LEAST SQUARES MATCHING WITH AIRBORNE LIDAR DATA FOR STRIP ADJUSTMENT

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ABSTRACT:

Matching is of great importance in photogrammetry and remote sensing and it is applied in many areas such as registration、DEM generation and so on. As a new type of airborne remote sensing sensor, Airborne LIDAR has gained much attention by photogrammetry and remote sensing communities. Many processing methods such as segmentation and clustering, filtering and classification, matching and strip adjustment of airborne LIDAR data have been researched. This paper focus on the matching of airborne LIDAR data and it mainly researches on the multi-strip least squares matching (LSM) for multi-overlapping regions .To get better matching result, a combined feature named as quasi-height is proposed, which is constructed by combining both the height and reflectance data. The combined feature is helpful for the strip adjustment which aims to correct geometric errors in data and need many corresponding points. To validate the efficiency of this method, a real project experiment is proceeded and the discrepancies among different overlapping strips are obtained which are used for the strip adjustment. The adjustment results demonstrate the validation of this matching method.

1. INTRODUCTION

As a kind of active and direct geo-referencing technique with high accuracy, Airborne LIDAR has gained more and more attention by researchers and users, which is being applied in many areas such as large scale DEM generation、 true ortho-rectified images' generation、 3D city modelling、topographic mapping、forest resource management、 risk assessment and so on. To derive more high quality products from airborne LIDAR data, many processing techniques like segmentation and clustering, filtering and classification, matching and strip adjustment of airborne LIDAR data have been researched. This paper researches on the matching of multi-overlapping airborne LIDAR data strips, which is useful and needed for the strip adjustment and automated in-flight calibration of LIDAR [Friess, 2006].

Like conventional photogrammetric image, airborne LIDAR data of larger areas is acquired in a stripwise manner too. As airborne LIDAR is a complex multi-sensor integrated system, there still exist errors even through careful calibration, which is demonstrated by many researches [Huising 1998, Schenk, 2001, Filin, S., 2003]. The existence of these errors can be checked by the 3D discrepancies between neighboring or crossing strips. Strip adjustment is needed to eliminate these errors [Burman, 2000, Kager, H., 2004,]. To proceed the adjustment, the tie points or features are needed which is always obtained through point cloud matching. There are some cases needing multi-overlapping data, for example the city 3D modelling, automated in-flight calibration of LIDAR and so on. To obtain a large scale data with high and uniform accuracy, strip adjustment with multi-strip matching should proceed. Following the muti-image least squares matching, this paper researches the multi-strip least squares matching with airborne LIDAR data for strip adjustment. It proposes a combined feature-quasi-height for matching, which is constructed by combining the height and reflectance data. Quasi-height is useful for airborne LIDAR data matching, which can obtain more reliable and accurate results even for the areas with both little height and reflectance variation. This's useful for strip adjustment which needs many corresponding points and aims to correct positional errors in data.

2. PREVIOUS WORK FOR AIRBORNE LIDAR DATA MATCHING

Airborne LIDAR works by sending a pulse to the ground and determine the 3D coordinates of the reflected points by calculating the distance 、 attitude of the transiting pulses and coordinates of the GPS receiver on board. The obtained 3D points are called point cloud. Right now there have been many matching methods of point cloud among which the ICP and its modified versions are the most common and popular ones. However there have been disadvantages such as low speed, the ICP series methods are not very suitable for the airborne LIDAR data matching. Airborne LIDAR data is geo-referenced, thus in most cases the discrepancies of the homogenous features among adjacent strips are small and the least squares matching can apply to them directly. However, there may be some cases in which data is obtained with poor calibration and the coarse matching is needed before applying the accurate matching .With regard to the coarse matching methods, [Bretar etal, 2004] used the modified Hough transform to match the airborne LIDAR data with a photogrammetric derived Digital Surface Model (DSM).

LSM is applied on airborne laser data for different uses. First, it is used to determine the discrepancies between overlapping laser strips and then it can be used to establish correspondences among strips, which are used in strip adjustment. The approaches of LSM applied on airborne LIDAR data can be classified according to the data structure of the laser points [Kraus etal, 2006]:

a) LSM is applied on the original irregular ground points by utilizing a TIN structure; e.g. [Mass 2002], [Kilian et al. 1996].

b) LSM is applied on the original irregular ground points by utilizing a box structure [Akca, 2007].

c) Before applying LSM, a regular raster is interpolated from the irregular points; e.g. [Burman 2000], [Behan 2000][Kraus etal,2006], then the conventional LSM for image is used.

LSM is developed for 2D image originally which is in fact a kind of 2.5D data; i.e. for each ground position (X, Y) only one third coordinate is assigned. Therefore the LSM approaches can be classified further according to what information is used as third coordinate during the matching procedure:

a) only the height is used as third coordinate [Kilian et al. 1996]

b) height and intensity of the return signal are used together as two separated – but co-registered – 2.5 D layers [Burman 2000], [Mass 2002] [Kraus etal,2006]

c) height and intensity of the return signal are used together to construct a quasi-surface[Akca 2007].

Intensity of the return signal is helpful in the least squares matching in regions with low height variation. Provided the intensity shows high variation, the horizontal shifts between the patches in both strips can be determined with high precision. Because the height and intensity information are co-registered, i.e. they are measured in the same laser deflection direction, both data sets have the same horizontal shifts. Thus the intensity is very helpful for determining the horizontal shifts .For the area with low height variation, adding the intensity to the height and constructing a new "height" named as quasi-height can increase the horizontal shifts estimation accuracy. However, the intensity is influenced by the noises and the incident angles, therefore they should be calibrated first to be used for matching.This paper deals with the intensity which has been calibrated.

3. MULTI-STRIP MATCHING WITH AIBORNE LIDAR DATA

Section 2 demonstrates that there has been much work on matching of airborne LIDAR data. However, the multi-strip matching has not been researched deliberately and most of these methods use the intensity directly and separately. In this section, generation of quasi-height and multi-strip least squares matching of multi-overlapping airborne LIDAR data are discussed.

3.1 Data Structure and Data organization

[Behan 2000]has pointed out it is difficult to extract feature points for least squares matching of interpolated raster LIDAR data and it's influenced by interpolation method. [Mass, 2002] has demonstrated least squares matching is better applied to the original irregularly distributed LIDAR data points organized in a TIN structure because original airborne LIDAR data points are not regularly distributed and an interpolation may introduce severe degrading effects. Therefore, this paper uses the TIN structure too. Since the data volume of airborne LIDAR data is always very large, and matching procedure only needs the overlapping areas, the overlapping areas are firstly determined. The overlapping areas are always in long strip shape and to minimize the limitation of data volume, the overlapping areas are divided into grid blocks and stored into individual files. They are only loaded into memory when needed.

3.2 Data Pre-processing and the generation of quasi-height

The block areas are divided into patches evenly according to their positions and the TIN of each patches are constructed in each block. Besides, to increase the reliability, some same pre-processings are proceeded before the matching as pointed out by [Mass, 2000]., like the exclusion of the occlusion and vegetation areas. To ensure the reliability, the filtering and classification is applied before the matching.

As mentioned above, intensity is helpful for determining the horizontal shifts. Adding intensity to height can construct a new feature- quasi-height. For areas with low height variation, it can increase the horizontal shifts estimate accuracy. The quasi-height of each LIDAR point is constructed as following:

$$QH(x,y) = H(x,y) + T(I(x,y)) \quad (1)$$

Where $QH(x,y)$ is the generated quasi-height , $H(x,y)$ is the real height value, $I(x,y)$ is the intensity value and $T(I(x,y))$ is the function of $I(x,y)$ and it can be formulated according to the illumination model, here we formulate it as $T(I(x,y)) = \lambda * I(x,y)$ simply and λ is the scale factor used to mapping the intensity to height value. In this paper, the least squares matching is applied on the quasi-height of LIDAR data because it can obtain more reliable and accurate matching points even for the areas with both little height and reflectance variation.

3.3 Multi-strip least squares matching

For each triangle of the TIN, its equation is defined as following:

$$z = ax + by + c \quad (2)$$

Where, z represents the height、intensity or the quasi-height in least squares matching. a,b,c are estimated by least squares fitting of the three nodes of the triangle. Obviously, the a,b are the two direction gradients of the point in the triangle.

For each group of multi-strip overlapping patches, the matching is proceeded as following:

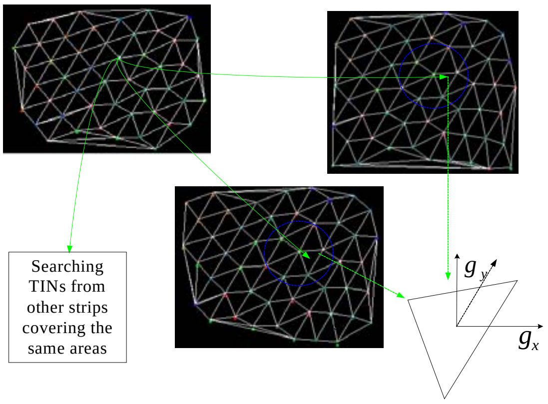

Figure 1. TINS of patches in multi-overlapping strips

Providing there exist s(s>=3) overlapping patches covering the same area, choosing one of them as the target patch and the others, which haven't been taken as the target patch, are taken as the searching patches in turn, then s(s-1) /2 equations can be formulated. As the point sets of the patches to be matched are not identical or arranged on a regular grid, matching is performed between discrete points in target patch and points derived from the corresponding TIN mesh in the other searching patches (see figure 1). According to the characteristics of the airborne LIDAR data, only the shift parameters are enough for the geometric transform and the "radiometric" transform is formulated as a simple linear transform. Then the quasi-height value of the n-th point of the m-th target patch to be matched can be formulated as:

$$\begin{aligned} & QH_{mn}(x, y) = \\ & q_{ml} + h_{ml} * QH_{ln}(x + a_{ml}, y + b_{ml}) \\ & m = 1, 2, \cdots s; l = 1, 2, \cdots s, m \,!= l \end{aligned} \tag{3}$$

Where, a_{ml}, b_{ml} are the planimetric shift parameters between the m-th and l-th corresponding patch, q_{ml}, h_{ml} are the linear transform parameters between the m-th and l-th patch. The least squares matching is based on the minimization of the sum the square of the quasi-height differences and s(s-1) /2 group error equations can be constructed based on (2) and (3). Besides, the planimetric shift parameters are constrained by :

$$\begin{aligned} & a_{ik} - a_{ij} - a_{jk} = 0 \\ & b_{ik} - b_{ij} - b_{jk} = 0 \end{aligned} \tag{4}$$

Where, $i = 1, 2, \cdots s-1, i < j < k <= s$, a_{ij}, b_{ij} is the planimetric shift between the i-th and the j-th strip patches, a_{ik}, b_{ik} . is the planimetric shift between the i-th and the k-th strip patches, a_{jk}, b_{jk} is the planimetric shift between the j-th and the k-th strip patches.

A combined adjustment for the s(s-1) /2 group error equations and equations (4) are proceeded to solve for the planimetric shift parameters. As the least squares matching is a non-linear system, the combined adjustment is proceeded iteratively. At last the height shift is determined by the difference of the interpolated height values of corresponding patches after planimetric correction.

4. EXPERIMENTS

To validate this method proposed in this paper, a real project data with parallel strips and crossing strips is used. This project consists of 5 strips flown in a north-south direction and 4 strips flown in an east-west direction, each strip with a length of about 20 kms. The distribution of this project is as following:

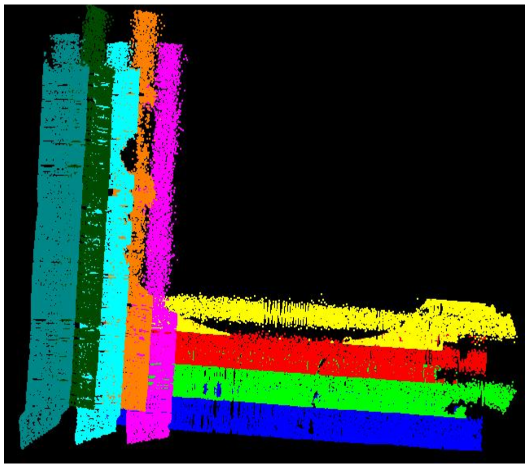

Figure 2. Distribution of the project data

Four of the nine strips are selected to conduct the strip adjustment. The matching method proposed in this paper is used and the matching results are used as the observations to proceed the strip adjustment. The adjustment model adopted here takes every strip as an independent model. The model treats the discrepancies as errors caused by the orientation errors, therefore each strip is corrected by taking a correction to the orientation angles observed by the inertial navigation system. The orientation correction values (table 1) are obtained through strip adjustment then the strips are corrected by the corrected orientation values.

	Roll shift(degrees)	Pitch shift(degrees)	Heading shift(degrees)
Strip 4	+0.0203	-0.0074	-0.0085
Strip 5	+0.0216	-0.0223	-0.0620
Strip 6	+0.0265	-0.0212	-0.0549
Strip 7	+0.0229	-0.0136	-0.0267

Table 1-Orientation correction values for the 4 strips

The LIDAR point cloud accuracy is evaluated by the differences between the height values in the strip and the average height values of the corresponding overlapping regions. The average difference is 0.0974 m before adjustment and 0.0785 m after adjustment. More important the orientation discrepancies are also smaller. Figure 3 and Figure 4 are one profile from the four strips before and after adjustment. After adjustment, it can see the height differences are much smaller and the level ground points from different strips coincide.

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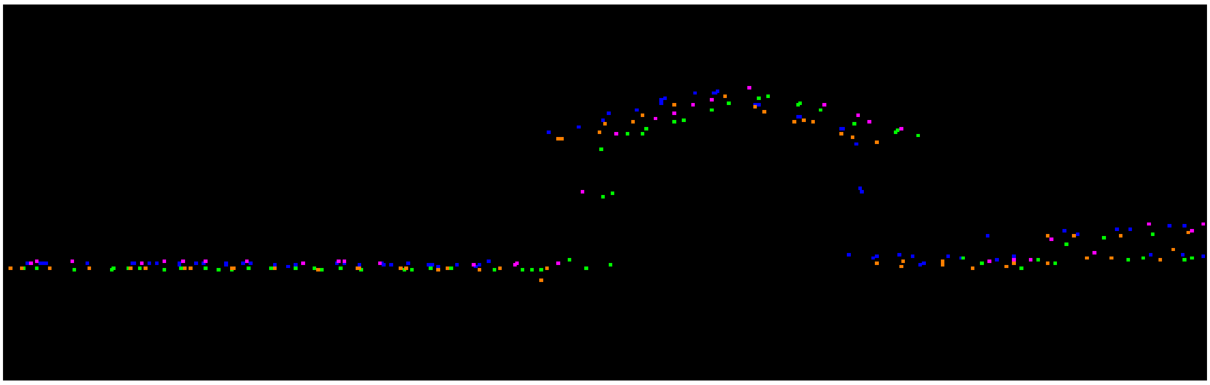

Figure 3. One profile of the four strips data (Before adjustment)

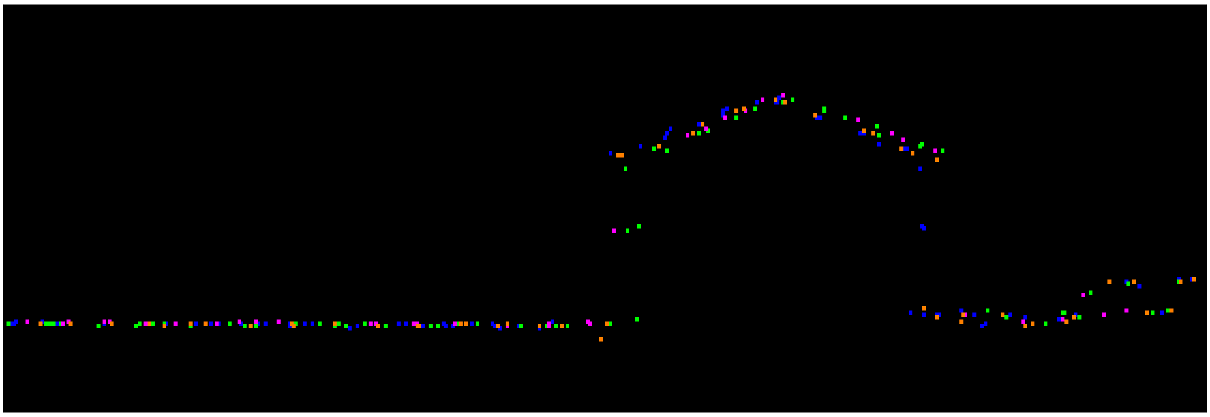

Figure 4. One profile of the four strips data (After adjustment)

5. CONCLUTION AND FUTURE WORK

This study focus on the multi-strip least squares matching with airborne LIDAR data in TIN structure. The matching function model is proposed by combining multi-strips based on the geometric constraints. It can be helpful in many applications such as strip adjustment, in-flight calibration of LIDAR and so on. The intensity information is also used to obtain planimetric shift where height variation is small. Different from other methods, intensity is injected into the height information other than matching the intensity separately and the quasi-height is constructed for matching. At last a real project data is experimented and the results demonstrate the method's efficiency. However, the matching accuracy hasn't been discussed here and it needs analyzed and researched more.

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