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Airborne LIDAR borsight error calibration based on surface coincide

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Abstract. Light Detection and Ranging (LIDAR) is a system which can directly collect three-dimensional coordinate information of ground point and laser reflection strength information. With the wide application of LIDAR system, users hope to get more accurate results. Boresight error has an important effect on data accuracy and thus, it is thought that eliminating the error is very important. In recent years, many methods have been proposed to eliminate the error. Generally, they can be categorized into tie point method and surface matching method. In this paper, we propose another method called try value method based on surface coincide that is used in actual production by many companies. The method is simple and operable. Further, the efficacy of the method was demonstrated by analyzing the data from Zhangye city.

1. Introduction

1.1. Airborne LIDAR
Light Detection and Ranging (LIDAR) is a system mounted on plane to collect 3D information of ground point. A typical LIDAR system has four components: 1) a differential global positioning system (DGPS) which provides position information of the platform. 2) an inertial measurement unit (IMU) which provides attitude information of the platform. 3) a laser ranging and scanning unit which can measure distances from sensor to the ground. 4) a CCD camera which collects image data, it is very useful for data post-processing. LIDAR is a complex system in that it requires DGPS, IMU, laser scanner and CCD camera to keep accurate synchronization. It calculates 3D coordinate of ground point based on distance collected by laser scanner, as well as the position and attitude information collected by POS.

1.2. Boresight misalignment
Laser scanner and IMU have independent coordinate system. If the scanner assembly is mounted with the cables to the front, X axis is positive to the head of the aircraft, Y axis is positive to the right wing of aircraft, and Z axis is positive to the ground. The two coordinate system axis should be parallel, but in fact, small angle always exists between IMU and laser scanner coordinate axis which is called

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boresight error: rotating around X axis is Roll, rotating around Y axis is Pitch, rotating axis Z axis is Heading.

Roll error lead to the formation of an inclined line by laser footpoint. It is more obvious on flat area. Pitch error will lead to laser footpoint offset in flight direction, making all the laser points forward or back. Compared with roll and pitch, heading error is complex in that it causes offset both in left-right and in forward-back.

2. Related works
In recently years, with wide application of LIDAR, the accuracy requirement is increasingly higher. Nevertheless, many reasons lead to laser point cloud poor accuracy. Boresight misalignment is one of system errors that has important effect on point cloud quality. Up to now, there is no unified standard in practice for boresight calibration.

The solution for dealing with or eliminating the effect of boresight errors can be categorized into two approached. One is based on a correction transformation of the laser points to minimize the difference between the corresponding LIDAR patches and ground truth. Kilian (1996) presents a method of transforming overlap LIDAR strips based on control points and tie points to make them coincide with each other. The method is similar to photogrammetric block adjustment[2]. The method could be further divided into two sub approaches: tie point method which uses known observed points of different attitudes to determine the boresight angles, maximizing the spatial coherence of the original data set [3-5]. With the approach, the boresight angles are either estimated using ground control points or by manually observing discrepancies between tie points in overlapping strips. The drawback of this approach is that the identification of distinct control and tie points in LIDAR data is difficult due to the irregular and sparse nature of the collected point cloud. The other approach uses surface matching (i.e. digital elevation model matching) in order to detect and compensate for misalignment angles [6-8]. Compared with tie point method, the method is more accurate and more robust. The method used in this paper is the one based on overlapping strips.

3. Calibration method
Calibration method used in the paper is called try value method based on surface coincide. The method needs special calibration filed flightline laid and special objects.

3.1. Roll calibration
To eliminate roll error, we generally choose data of a single flight line flown in opposite directions over a flat surface (for example road), then measure the separation h1, h2 of the two flightlines on the profile, measure profile Width, using formula (1) compute the roll value in radian.

\[ \text{Roll} = \frac{(h1 + h2)/2}{\text{Width}} \quad (1) \]

3.2. Pitch calibration
Pitch error defines the misalignment around Y axis between the IMU and the laser. It is not apparent over a flat surface. To eliminate the error, we select data for a single flight line flown in opposite directions over an evenly sloped surface. We can draw a profile in the along track direction through both surfaces, then measure offset between both profile a, and measure flight height H. Generally, we will compute average AVE based on many offsets to get better effect, using formula (2) compute the pitch value in radian.

\[ \text{Pitch} = \frac{(a/2)}{H} \quad (2) \]

3.3. Heading calibration
Heading error defines the misalignment around the Z axis between the IMU and laser. In the middle of the swath (the flight nadir point), no heading error exists. However, with the increased distance between object and the flight nadir point, the error will be increasingly larger. In addition, heading
error is not apparent over a flat surface. To eliminate heading error, we collect data of two overlapping flight lines flown over sloped surface, and select sloped area along track direction on the edge of one swath and in the middle of the other swath, side overlapping is about 60%. Like pitch error, we compute average offset $b$ between both profile and measure distance between both trajectory $w$, using formula (3) to compute the heading value in radian.

$$\text{Heading} = \frac{b}{w}$$  \hspace{1cm} (3)

4. Experiment

4.1. Sensor

There are many LIDAR systems products, such as Optech, Riegle and Leica. Our test data were collected through ALS70-HA produced by Leica(Canada), figure 1 is the ALS70-HA system. The maximum flying height of the system is 5000m, maximum measurement rate is 250 KHz, and field of view is 0-75 degrees. It includes digital frame camera RCD30 and thus, laser point cloud and CCD image can be collected at the same time.

4.2. Test field

This test was performed in order to evaluate the efficacy of the method. Test field is Zhangye city, Gansu, China, two parts were included: calibration field and flight test area. Zhangye (figure 2) is located at northwest of Gansu. It belongs to continental climate, with dry and rainless as its main feature. The average temperature is 6 $^\circ$C, with abundant light supply, and average altitude is 1400-1600m.

Calibration field is located southeastern of zhangye city which includes flat area and slope objects. The site was chosen in order to meet calibration requirement, flight altitude is 2900m. Flight area is also in zhangye city, but its area is larger with more kinds of objects. Flight area data aims to validate the calibration parameter valid and robust, flight altitude is 2700m.

![Figure 1. ALS70](image1)

![Figure 2. Flight test field](image2)

4.3. Strips

For boresight calibration, strips plan is very important. There are five strips, and layout is as follow:

1. A single flight line flown in opposite directions which perpendicular to the road and across the road.
2. A single flight line flown in opposite directions which perpendicular to the building ridge and over ridge line.
3. Two overlapping flight lines in the same direction which perpendicular to the building ridge and the ridge is included in two strips.
4. A strip along road direction and over the road

In most cases, building ridge is parallel to road, so (1) and (2) can share two strips, (2) and (3) share a strip. Figure 3 is our calibration field flight lines.
4.4. Result analysis

We use calibration field data to compute roll, pitch, heading parameters value in ALSPP, it is fast and accurate. Many experiments have proved that calibration sequence of roll, pitch and heading affect the effect and efficiency of calibration, and the roll-pitch-heading is the best sequence. To check the calibration effect, generally, we only draw profile on the surface to check two flightlines coincide. In addition, we used overlapping area elevation difference to check the calibration effect. Its benefit is that we can know calibration effect on the whole not part, and it is more accurate. The paper used red and blue to represent +15cm and -15cm, respectively. If red and blue are uniformly distributed on the elevation difference, it indicates the calibration result is good.

Before calibration (figure 4) and after calibration (figure 5) of roll error make us know the roll calibration result.

![Figure 4. Before calibration of roll error](image)

![Figure 5. After calibration of roll error](image)

Before calibration (figure 6) and after calibration (figure 7) of pitch error make us know the pitch calibration result.

![Figure 6. Before calibration of pitch error](image)

![Figure 7. After calibration of pitch error](image)

Before calibration (figure 8) and after calibration (figure 9) of heading error make us know the heading calibration result.
The overlapping strips elevation difference after roll, pitch and heading calibration is shown in figure 10.

Generally, project will require the same flight height between calibration field and flight test area in order to avoid calibration parameter adjustment. Base on this principle, the paper conducted experiment and proved that these parameters are good for test area, figure 11 show the result.

5. Conclusion
Boresight misalignment is a main system error and it has to be eliminated by user when sensor is mounted every time. In addition, range has to be calibrated after boresight calibration. Compared with other methods, the method introduced in this paper has no complex model, it is operable and easy to learn. So the method is used by many companies. However, it needs many manual operations, I will focus on how to realize automatic in future research.

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