DATA PROCESSING TECHNOLOGY OF AIRBORNE 3D IMAGE

YOU Hongjian
LIU Shaochuang
LI Shukai

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ABSTRACT Airborne 3D image which integrates GPS, attitude measurement unit (AMU), scanning laser rangefinder (SLR) and spectral scanner has been developed successfully. The spectral scanner and SLR use the same optical system which ensures laser point to match pixel seamlessly. The distinctive advantage of 3D image is that it can produce geo-referenced images and DSM (digital surface models) images without any ground control points (GCPs). It is no longer necessary to survey GCPs and with some softwares the data can be processed and produce digital surface models (DSM) and geo-referenced images in quasi-real-time, therefore, the efficiency of 3D image is 10~100 times higher than that of traditional approaches. The processing procedure involves decomposing and checking the raw data, processing GPS data, calculating the positions of laser sample points, producing geo-referenced image, producing DSM and mosaicing strips.

The principle of 3D image is first introduced in this paper, and then we focus on the fast processing technique and algorithm. The flight tests and processed results show that the processing technique is feasible and can meet the requirement of quasi-real-time applications.

1 Introduction

Remote sensing has been applied in many fields in the past decades, but the mode to acquire and process the remote sensing data does not change radically. The remote sensing image must be geo-referenced through on ground control points (GCPs), and stereo matching must be applied in order to get 3D information. It is time-consuming and labor-consuming to survey GCPs, so it is difficult to meet the requirement of some real-time or near-real-time applications. In fact, GCPs are points with known coordinates, therefore, if the coordinates of ground points can be measured from the air when the images are acquired, then these points can be used as GCPs. This idea was thought out in the early 1990's and becomes feasible with the development of scanning laser rangefinder (SLR), inertial navigating system (INS) and GPS. The prototype of airborne 3D image was developed in the late 1996 and we began to develop operational 3D image in 1998. The distinctive characteristic of 3D image is that it can produce DSM and geo-referenced image simultaneously without any ground control points. The goal to develop airborne 3D image is to provide DSM and geo-referenced image in real-time without GCPs. This paper discusses the techniques and algorithm concerning data processing of 3D image fast in order to meet the requirement of quasi-real-time applications.

2 Airborne 3D image

The principle of airborne 3D image is shown in
It is composed of four key components: GPS, attitude measurement unit (AMU), SLR and scanner. GPS gives the accurate coordinates of the image, SLR can measure the range from the image to ground without reflector and AMU gives the accurate attitude of the image. According to the geometric principle, the coordinates of ground points can be determined accurately, while the scanner acquires the image of ground simultaneously.

The characteristic of 3D image is that SLR and scanner use the same optical system, and they are both controlled by coder. During the operation, the coder drives the scanner to acquire the spectral information continuously while it drives SLR to measure the range every several fixed pixels. Because of using the same optical system, the laser sample point matches pixel seamlessly.

The synchronization of the different component is also realized through coder. When the scanner scans the nadir, the coder generates a pulse and then this pulse drives the GPS receiver to generate a time mark (GPS can measure the precise time of this pulse and store it in its memory). This pulse also drives the AMU to acquire the attitude of the image.

The AMU, scanner and SLR are all mounted in a rigid plate. The stored raw data include raw image, laser range, attitude parameters and GPS data. Fig. 2 shows the function link among different components. Fig. 3 shows the raw image coupled with laser sample points (white pixel in the image). It shows how the laser points are distributed in the image.

3 Fast processing technology of 3D image

It is necessary to process the data fast in order to achieve the high efficiency of 3D image after it acquires the raw data. The processing consists of the following steps: 1) decomposing and checking the raw data, 2) calculating positions of laser sample points, 3) producing DSM, 4) rectifying the raw image to produce geo-referenced image, 5) strips mosaicing. Fig. 4 shows...
3.1 Preprocessing the raw data

The raw data acquired by 3D image are decomposed into the raw image, attitude and laser data first. Then each data are checked to see if they are valid and integrated. Checking the data is a key step, because it can determine whether the data can be processed and whether they should be re-acquired.

3.2 Calculating the position of laser sample point

Because the attitude, position and laser range of each laser sample point are known, the 3D position can be calculated according to geometric principle as follows.

\[
\begin{align*}
Y &= Y + d \cdot A^* \\
\end{align*}
\]

where \( d \) is laser range, \( A \) is the coefficient matrix determined by the positioning principle of 3D image, \( \omega, \alpha, \gamma \) are attitude parameters, and \( \theta \) is the scanning angle. A more detailed description can be found in Liu, et al (1999).

3.3 Producing DSM

Grid data structure is used to produce DSM image and geo-referenced image. Information header embodies the start coordinates of this strip and other parameters, such as the height and width of this strip, the sample interval of DSM or the resolution of the image. On the basis of all the laser sample points, the scope of the strip can be easily calculated. If the sample interval of DSM is given, the grid coordinates of each laser point can be calculated fast. The equation to calculate the grid coordinate \((I,J)\) from laser point \((X,Y)\) is shown as follows.

\[
\begin{align*}
I &= (X - X_{\text{min}}) / \text{SampleInterval} \\
J &= (Y - Y_{\text{min}}) / \text{SampleInterval}
\end{align*}
\]

All laser sample points are converted into grid coordinates according to this equation, then rough DSM is generated. DSM image can be produced by interpolation based on the rough DSM. There are many interpolation methods. We use following polynomial function to interpolate DSM.

\[ H_f = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2 \]

where \( a_0, a_1, a_2, a_3, a_4, a_5 \) are coefficient parameters, \( x, y \) are the grid coordinates of laser points. Fig. 5 and Fig. 6 show the rough DSM and interpolated DSM.

3.4 Fast rectifying remote sensing image

Owing to the limit of pulse rate of laser, the 3D image does not drive laser to range every pixel during operation, but it drives laser to range every several fixed pixels. These laser sample points with known coordinate can be used to rectify raw image. On the basis of our experiences, cubic polynomial method is easy to use and can meet the accuracy, so we use cubic polynomial function to rectify the raw image. The raw image is scanned line by line, and the pixels within a line is also scanned sequentially, so the coordinate of the pixel \((u, v)\) may be thought of as cubic function of the pixel number \( n \):

\[
\begin{align*}
u &= a_0 + a_1 \cdot n + a_2 \cdot n^2 + a_3 \cdot n^3 \\
v &= b_0 + b_1 \cdot n + b_2 \cdot n^2 + b_3 \cdot n^3
\end{align*}
\]
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3.3 Strips mosaic

The geo-referenced image and DSM image of a strip can only cover a part of the area, because field of view (FOV) of 3D image is limited. Many strips must be acquired and processed in order to cover the whole area, the overlap rate of strips should be more than (15 ~ 25)%. After DSM images and geo-reference images of each strip are produced, strips should be mosaiced together. In order to mosaic smoothly, the overlap data must be processed correctly, an alterable weight coefficient is designed to combine the strips:

$$G_{overlap} = \frac{R_l}{R_r + R_l} G_r + \frac{R_r}{R_r + R_l} G_l$$

where $R_r$ is the distance from current pixel within the overlap area to the right side of overlap, $R_l$ is the distance to the left side of overlap, $G_r$ is the...
gray-level or DSM of the right strip of the overlap, and \( G_l \) is the gray-level or DSM of the left. Because of the complexity of flight, the overlap of each line in the two neighboring strips is different.

Therefore, the coefficient changes with the change of the scanning line and pixel within overlap area. Fig. 9 shows five neighboring strips and Fig. 10 shows the mosaiced result.

![Fig. 9 Five neighboring strips](image)

![Fig. 10 Mosaiced image](image)

4 Flight test and result

After the airborne 3D image was developed, several flight tests have been conducted in China. The latest test was conducted in October 2000. Totally, 93 strips were acquired which cover an area of about 342 km\(^2\). The flight height is 650 m and FOV is 30\(^\circ\). The image resolution is 2.0 m.

The raw data are processed by the developed software based on fast processing technique and algorithm discussed above. Table 1 sums the processing time of each module. Only about 2 hours is spent to produce DSM and geo-referenced image of the whole area. Fig. 11 shows part of geo-referenced image of the test area.

![Fig. 11 Geo-referenced image](image)

| Module                          | Calculating time/min |
|---------------------------------|----------------------|
| Decomposing and checking data   | 2                    |
| Calculating GPS position        | 4                    |
| Calculating position of laser points | 35              |
| Producing DSM                   | 24                   |
| Producing geo-referenced image  | 50                   |
| Strips mosaic                   | 10                   |
| Total                           | 125                  |

5 Conclusions

In this paper, the fast processing algorithm is demonstrated that it achieves high efficiency of airborne 3D image. The discussion and results shown prove that fast processing technology can meet the requirement of quasi-real-time applications. Therefore, we can make full use of the high efficiency of 3D image to monitor high dynamic areas, such as special interesting areas and urban areas, environment resources investigation and so on.

In the near future, the scanner of 3D image may be designed to include 8~16 bands. Consequently, it will be possible to develop a high automatic, positioning and qualitative ability integrated airborne remote sensing system. It will be also possible to improve the accuracy of GPS, attitude measurement unit and laser range finder. So it is feasible that the accuracy of the 3D image reaches the regulation of 1 : 5 000 and even 1 : 2 000 scale thematic mapping. The fast processing algorithm should be further developed to meet the real-time applications.
Fig. 11 Part of geo-referenced image

References

1 Baltzavias E P. Airborne laser scanning: existing systems and firms and other resources. *ISPRS Journal of Photogrammetry & Remote Sensing*, 1999, 54(2–3): 164–198
2 Li S K, Xue Y Q. Airborne multidimensional imaging system. Beijing: Sciences Press, 2000 (in Chinese)
3 Liu S C, Sha H, Xiang M S, et al. Positioning principle and accuracy of laser-ranging and multi-spectral imaging mapping system. *Acta Geodaetica et Cartographica Sinica*, 1999, 28(2): 121–127 (in Chinese)