Study on analysis from sources of error for Airborne LIDAR

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Abstract: With the advancement of Aerial Photogrammetry, it appears that to obtain geo-spatial information of high spatial and temporal resolution provides a new technical means for Airborne LIDAR measurement techniques, with unique advantages and broad application prospects. Airborne LIDAR is increasingly becoming a new kind of space for earth observation technology, which is mounted by launching platform for aviation, accepting laser pulses to get high-precision, high-density three-dimensional coordinate point cloud data and intensity information. In this paper, we briefly demonstrates Airborne laser radar systems, and that some errors about Airborne LIDAR data sources are analyzed in detail, so the corresponding methods is put forwarded to avoid or eliminate it. Taking into account the practical application of engineering, some recommendations were developed for these designs, which has crucial theoretical and practical significance in Airborne LIDAR data processing fields.

1. Introduction
In recent decades, with the development of Aerial Photography, Airborne LIDAR has attracted the mapping industry a lot. Airborne Light Detection and Ranging (LIDAR) technology that is an emerging technology for earth observation, is mainly made up of the Laser Range Finder, Inertial Navigation System (INS), Global Navigation Satellite System (GNSS) and High-resolution digital cameras and other equipment. Pulsed laser range finder can take advantage of information behind to get the real target detection directly, steep slope, the roughness coefficient case, even reflectivity information, yet digital
cameras can record real-time image information of the target, through a particular process to produce ground real three-dimensional and three-dimensional imaging results from surface area and coordinate information of sampling points, a certain strip, such as high-density point cloud data, high-resolution orthophoto DOM, a variety of Digital Terrain Model(DTM) and large scale topographic maps, and digital surface models (DSM), etc. Lidar scanner data through post-processing software can be widely used in land resources, urban planning and construction management, digital three-dimensional modeling, to be applied to an electronic map\textsuperscript{[1]}.

Airborne LIDAR measurement technology, its’ height accuracy may be up to 13cm, or horizontal accuracy may be up to 20 centimeter in the open air. To improve the accuracy of Airborne LIDAR Systems and access to high quality point cloud data, some scholars conducted extensive studies. Domestic and foreign scholars have conducted in-depth study of the accuracy. Domestic scholars such as Shukai Li, Shaochuang Liu, especially Hong You in construction and other red from photogrammetry collinear equations deduced Airborne 3D imager system geometry, and affect the positioning accuracy error sources qualitative analysis\textsuperscript{[2]}. Xiaohong Zhang (2007) studied the Airborne LIDAR’ accuracy from elevation or horizon\textsuperscript{[7]}. Foreign scholars, Schenk (2001) devoted much time to studying the sources of error on LIDAR System\textsuperscript{[3]}. However, there are numerous foreign scholars exploring on the impact of Airborne Laser scanning measurement accuracy systematic error analyzes \textsuperscript{[4, 5]}. In this paper, considering the research status of domestic and foreign scholars, we demonstrates common error sources were elaborated or analyzed from Airborne LIDAR, yet the corresponding method to avoid or eliminate will be enforced to improve accuracy based on practical experience of great significance for subsequent processing point cloud data.

2. Airborne LIDAR error source

Airborne LIDAR System is a complex integrated system, resulting in its accuracy affected by the interaction of the various components of the system. From Airborne LIDAR ’error sources being various even very complex, they can be divided into two major aspects: single error and integrated error, as shown in Figure 1.

![Error Category](error-category.png)

**Figure 1** Error Category

2.1 Single error

2.1.1 Ranging error The core equipment used to be rangefinder about Airborne LIDAR System. All factors can affect the precision of laser pin point coordinates, but the ranging accuracy, which is the most complex. According to Schenk (2001), described the mathematical model, says that LIDAR point clouds
The no error geolocation equation:

\[ P_w = P_{GPS} + R_{GPS} R_{GEO} R_{INS} (R_{LB} S + l_0) \]  

\[ P^*_w = \Delta P_{GPS} + P_{GPS} + \Delta R_{INS} (\Delta R_{LB} S + \Delta R_{LB} l_0) \]

\( \Delta P_{GPS} \): the GPS positioning error; \( \Delta R_{INS} \): Attitude IMU error; \( \Delta R_{LB} \) and \( \Delta R_{LB} \): placed foot error and laser scanning angle error; \( \Delta s \): Laser point ranging error; \( \Delta l_0 \): Laser point ranging error with GPS and INS; After the adoption of (1) and (2) added to the system error correction, Laser ranging error is between 2 centimeter and 4 centimeter \cite{6}. Ranging error elimination can be carried out by various experiments in the room to eliminate, the residual error after calibration can reach centimeter level \cite{7}.

### 2.1.2 Measuring angle error

Angle measurement error is attitude angle error and scan angle error from the GPS and INS integrated. Attitude (IMU) error is mainly horizontal error except for laser gyro sight deviation, acceleration allowed timing, complex measurement noise, the presence of non-orthogonal between the bearing and the like, mainly affecting roll angle, pitch angle, flight angle, which can by flying at low altitude to reduce the influence. Due to the installation, design and other reasons such scanning system axis direction and original state with a certain bias, leading to the starting angle scanning angle greater than 0 degrees, named scanning angle error, which can be measured at the factory as long as the instruments prescribed time calibration to, but the actual work do not consider such errors generally \cite{6}.

### 2.1.3 Location error

The positioning errors of GPS are all kinds, including satellite orbit error, satellite clock error, the receiver clock error, multipath, phase center of instability, and there is a constellation of satellites, observation noise, integer ambiguity resolution is whether is correct or not, etc. (Zhang Xiao Hong, 2001). GPS positioning uses a dynamic difference method, while recording the GPS carrier phase and pseudo distance from ground-based reference stations from the data in conjunction with data from the satellite carrier phase and pseudo-together after the flight to use Novatel Inertial Explorer8.6 (IE) solver, less than 50km in baseline length can reach between 23cm and 32 cm accuracy \cite{8}. Some scholars use differential GPS real-time dynamic three-dimensional coordinate measurement target, up to centimeter-level accuracy (Cong hui Feng, 2007).
2.1.4 Time synchronization error. There are Laser rangefinder, GPS differential positioning, IMU attitude, which interfere with each other, working independently of each other, with having their own time recording apparatus. In order to get a correct three-dimensional coordinates of the laser point in space, we must ensure that the laser ranging value at launch, and the attitude of observational position are at the same time, so they need to be imputed to the respective time uniform time UTC or GPS time. If the time is not, there will be positioning errors [9]. Interpolation can be linear or low-order polynomial fitting method to eliminate the time offset, but some tests shows that if the data updated rate GPS signal receiver is more than 2 times per second, two adjacent epoch GPS antenna location linear interpolated between two adjacent epochs GPS antenna position at a time, you can reduce the impact of the time synchronization error (Da hai Guo etc., 2006).

2.1.5 Interpolation error from the data. Interpolation error is due to various airborne LIDAR system having different sampling frequencies caused. At present, the frequency of the laser ranging system can be up to 20 kHz, however, IMU data sampling frequency is generally 200Hz, while the GPS data sampling frequency is only 20Hz. Therefore, in order to get the correct position and attitude information of each of the laser spot, it is necessary for GPS and IMU data interpolation processing to eliminate certain outside influences. Domestic scholars, Shukai Li [10], made full use of pulse time difference 5s, namely track data fitting processing, accuracy up to centimeter level. Generally, the interpolation error depends on weather changes airflow during flight, the error of the time offset impact is between 3 centimeter and 5 centimeter [11].

2.2 Integrated error
We need to consider the relationship between the axes of the reference coordinate system and the scanner IMU reference coordinate system when each of system is integrated. In general, the installation integrates axes must parallel to each other, but it does not guarantee parallel to each other between themselves in the actual installation process, resulting in the flight direction around the roll angle (Roll) error, about the direction of the wing pitch angle (Pitch) error angle about a vertical navigation (Heading) error. Roll angle error is mainly reflected in the plane of the scan lines having a certain inclination; flight angle error can cause ranging inaccurate, mainly in track route deviation, distorted, broken phenomenon [12]. Haikun Yu, Peng Li, Nan Liu [13] and other studies of airborne LIDAR collimation calibration method, application of new technology in the Leica Gallery measurement are discussed in detail so that both sides of the roll angle error route inconsistent level phenomenon; pitch angle error will cause the laser plane position data before and after the dislocation phenomena; flight angle error will cause the strip to the right of the point cloud is shifted forward, the left back offset. In the actual operation of the integrated error elimination generally do calibration experiments can eliminate the corresponding error.

3. Route design
Based on the above sources of error analysis, the paper puts forward the design of some suggestions, to a certain extent, the elimination of error plays a role of great importance for subsequent processing point cloud data. Laser radar equipment and high-resolution digital camera parameters employed, by means of a number of surface features characteristic to develop a reasonable rule of Airborne LIDAR flight
program, considering the point cloud density point cloud accuracy, attitude accuracy, overlap and other issues [13]. Following routes laid:

- The best test area is more typical spire angular roof or gable roof, mutually perpendicular to the road;
- Endurance test area is best taken by the forward and reverse flight alternate, also jumper aerial;
- Next to the route to the best degree of overlap in the 15% -35%.

After the route design, we also need to work to improve data quality secondary post-processing, mainly on the ground measuring points laid condition. There are two types: static and linear measuring point measuring point. Linear measuring points can be laid flat along the road near the route laid, namely RTK measurement, at regular intervals a point about 5 meter, a length of approximately 4 kilometer, accuracy should be at least within 5 centimeter, this method is cumbersome, the workload is relatively large, but the actual work is not taken. While static measuring point layout, can be good to overcome this problem, but also improve accuracy. To choose a certain geographical constraints, the general choice of four weeks without cover, the terrain is more open, less water area, if there is terrain depressions, preferably with a tripod stand up for a long time measurement accuracy can be improved, accuracy up to 2 centimeter [14].

4. Conclusion

The paper discourses Airborne LIDAR measurement system based on the principles of composition, from the time the sensors integrated error generated by a detailed discussion on the causes and effects of error generation mechanism, was analyzed, and a variety of error processing were discussed, summed up the corresponding elimination method, the accuracy of the evaluation were analyzed. Route planning and design of the measuring point programs can reduce the error object to meet specific project needs. In the coming years, Airborne LIDAR mapping technology will become the focus of research in the field, with high precision, high density, high efficiency, product rich features obvious advantages, will gradually replace the traditional mapping technology. In some areas, it already has applications such as emergency mapping for geological disasters, earthquakes, landslides, mudslides and other automatic tracking and dynamic monitoring, real-time assessment of post-disaster situations; remote sensing applications for feature identification and classification of auxiliary geography Census; high-voltage transmission, power line for the safety distance detection.

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