS, INS attitude measurement system, digital camera and computer, wherein the flight platform can be replaced by an airplane; the working principle of the laser scanner is basically similar to that of ordinary microwave radar, but the wavelength of the laser scanner is smaller than that of ordinary microwave radar. The point cloud data obtained by airborne lidar systems can penetrate the leaf canopy of vegetation. Compared with the traditional photogrammetry technology, data acquisition is faster and the absolute accuracy is higher.

12.2.2 Working Principle of Airborne Lidar System

The interaction between the laser beam emitted by lidar and the detected object to produce an optical echo is the basis of lidar detection [8, 9]. In fact, the working process of an airborne lidar system is a process of repeatedly transmitting and receiving laser points. This working process expresses the results of sampling the surface of the target object by the system through a point cloud diagram composed of spatial points with a certain resolution (see Fig. 12.1).

The laser ranging unit includes a laser transmitter and a receiver. Laser scanning is an active working mode. The laser transmitter generates a laser beam, and the

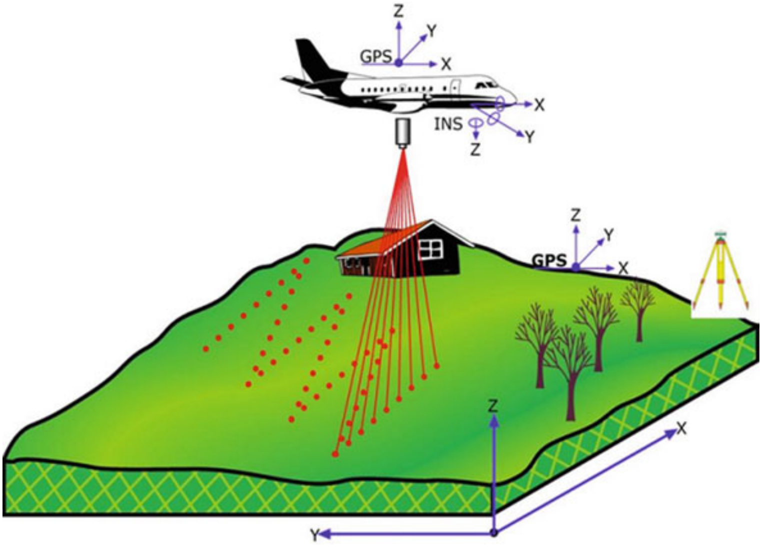

Fig. 12.1 Working principle of airborne lidar system

scanning device controls the direction of the laser beam emitted. After the receiver receives the reflected laser beam, it is recorded by the recording unit. At the same time, the Inertial Navigation System (INS) attitude measurement system can accurately measure the instantaneous space attitude parameters of aircraft: roll angle, tilt angle and heading angle.

After the airborne radar laser system receives the echo, the detected optical signal can be recognized by the computer system and processed accordingly. Finally, various data about electric power engineering surveying and mapping are generated, stored in the surveying and mapping system for operation and use, and can also provide corresponding data reference for future daily management and operation.

12.3 Application of Lidar Technology in Power Engineering Surveying and Mapping

12.3.1 Data Processing

With the rapid development of science and technology and the pursuit of airborne lidar technology, airborne lidar technology has been widely used in computer games, mold manufacturing, cultural relics excavation, tunnel construction and other fields; especially in the last decade, with the continuous innovation and development of various professional software and computer hardware environment, its application fields have become more extensive, and it has gradually entered every field of people's daily life from the laboratory [10]. After processing and analyzing the data by using the professional software of a 3D Geographic Information System (GIS), the 3D real scene along the field line can be moved indoors, and the computer display of a 2D map, 3D map and plane cross-section map can be realized. In this way, designers can fully consider the influencing factors such as landform, social environment and ecological environment, and then combine their own experience and technology to optimize the design of the line and output the results that meet the standards of the power industry.

Make a flight plan, including band division, heading overlap, lateral overlap, laser wavelength, scanning angle, altitude, camera shooting interval, etc. The laser scanning measurement data, Global Positioning System (GPS) measurement data, flight attitude data and aerial photography data are jointly processed; then these data are classified, denoised and filtered to generate orthographic images and 3D models [11, 12].

Data preprocessing refers to the process of positioning, orientation, calibration and coordinate transformation of the original laser data, and it is also necessary to determine the external orientation elements of the digital image. The positioning and orientation part uses GPS data, IMU data and various parameters provided by the system. In order to correct the errors of the three attitude angles of the lidar, it is calibrated according to specific ground objects and airborne lidar data samples.

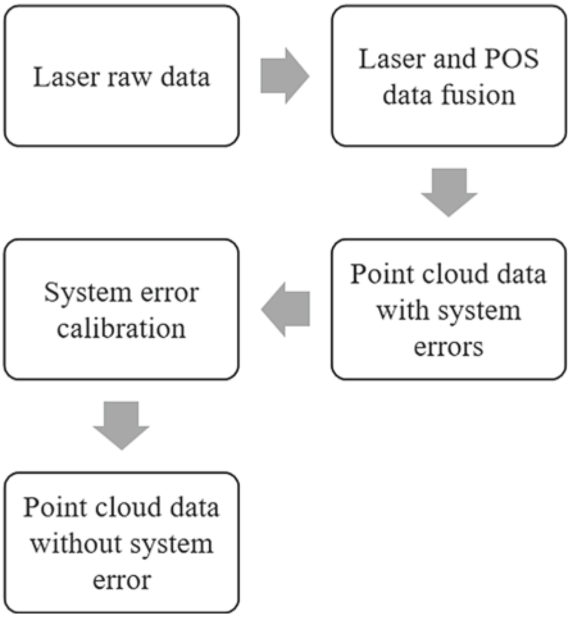

Fig. 12.2 Flowchart of point cloud preprocessing

The preprocessing process is that the original point cloud data mainly contains the angle and time information of laser emission, and the data with distance and angle is processed by software, and the corrected data is fused with the integrated navigation data to generate point cloud data with errors. The operation flow is shown in Fig. 12.2:

In order to correct the roll value, the height difference (d_1, d_2) and the distance between two points on two opposite flight routes are measured. Calculate the correction value Δr of the roll angle according to the following formula:

$$\Delta r = \frac{d}{\text{swath width}} \tag{12.1}$$

By using the calibration parameters, the cross sections of the point cloud data of two opposite routes in the scanning direction are finally adjusted to overlap each other.

Pitch angle of system integration is mainly reflected in the deviation of laser point cloud in the vertical direction of laser scanning line (flight direction of aircraft). The comparison method of pitch angle is that we use two flight belts to fly back and forth, which are perpendicular to the roof line of the house and fly over the spire house at the same time. Pitch angle is calculated by trigonometric geometry:

$$\Delta P = \frac{D}{2H} \tag{12.2}$$

where D represents the distance between planes flying back and forth to obtain the same position information. H stands for flying altitude.

The error of heading direction will change the position of the center of the scanned object and deform the object, so it is relatively difficult to check the heading angle error. The length of the calibration baseline (the distance from the nadir of the route to the center of the target object) is short, and the object offset is small, which makes the calibration error large.

According to the error influence law of `heading`, the formula for calculating heading error can be obtained as

$$\Delta p = \arctan \frac{\sqrt{D}}{S} \tag{12.3}$$

where S is the plane distance from the target center to the intersection of the routes.

12.3.2 Selection of Key Parameters of the System at Different Flight Altitudes

With the support of airborne LIDAR technology, power enterprises can quickly scan and recover the accurate 3D spatial positions of terrain and objects in line corridors by using laser lidar measurement technology, and can record the information of environmental variables during operation in real time. The geographical environment and other conditions around lines and equipment are displayed perfectly and intuitively by means of stereoscopic simulated images, thus providing clearer and more accurate information reference for the management and decision-making of power enterprises.

In the application of airborne lidar to ground mapping, according to different mission objectives, the flying height of the aircraft is usually between 1000 and 6000 m. At the flying height of 3000 m, the radar system should work in the near-saturation imaging mode, in which the root mean square error of ranging first decreases and then increases with the fringe width, and there is an optimal fringe width to minimize the ranging error.

In the airborne surveying and mapping system, the number of sampling units N in each sampling channel is set to 1200. In order to ensure that the distance gate width is enough to cover the depth of field of the measured object, the time slot width $t_{bin} = 1.26\,\text{ns}$ of the system is the corresponding distance gate width Gate $= 172\,\text{m}$ at this time.

In the mapping experiment of fixed targets, the position of fringe image in the sampling channel can usually be changed by adjusting the delay between detector and laser. That is to say, if the depth of field of the measured object is not particularly large, we can ignore the influence of fringe bending on ranging accuracy. However, in the application of airborne mapping to the ground, we usually can’t know the

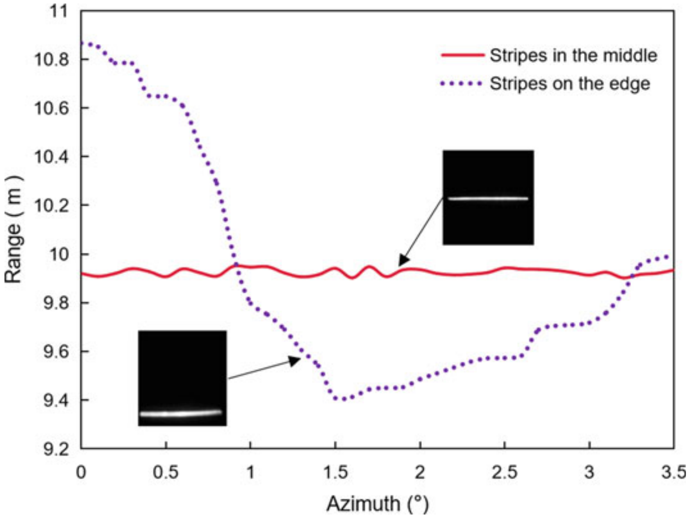

Fig. 12.3 Bending of fringe images at different positions

elevation information of the measured object in advance, and the fringe image may appear at any position of the sampling channel, so the distance deviation caused by fringe bending must be considered at this time.

From Fig. 12.3, we can see that when the fringe image is at the edge of the sampling channel, the distance extraction result is obviously curved; when the fringe image is in the center of the sampling channel, the distance extraction results are basically the same.

According to the calculation result of the signal centroid, the distance value corresponding to the centroid position can be queried in the calibration matrix, so that more accurate distance extraction results can be obtained. By changing the time delay between the detector and the laser, the fringe images move in the whole time-resolved channel, and the fringe images at different positions are stored at certain intervals, interpolating the distance values at all centroid coordinates to obtain the distance calibration matrix of all charge coupled device (CCD) pixels.

12.3.3 Accuracy Analysis

Strong wind, snow and ice weather may cause conductor dancing, change the distance between conductors and split conductors, and easily cause short-circuit discharge. Lidar can accurately measure the distance between each split sub-conductor under the condition that the line is live and not in contact with the line, and provide guidance for making spacer bars.

Based on the 3D scene processed by lidar measurement technology, the real situation in the field is displayed on the computer, and the whole line can be understood from the global to the microscopic, as shown in Fig. 12.4.

See Fig. 12.5 for the accuracy requirements of lidar data processing:

The accuracy of classified point clouds is checked by stereo image pairs, that is, the obvious corner points of ground objects are collected on stereo image pairs, and the same corner points are collected on the point cloud model, and then the plane and elevation are compared to check their accuracy. 30 inspection points were collected

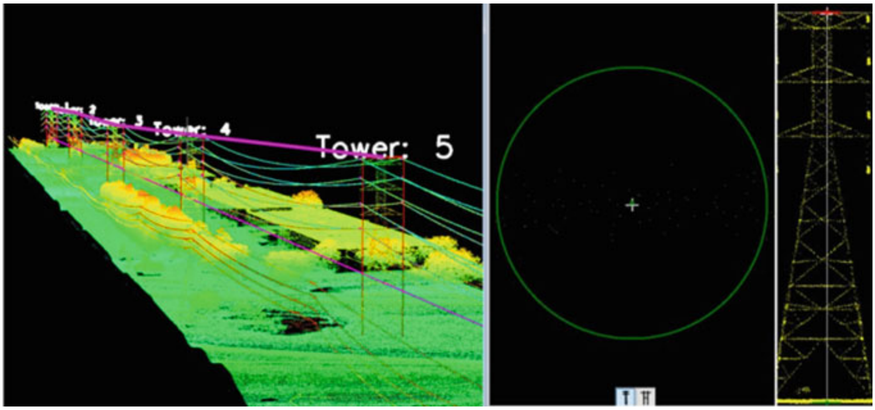

Fig. 12.4 Line 3D laser point cloud obtained by lidar measurement technology

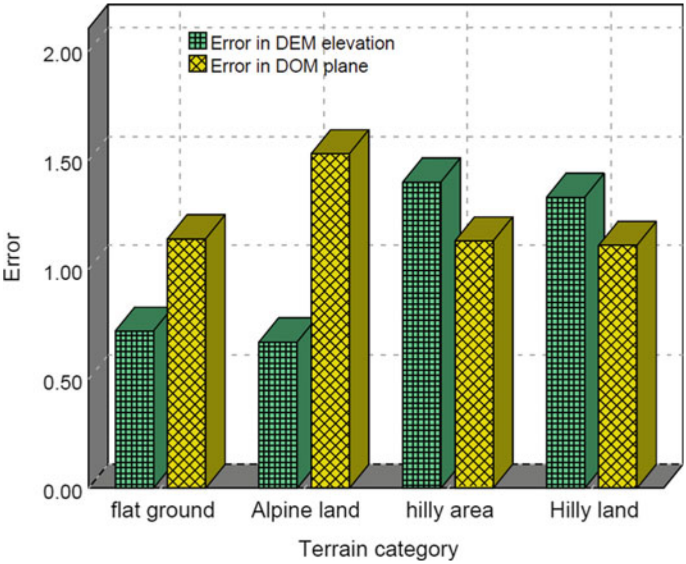

Fig. 12.5 Required precision

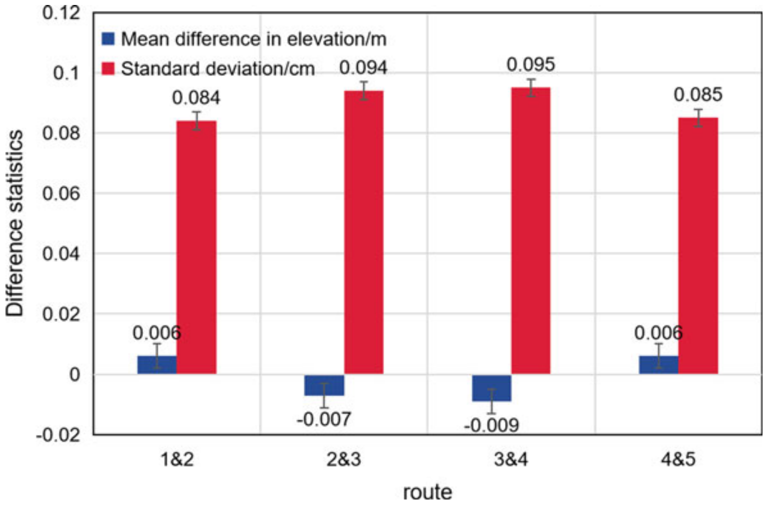

Fig. 12.6 Statistics of elevation difference in overlapping areas

evenly in this survey area, and the results showed that the median error in the plane was 0.15 m, the maximum error was 0.7 m, the median error in elevation was 0.16 m and the maximum error was 0.12 m, which met the requirements of making 1:2000 DEM and DOM from point cloud data.

After band adjustment, the internal accuracy (relative consistency) of point cloud data must be evaluated. It is usually realized by checking the consistency of lidar points in overlapping zones. In addition to zonal mapping, airborne lidar data usually have overlapping areas between different routes. Figure 12.6 shows the statistical results between five parallel routes in a small area.

The first line indicates that the difference of most points in the overlapping area of route 2 and route 3 is within the range of -0.007 ± 0.094. For areas with large slopes, this index of elevation difference also reflects the accuracy of the plane, because the error of the plane will bring the error of elevation. It is difficult to distinguish the plane difference of laser point cloud data because of its discontinuity. The plane difference can be realized by comparing the plane differences of the same name points of the feature objects directly extracted from the original data.

The better point cloud data of the laser reflection surface of the conductor can fit the outgoing line type. For many years, the reflection surface of the wire has been poor, so it is difficult to return to the pulsed laser and obtain continuous point clouds. For power lines of 10 kV and below, the conductor section of communication lines on the ground is small, so it is impossible to return a pulsed laser, and it cannot be identified in the aerial survey industry. The identifiable power line elevations are shown in Table 12.1.

After calculation, the mean error between the fitting elevation of power line point cloud and the measured elevation in this project is 0.17 m, which can meet the requirements of power line selection accuracy. After the route selection, the height

Table 12.1 Line height measurement

Circuit	Approximate difference/m
1	−0.042
2	−0.157
3	−0.141
4	−0.144
5	−0.161

of crossing the point line is analyzed by using the point cloud data, which can be used by the tower arrangement of line electrical specialty. Compared with the previous projects that need to go to the site to measure the line height, it saves time and improves the operation efficiency.

12.4 Conclusion

At present, airborne lidar measurement technology is mainly used to quickly obtain large-area 3D topographic data and quickly generate digital products such as DEM, especially the real topographic maps of forest-covered areas and mountainous areas, including strip-shaped target topographic maps. As capillaries of electric systems, transmission lines play an irreplaceable role in transmitting electric energy. Using an airborne lidar system to design power lines, only a few ground control points and field mapping work are needed to obtain high-precision 3D coordinates of ground points. Using airborne lidar technology to obtain terrain data has high accuracy and high speed, which can greatly reduce or even avoid the field survey work of surveyors and greatly improve work efficiency. Laser can penetrate the canopy of vegetation to reach the surface, and at the same time obtain information on the ground and vegetation, which is more abundant than that obtained by traditional aerial photogrammetry, and can also reduce the layout of ground control points. Based on the above characteristics, airborne lidar technology will play an increasingly important role in the construction and maintenance of the national power grid.

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