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Application of Long Range Airborne LiDAR in Mapping High-density Vegetation Terrain in Mountainous Areas

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Abstract

In the field of surveying and mapping, the accurate measurement of dense vegetation in mountainous areas is always a challenge. First of all, the use of conventional GNSS technology and total station operation, it is faced with more labor and resource investment, heavy economic burden, high safety risk and long operation cycle drawbacks. Secondly, the use of satellite remote sensing images and UAV aerial photography technology, due to the cover of surface vegetation, often can not clearly capture the surface condition covered by dense vegetation, and it is difficult to ensure the accuracy of measurement results. With the continuous development of LiDAR technology, airborne LiDAR measurement technology has gradually become a mature measurement means, combined with point cloud data processing, optimize the point cloud classification algorithm, can maximize the accuracy of height measurement in dense vegetation areas. Therefore, the use of airborne LiDAR to obtain the elevation data of the measuring area is a more ideal measurement method. The long range and multi-echo airborne LiDARis used to obtain terrain data with point cloud density of 21 points /m2, which solves the problem of terrain mapping under such terrain conditions.

Keywords

LiDAR; Point Cloud; Drones; Topographic Survey.

1. Introduction

The photovoltaic power generation projects in Guizhou are usually in the form of mountain photovoltaic power stations. Compared with other types of power stations, this kind of power station has a higher difficulty in design and construction. For this reason, a high degree of mathematical accuracy is required for the geographical mapping of the project, especially for the elevation measurement in heavily forested areas. Only by mastering the fine topographic survey data in the planned construction area of photovoltaic power generation, can we properly plan in the design and construction links to ensure the smooth progress of photovoltaic power generation projects. In view of this, when photovoltaic power generation projects are carried out in mountainous areas, the topographic mapping of dense forest areas becomes the core and challenge of the work.

The problem with PV projects in mountainous areas is that the jungle is heavily vegetated. The traditional measurement methods,such as total station, Global Navigation satellite System (GNSS),real-time dynamic differential technology (RTK), are not only inefficient, but also expensive. However, if the UAV is chosen for aerial photo grammetry, it is difficult for the photographic equipment to capture the surface image shaded by plants due to the cover of dense vegetation, which directly affects the ability to obtain the true elevation data of the surface, and thus makes the accuracy of the topographic map difficult to meet the standard[2] . With the progress of science and technology, the aerial LiDAR detection technology, which integrates multi-functional sensors such as GNSS,IMU and laser scanning, was born. The technology installs a variety of sensors, such as GNSS, IMU and laser scanner, on the UAV carrier. With the combined application of these sensors, precise position and attitude data as well as laser scanning information can be collected. In addition, the laser radar system carried by the UAV, because it is placed on the aircraft, can overcome the complexity of the terrain and obstacles blocking the problem. The system is not only known for its efficient data collection and high mathematical accuracy, but also relies on the small diameter of the laser beam and multi-wave echo technology, which enables it to accurately obtain the coordinate information of the surface through the gaps in the vegetation.

Airborne LiDAR technology is advancing rapidly. Different from optical remote sensing technology that passively receives information, it represents an active remote sensing method. Its ignificant advantages are reflected in efficient acquisition speed, excellent data accuracy and strong vegetation penetration ability[3].

Liu et al[4] show that although airborne LiDAR technology has shown excellent horizontal and vertical measurement accuracy in the rendering of river terrain in the lower reaches of the Jinsha River, in the face of dense forest areas, it is still necessary to use traditional measurement means to improve data acquisition and ensure the integrity and accuracy of information. In order to solve the problems such as inconsistent resolution, low overlap and excessive redundancy of ground data in airborne LiDAR data acquisition, Pan[5] innovatively proposed an intensity regulation registration method that integrates ground area division and motion trajectory information. On this basis, a set of cost-effective and simple structure airborne LiDAR system was successfully constructed, and the core technology of three-dimensional space reconstruction was deeply studied and improved, which significantly improved the accuracy and efficiency of the reconstruction operation and ensured the excellent performance of the reconstructed three-dimensional scene in terms of resolution and accuracy. Zhao et al[6]gave full play to the advantages that airborne LiDAR can directly obtain three-dimensional information of surface objects, and applied it to forest resources investigation to quantitatively extract a variety of forest parameters such as tree height, stand cover and density, and stock amount. Aiming at the side slope of a road near Zhuhai Scenic Spot in Yixing City, Peng et al[7] used the LiDAR technology mounted by UAVs to carry out low-altitude high-precision scanning and obtained a large amount of laser point cloud information. These data were processed by filtering technology, and the digital elevation model and contour map were drawn. Based on these results, the surface characteristics of the potential landslide hazards in this area were analyzed in detail, the hidden landslide signs were successfully identified, and a set of airborne LiDAR technology scheme was formed for the rapid detection of small geological hazards in densely vegetated areas. Ye et al[8] successfully constructed a digital elevation model (DEM) and corresponding slope distribution map by processing airborne LiDAR data points in desert areas in two periods respectively. With the fusion application of geographic entity orientation and pixel-level change detection technology, the movement trajectory and displacement of sand dunes are accurately tracked and recorded.

At present, airborne LiDAR technology has been widely used in many industries, but the research on its mapping of dense forest land in mountain photovoltaic power generation projects is not enough. In view of this, this study selected a mountain photovoltaic power generation project with rich vegetation coverage as a case study, aiming to explore the application potential and accuracy of airborne LiDAR technology in difficult terrain mapping. By comparing the technology with the data obtained from the ground checkpoint, this paper aims to confirm the accuracy of the research results. This research has a certain reference and practical application value for the future research and practice in similar fields.

2. The Working Principle of Airborne LiDAR System

2.1 The Working Principle of Airborne LiDAR System

(1) Emitting laser pulses: airborne LiDAR systems usually use the laser transmitter on the aircraft to emit laser pulses, which will be focused into a very small point by the laser beam when launched.

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(2) The interaction between the beam and the ground: after the laser pulse reaches the ground, it interacts with the object on the ground, and part of the energy is reflected back to form an echo signal.

(3) Receive echo signal: The airborne LiDAR system will receive the reflected signal, which not only contains the position information of the target, but also includes the direction, speed, intensity and other details.

(4) Processing signal data: The signals received by the airborne LiDAR system can be processed and analyzed using electronic equipment, which is used to generate 3D maps or point cloud data.

2.2 Reasons for the Adoption of Airborne LiDAR System

(1) Difficulties in surveying and mapping under the condition of high-density vegetation terrain surveying in mountainous areas.

① complicated topography: the mountainous area has large

relief and complex and changeable terrain, with special landforms such as landslide, collapse and debris flow, which bring great difficulties to the surveying and mapping .

② active crustal movement: active crustal movement in mountainous areas,complex geological structure,frequent disasters such as earthquake and land subsidence,lead to constant changes in topography, which makes the surveying and mapping data unstable and difficult to accurately reflect the actual topography .

③ harsh climate: the climate in the mountain area is changeable, there is more precipitation, fog and unstable weather, these conditions bring great difficulties to the surveying and mapping work and affect the quality and effect .

④ dense vegetation: the dense vegetation in the mountain area shields the ground characteristics, making it impossible to obtain accurate topographic data during surveying and mapping.

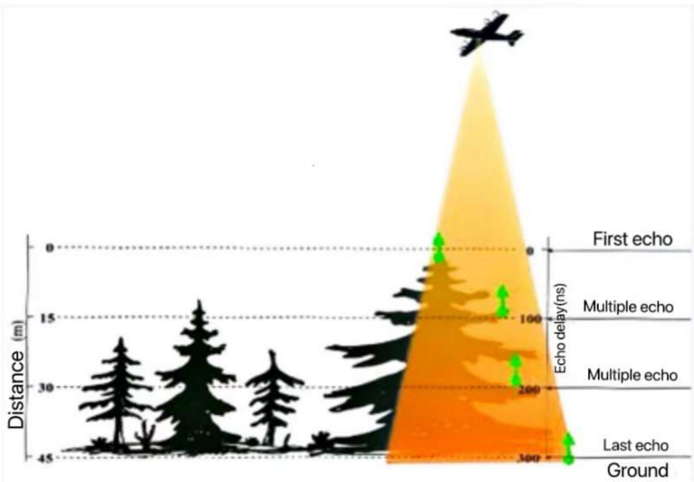

Fig.1 Principle diagram of airborne LiDAR system penetrating vegetation.

(2) The advantages of long range multi-echo radar

① long range: long range radar can cover longer distances, which is especially important for large-scale terrain survey and target detection in complex environments.

② multi-echo technology: the multi-echo technology can improve the accuracy and reliability of data by transmitting and receiving the laser signal several times.

③ high density point cloud: high density point cloud can provide more detailed ground object information, and is suitable for precise reengraving of ground object features.

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④ stability in harsh environment: multi-echo technology can maintain relatively stable detection performance in bad weather. By correcting the data many times, the laser radar can maintain high ranging accuracy and stability in the bad weather such as rain, snow, haze, sandstorm .

3. UAV LiDAr Operation Workflow

The work flow of UAV LiDAR operation mainly includes two steps: data acquisition and processing. The specific technical process is shown in Fig.2.

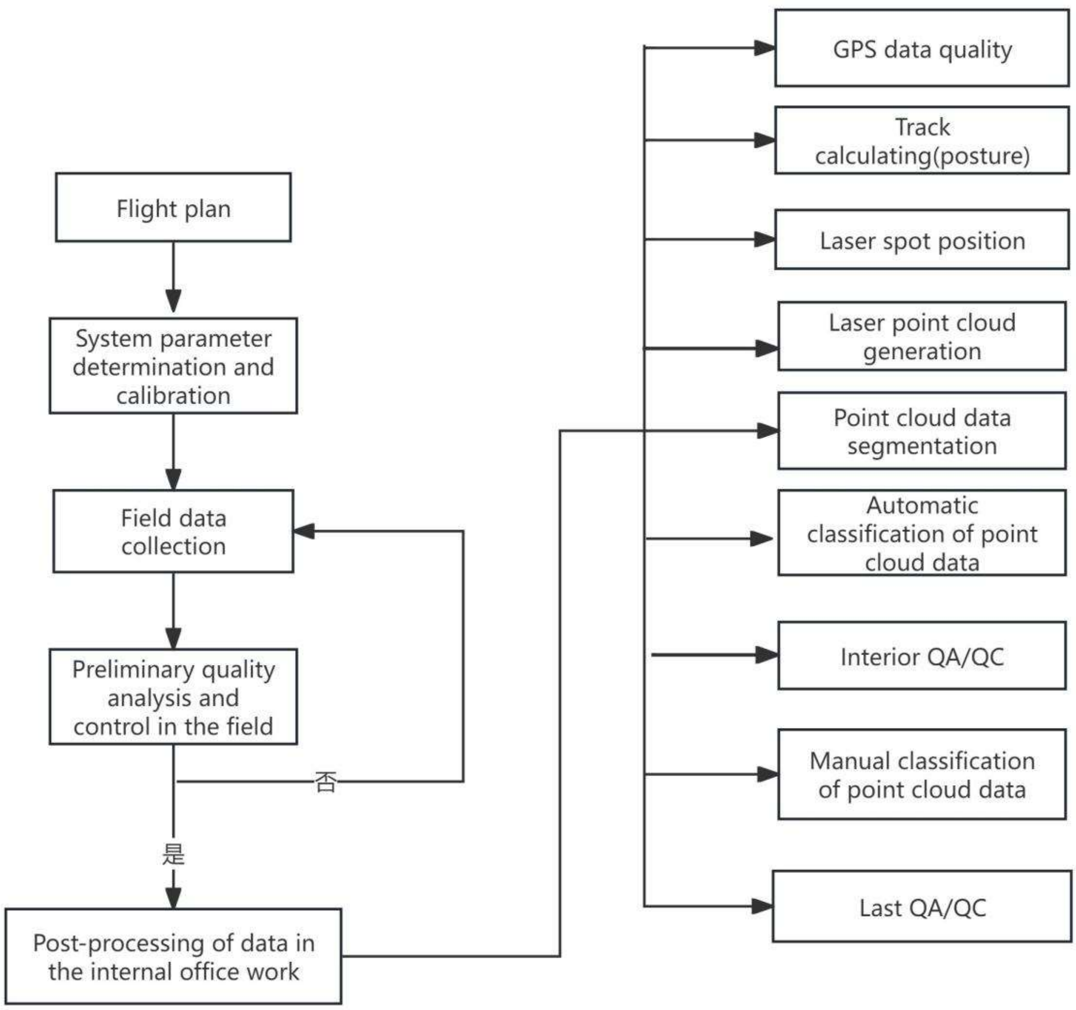

Fig.2 Work flow of UAV LiDAR measurement.

Airborne LiDAR technology refers to the technology of using a UAV equipped with a LiDAR lens to conduct LiDAR scanning on the ground to generate a ground point cloud model. The advantage of airborne LiDAR technology is that it integrates the flexibility and convenience of UAV, the real-time positioning of GPSRTK and the point cloud data results of 3D laser scanner, which reduces the data volume on the basis of improving the operational efficiency and the operability of the results. As a result, the point cloud model is different from the 3D reality model, which has stronger operability, and is more conducive to eliminating non-essential factors when applied, so as to improve the data accuracy. At present, the application of airborne LiDAR technology in surveying and mapping has become a research hot spot, and is gradually replacing the traditional operation mode, becoming a new surveying and mapping method.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0046

4. Engineering Application and Demonstration

4.1 Overview of the Research Area

The altitude of the wind farm is about 1310.6 meters, the landform type is mountainous, and the ground is mostly grassland,woodland, orchard and agricultural land. The topographic map and other data obtained from this survey can be used for scientific site selection, layout planning, avoiding blind investment and waste, and preparing for the later design and planning. The actual environment terrain is changeable, relying on the traditional manual measurement method, heavy on-site operation, extremely difficult operation, while the safety of staff and equipment is difficult to ensure. UAV aerial photogrammetry technology, however, is limited by its inability to penetrate the plant cover and obtain effective ground elevation information[10] If the conventional surveying engineering technology is used to supplement the data, the workload will be significantly increased. In order to improve the efficiency of the operation and ensure the speedy completion of the task, it was decided to use the KWT-X6L-15 UAV produced by Keweitai and equipped with the AS1300HL LiDAR equipment of Huatai Company.

Fig. 3 Topographic map of the research area.

4.2 Accuracy Verification

In the process of field flight, GNSS-RTK method is used to collect a small number of terrain feature points, so as to prepare model data and topographic map data for later inspection.

(1) Some check points were set up in key areas to check the reliability and accuracy of the topographic map results in the later period;

(2) In areas with obvious features, such as room corners, road corners and other places where plane positions can be clearly distinguished, set up plane checkpoints for later DEM inspection ;

4.3 Implementation of Technology

4.3.1 Point Cloud Data Acquisition

In the early stage of the project, the construction personnel have carried out research on the relevant equipment. Considering the altitude, drop and topography of the flight area, after comprehensive research in all aspects, it is proposed to adopt Keweitai KWT-X6L-1UAV to carry the AS1300HL

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0046

LiDAR system equipped with Huatai (see Fig.4). The specific platform and parameters are shown in Table 1.

Fig.4 AS1300HL LiDAR system.

Fig.5 Schematic diagram of the route.

During the flight, GNSS signals of the base station and UAV are stable, and the flight platform, LiDAR and aerial camera work normally. The measuring area is 51.12km2, the maximum drop is 469m,and the flight task is carried out in a fixed altitude flight mode. The highest altitude is 1469m, the lowest altitude is 1000m, the course overlap degree of the design course of the measuring area is 80%, and the side overlap degree is 72%. A total of 6 UAV flights were carried out, and 4480 ground images were obtained. The ground resolution of the images reached 6.9cm, which met the resolution requirement of 1:2000 topographic map. In order to confirm the accuracy of the measurement of the

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UAV equipped with LiDAR system, special feature points were selected in the measurement area for accuracy verification, which were designed to evaluate the accuracy of the plane positioning and elevation measurement. The selected feature points mainly cover the following types: turning points at street junctions, corner positions of buildings, and elevation measurement points in vegetated areas.

4.3.2 Data processing

The airborne LiDAR data processing process is mainly divided into two parts: airborne LiDAR point cloud data processing and airborne LiDAR point cloud data filtering classification processing.

(1) Airborne LiDAR point cloud data processing

After the inspection of the image data collected by the field industry is correct, the internal data processing is carried out. After the image processing is completed by the Pix4D software, the orthophoto image of the area is produced (see Fig.6).

The orthoprojective image data (DOM) is in *.tiff format(coordinate information is reserved in TFW file). The image features clear details, moderate contrast, distinct layers, basically balanced colors, and image histograms are basically close to normal distribution. The orthophoto data is used for the later collection of ground objects.

Fig. 6 Digital orthophoto image of the mission area.

After inspection, the ground resolution is better than the requirement of 10cm (see Fig.7), and the orthophoto resolution meets the accuracy requirements of ground object rendering.

Fig. 7 Orthophoto resolution inspection.

According to the orthophoto data produced by Pix4D software, combined with the 3D reality model, the DOM data produced was loaded into the Southern CASS software to check the plane accuracy of the ground objects. After inspection, the median error of DOM plane is 0.12m, which is less than the relevant requirements in Digital Orthographic Map of Basic Geographic Information 1:500, 1:1000 and 1:2000 (CH/T9008.3-2010). After the accuracy meets the requirements, the ground object collection work begins. See Fig.8 for partial ground object collection display.

Fig. 8 Ground object data acquisition.

(2) Airborne LiDAR point cloud data filtering and classification processing

① Point cloud denoising is processed by Terrasolid processing software. Manually intervene and delete the noise points that cannot be removed automatically. Otherwise, abnormal classification will be caused by noise interference during point cloud classification, and the normal ground points will be incorrectly classified and deleted later, resulting in bug errors.

② Automatic classification of point clouds. Set relevant parameters to classify ground, vegetation, building and other types of point clouds according to the terrain and ground features.

Terrasolid trial software adopts iterative morphological filtering method to classify ground point clouds. Firstly, the test area is divided into 500m*500m blocks, and then blocks are processed. The lowest point and ground points within a certain height difference are selected as ground seed points in the classification of Terrasolid trial software. In the uncovered surface, there are more than 70 surface data points per square meter on average; In the sparsely forested areas, that number drops to about 20. In densely forested areas, airborne laser scanning technology can capture about 10 highly accurate surface data points per square meter. This discovery means that the surface point data collected by airborne LiDAR technology can meet the requirements of large-scale mountain terrain mapping, both in terms of elevation accuracy and point density.

③ The software filtering effect of some special terrain areas such as steep ridges and cliffs is poor, at this time, manual intervention is needed to classify the effective ground points into the ground point layer.

④After the processing is completed, the point line is checked with the measured checkpoint, and the accuracy of ground points after filtering is mainly checked. The median error of point cloud elevation is 0.07m, which is less than the requirement of 0.85m in the 1:2000 topographic map of flat terrain in the Technical Specification for Airborne LiDAR Data Acquisition (CH/T 8024-2011). After the accuracy meets the requirements, the terrain editing work begins.

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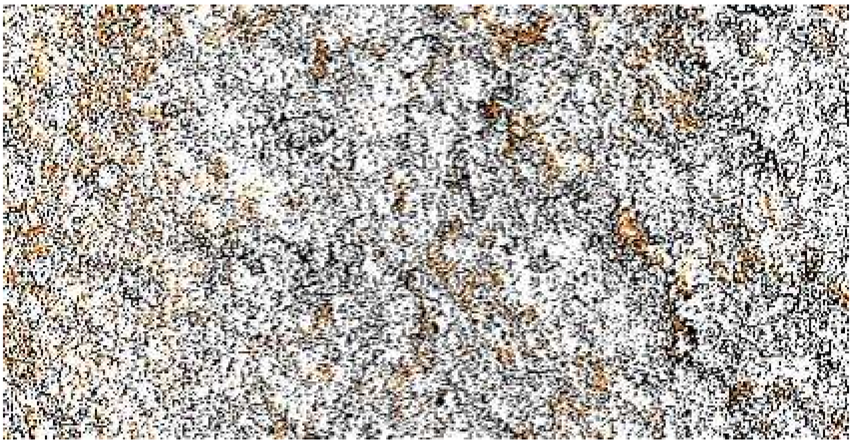

Fig. 9 Classifies ground point data.

4.3.3 Topographic Map Compilation

The topographic map is compiled according to the point cloud data after noise removal. The topographic map of the mission area is required to be a 1:2000 topographic map with a basic contour distance of 2m; The density of elevation notes should be 5 to 10 points per 100cm2 on the map.

First, the DOM results were imported into CASS software in South China to generate the final ground object data; After classification, the ground point data is used to generate the elevation notes and contours; The two are combined to check and edit each other to form the final topographic map file, combined with the field GNSS-RTK collection of checkpoints and ground object data, based on Cmap software for final compilation, after the compilation is completed,the topographic map results are preliminaries quality inspection, and the parts with problems are modified in accordance with the requirements of the specification.

4.3.4 Precision Check

The accuracy inspection of LiDAR measurement results adopts the inspection method combined with total station and GNSS measurement.

The total station is mainly used to collect the obvious feature points of the village, such as the corner points. GNSS mainly measures the elevation points in the vegetated area outside the village, and is used to check the elevation accuracy of the point cloud results. Oblique photogrammetry was carried out on all villages to extract a large number of feature points and check the plane accuracy of the point cloud. In order to verify the accuracy of airborne LiDAR measurement results, the elevations of different terrain types such as flat land, mountain, building area, vegetation high-density area, sparse vegetation area and rock bare surface were collected respectively in the test area. The check points were evenly distributed throughout the test area to check the classification effect of point clouds.

Table 1. Technical index of point cloud density.

Terrain Categories	Median error in elevation
Flat Ground	0.25 m
Hilly fields	0.35 m
Mountain	0.85 m
High Mountain	1.0 m

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Table 2. The mean square error index of point cloud elevation accuracy.

Indicators	Requirements
Average point cloud intervals	< 2m
Average point cloud density	> 0.25p/m2

Before classifying and de-noising the point cloud data, the project first carries out the necessary quality check, and uses Terrasolid software to check the point cloud density and point cloud elevation accuracy(see Figs.10 and 11).

Fig.10 Point cloud density check.

For the extraction work of surface points in dense forests and mountainous areas, the density calculation experiment was carried out to evaluate the density distribution of surface points in this region. The relevant calculation results are shown in detail in Table 3.

Table 3. Calculation results of surface point density.

Density of surface	Dense	Sparsely	Bare
points/PCS /m	forest area	wooded areas	surface
H Mountain	12	21	78

The average uncovered surface has more than 70 surface data points per square meter; In the sparsely forested areas, that number drops to about 20. In densely forested areas, airborne laser scanning technology can capture about 10 highly accurate surface data points per square meter. This discovery means that the surface point data collected by airborne LiDAR technology can meet the requirements of large-scale mountain terrain mapping, both in terms of elevation accuracy and point density.

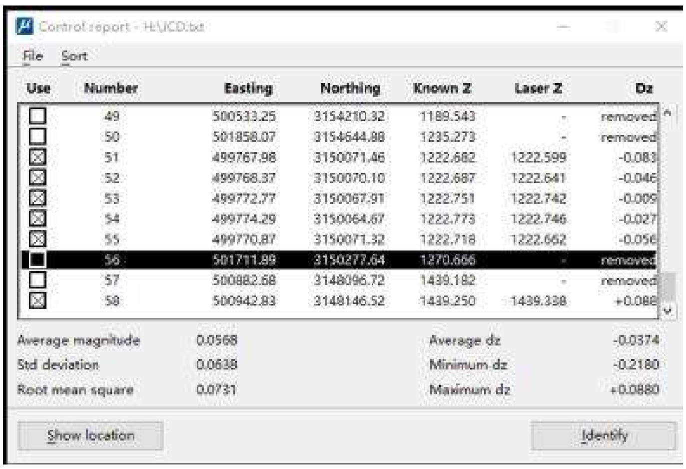

Fig.11 Elevation accuracy check of point cloud.

After in-depth comparison and analysis of the field verification data, we found that the highest elevation error of each detection point was 0.0218 meters, while the average elevation error of the whole measurement area was controlled below 0.01 meters, and the standard deviation of the error was 0.063 meters. This shows that the deviation between our measurement data and the actual value is very small, the accuracy of the measurement work is high, and the data error shows good stability. Through the further calculation of the elevation of the detection point, the average error of the elevation of the point is 0.07 meters.

5. Conclusion

Airborne LiDAR systems acquire 3D digital data on the ground, which can maintain high accuracy, strong flexibility and low economic cost under any weather conditions, so it has great application potential. Through this case study and accuracy evaluation, we can draw the following conclusions: (1) there are many kinds of data generated: digital surface model (DSM), orthophoto (DOM), digital elevation model (DEM). (2) Outstanding high-precision results:

Relying on the airborne LiDAR system, a large number of fine surface high-precision data can be collected, and the density of ground points per square meter reaches 21, which fully conforms to the cartographic accuracy standards. In addition, the data quality isexcellent, with the elevation error of the checkpoint no more than 0.07 cm as proof, fully adapted to the accuracy requirements of making large format topographic maps. (3) High production efficiency: The use of airborne LiDAR technology can quickly collect surface and spatial information in a wide area, thus reducing the dependence on numerous ground control and monitoring points. This greatly reduces the burden of field operations, shortens the engineering cycle, and improves the efficiency of the project schedule.

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