DSM GENERATION FROM IKONOS STEREO IMAGERY

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Abstract: Digital surface model generation from IKONOS stereo imagery is a new challenge in photogrammetric community, especially when the satellite company does not provide the raw data as well as their ancillary ephemeris data. In this paper we utilized an estimated relief displacement azimuth and the nominal collection elevation data included in the metadata file to correct the relief displacement of GCPs, together with a linear transformation for geometric modeling of IKONOS imagery. Space intersection is performed by the trigonometric intersection assuming a parallel projection of IKONOS imagery due to its small FOV and frame size. In the experiment, less than 2-meters of RMSE in orbit modeling is achieved denoting the potential positioning accuracy of the IKONOS stereo imagery.

Keywords: Geometric Modeling, Digital Surface Model, and Metadata.

1. Introduction

The generation of Digital Terrain Model (DTM) from remotely sensed stereo-images, such as aerial photos, satellite images, and airborne scanning images, is an important task for various remote sensing applications. The generated DTM from remotely optical sensor by image matching is actually the canopy of the earth surface, that means it include not only bare soil terrain but also trees, buildings, etc. So, the result is also denoted as Digital Surface Model (DSM).

Normally, the generation of DSM from remote sensed stereo images includes the following four steps: (1) aerial triangulation or orbit modeling, (2) image matching, (3) space intersection, and (4) grid DSM interpolation. The task of orbit modeling is generally to find the relationship between the ground object and its corresponding position on the image plane. Since the Space Imaging Inc. does not provide IKONOS raw data as well as their orbit ancillary data, a rigorous solution for orbit modeling is not practical. Further more, the IKONOS stereo images are distributed in a quasi-epipolar geometry reference where only the terrain parallax in the scanner direction remains. Chen, *et al*. [1] proposed a method for IKONOS GEO image for ortho-image generation. This paper adopts the same concept for IKONOS stereo imagery with minor modification. After that we perform image-matching technique to automatically find the conjugate points on the stereo images. A further space intersection can thus be used to get its corresponding ground object's three-dimensional coordinate. The results after space intersection are irregular ground points. It can be described by a Triangular Irregular Network (TIN) structure or grid DSM. For grid DSM, an extra interpolation procedure is necessary.

2. Geometric Modeling

In order to perform geometric modeling of IKONOS stereo imagery, the following three topics are necessary. They are (1) the imaging geometry, (2) image to map registration, and (3) 3-D modeling for space intersection.

1) Imaging Geometry

Due to the IKONOS imagery has a small FOV and small frame size on the ground, we assume the imaging geometry of the image as a parallel projection. Figure 1 shows the original IKONOS stereo images for this study. Some basic information for the stereo images is list in table 1. Except for the gray background items, all data are coming from the metadata. In which the *Nominal Collection Azimuth* is defined under the original acquired image with respect to the ground coordinate system, not under the epipolar coordinate system. Figure 2 shows the diagram of stereo images with respect to the ground coordinate system and the epipolar coordinate system. Please notice that we assume the imaging is a parallel projection. According to figure 2 along with the *satellite inclination angle,* we can estimate the *Relief*

Table 1. Some characters of the IKONOS stereo images.

		Left Image	Right Image
Nominal Collection Azimuth (NCA)		189.3098°	28.7620°
Nominal Collection Elevation (NCE)		62.59325°	84.16201°
Relief Displacement Azimuth (RDA)		271.2098°	110.662°
Datum	WGS84	B/H	0.61
Reference Height	104. 40632 meters	FOV	0.93°
Scan Azimuth	179.98°	GSD	1.0 m
Inclination	~ 98.1°	Frame	11 x 11 km
Local Vertical Datum Shift	~ 23.0 meters	Satellite Height	681 km

Displacement Azimuth (RDA) under the epipolar coordinate system by equation (1).

The utilized IKONOS in-track stereo images are provided in a quasi-epipolar geometry reference. They are actually ortho-rectified along fly direction under the WGS84 datum using a flat height as the DTM, i.e. *Reference Height*. So, only the terrain parallax in the scanner direction remains. The map projection we utilized, i.e. TWD67, is the Transverse Mercator (TM) under the GRS67 datum. Figure 3 illustrates the

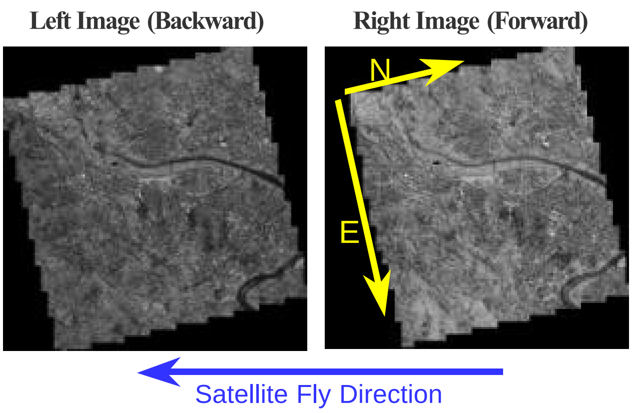

Fig. Stereo images of study area.

$$RDA = 180.0 - Inclination + NCA \qquad (1)$$

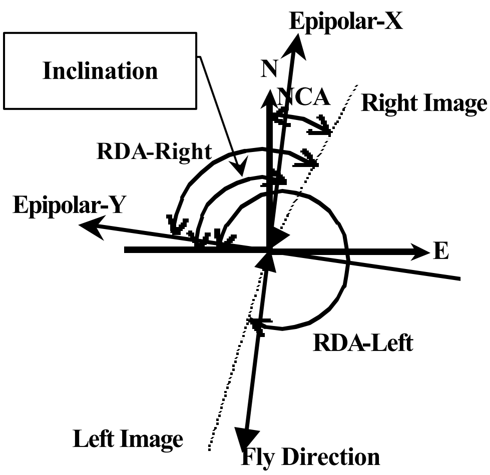

Fig2. Diagram of used stereo-images.

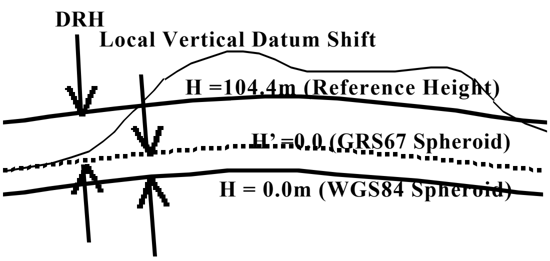

Fig3. Reference height vs. WGS84 and GRS67 spheroid.

Reference Height in GRS67 and WGS84 spheroids. In which, the *local vertical datum shift* describes the difference between those two datums.

2) Image to Map Registration

In order to correct the relief displacement from the quasi-epipolar stereo images to the TWD67 map projection, the local vertical datum shift should be taken into account. The difference between the reference height and the local vertical datum shift is denoted as DRH. The original stereo images are created using the *reference height* under WGS84 that is greater than the local vertical datum shift. So, in the process of relief displacement correction the object height (Z) should minus a value of DRH to calculate the disparity component on each axis by equation (2).

$$\begin{aligned} dL &= (Z - DRH) * \cos(RDA) / \tan(NCE) / GSD \\ dS &= -(Z - DRH) * \sin(RDA) / \tan(NCE) / GSD \end{aligned} \qquad (2)$$

Ground control points are utilized to perform the image to map registration. This procedure is similar to Chen, *et al*. [1] with a little modification that we use the estimated RDA instead of NCA. The relationship between the image coordinate system (L, S) and the map coordinate system (X, Y) can be obtained using equation (3).

$$\begin{aligned} L &= a0 + a1 * X + a2 * Y + dL \\ S &= b0 + b1 * X + b2 * Y + dS \end{aligned} \qquad (3)$$

Utilizing equation (2) and (3), one object with coordinate (X, Y, Z) on the ground, we can calculate its location on the image with coordinate (L, S). For convenience, we define the epipolar coordinate system (Epipolar-X, -Y) as the same as the image coordinate system (L, S).

3) 3-D Modeling

The essence of 3-D modeling is to estimate the corresponding ground object coordinates of two conjugate points on the stereo images. Since we assume the imaging geometry of IKONOS imagery as parallel projection, the 3-D modeling can be simplified by using trigonometric intersection. The major issue of this task is to estimate the disparity component of conjugate points on each axis of the epipolar images. The first step is to estimate the ground height (Z) of their corresponding ground object. The satellite nadir location (Xc, Yc) is defined under the epipolar coordinate system. It can be calculated by using the satellite height, NCE and RDA. The trajectory of satellite's viewing direction has two components on each axis of the epipolar coordinate system, i.e. (dXR, dYR) for right image, and (dXL, dYL) for left image. Incorporating satellite height with those four quantities we can estimate the elevation angle (θ, φ) for each image on each axis.

Figure 4 shows the stereo pair that was projected on the epipolar coordinate system X-Z plane. One ground point (X,Y,Z) was captured on the stereo images at the location of S_L and S_R. After correcting the relief displacement, its position is located at S_G. The total of disparity is equal to $GSD*(dSL+dSR)$ on the epipolar coordinate system. Thus, we can calculate the ground height (Z) using equations (4~6).

$$PL = dXL / (dXL + dXR) \quad (4)$$

$$dS_L = PL * (dSL + dSR) \quad (5)$$

$$Z = dSL * GSD * \tan(q_L) \quad (6)$$

Accordingly, we can estimate the y-parallax (dL_L) for left image by equation (7).

$$dL_L = Z / \tan(j_L) / GSD \quad (7)$$

The image location (S_G, L_G) after relief displacement correction can thus be obtained by equation (8).

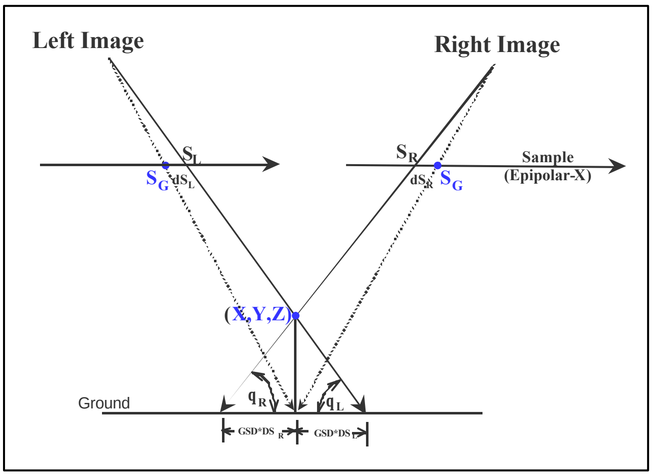

Fig4. Trigonometry of the stereo pair projected on epipolar X-Z plane.

$$S_G = S_L - dS_L$$
$$L_G = L_L - dL_L \quad (8)$$

Finally, applying the inverse of equation (3) we can get the ground coordinate (X, Y).

3. Case Study

1) 3-D Modeling

Six ground control points are utilized for calculating the image to map transformation coefficients. Another 83 check points are utilized to analyze the proposed 3-D modeling method. Figure 8 illustrates the error vector of the checkpoints. In which, we achieve a RMS error of 1.37m / 1.58m / 2.44m, and a mean error of 0.72m / 0.89m / -0.14m on X, Y, Z axis respectively. The mean error is less than one pixel denoting that the modeling error is within the range of random error and the bias is small enough. From the RMSE we known that the planimetric accuracy is within 2 pixel of ground sampling distance. Due to the base-height ratio of the stereo images is 0.61, the height accuracy is also within the range of random error when comparing to the planimetric error. Since the 3-D modeling is based on the provided nominal collection azimuth and elevation data, the positioning accuracy is highly relied on the provided metadata. It denotes the potential positioning accuracy when IKONOS stereo images are utilized and a parallel projection is assumed.

2) DSM Generation

Image matching and DSM generation is proceeding with a coarse-to-fine strategy. Least squares area-based template matching is adopted to solve the correspondence problem. Figure 5 illustrates the generated DSM with a ground sampling distance of 4 meters. The height of the DSM is range from 20 to 200 meters. Since we don't have a high-resolution ground truth of surface model for accuracy analysis, the accuracy of the generated DSM is not analyzed. However, the accuracy of the generated DSM is highly relied on the image matching technique and the algorithm for DSM interpolation.

4. Conclusions

In this paper we have developed a 3-D positioning method using IKONOS stereo images based on a parallel projection assumption and trigonometry. The proposed 3-D modeling method adopts the provided nominal collection azimuth and elevation data, so the positioning accuracy is highly relied on the provided metadata. However, from the experimental result it demonstrates that when IKONOS stereo images are utilized for DSM generation a potential positioning accuracy less than two meters can be achieved.

5. Acknowledgement

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6. References

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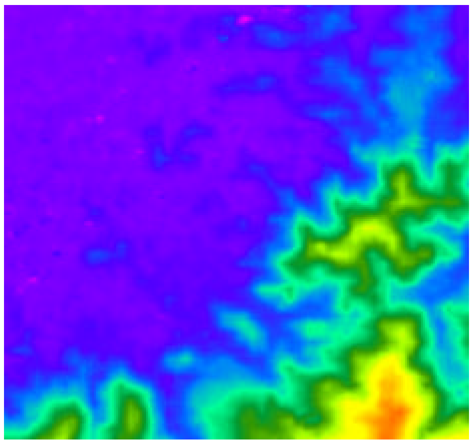

Figure 5. Generated DSM.