REGISTRATION OF IKONOS-2 GEO-LEVEL SATELLITE IMAGERY USING ALS DATA - BY USING LINEAR FEATURES AS REGISTRATION PRIMITIVES

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ABSTRACT ...To make use of surveying data obtained from different sensors and different techniques in a common reference frame, it is a pre-requite step to register them in a common coordinate system. For this purpose, we have developed a methodology to register IKONOS-2 Satellite Imagery using ALS data. To achieve this, conjugate features from these data should be extracted in advance. In the study, linear features are chosen as conjugate features because they can be accurately extracted from man-made structures in urban area, and more easily than point features from ALS data. Then, observation equations are established from similarity measurements of the extracted features. During the process, considering the characteristics of systematic errors in IKONOS-2 satellite imagery, the transformation function were selected and used. In addition, we also analyzed how the number of linear features and their spatial distribution used as control features affect the accuracy of registration. Finally, the results were evaluated statistically and the results clearly demonstrated that the proposed algorithms are appropriate to register these data.

KEY WORDS IKONOS-2 Imagery, ALS data, Linear Features

1. INTRODUCTION

Since the launch of IKONOS-2 satellite on 24th September 2007, the high-resolution satellite imagery is available commercially and has been widely used in various application fields. The detail overviews of IKONOS-2 satellite may be found in Dial (2001). Current research is focused on ways to improve the ability of collecting and utilizing the imagery.

One of the major current issues is compensating for the systematic errors in the RPC (Rational Polynomial Coefficients) model of IKONOS-2 satellite imagery. As well known within the photogrammetric community, the RPC model is an alternative of the rigorous sensor model of the IKONOS-2 satellite image. This model was released by SI (Space Imaging) to withhold the camera model from being public release. More detail descriptions of RPC models can be found in Grodecki (2001). According to the absolute accuracy specification of IKONOS-2 satellite imagery, it is 25 m (RMS 1-sigma) for the Geo-level image product. Significant contributors to the error in RPC geo-positioning are biases in exterior orientation, and especially errors in attitude determination. (Grodecki et al., 2003; Fraser et al., 2003). Such systematic errors usually cause problems in determining high accuracy 3D object point and extracting meaningful information. To compensate such positional biases, many researches have been mainly conducted by using GCPs (Geometric Control Points) which are obtained by GPS (Global Positioning System) surveying. However, the outdoor GPS surveying for GCPs usually take up a significant amount of time and efforts. Furthermore, sometimes, it is difficult to obtain GCPs by GPS surveying due to the difficulty of accessibility of target area.

To circumvent these limitations, ALS data have recently been proposed as an alternative to GCPs as geometric control datasets for registration of image data. The ALS (Airborne Laser Scanning) systems have been adopted in a wide range of applications such as creating digital surface models and ortho-photo generation thanks to its ability to accurately and rapidly process three-dimensional (3-D) terrain coordinates over target areas. Their potential for simplifying the processing and increasing accuracy has been examined in registration of aerial photos (Habib et al. 2005; Lee et al. 2006). While the successful use of ALS dataset has been demonstrated in registration of aerial photos, this approach still requires improvement in IKONOS-2 satellite imagery. Therefore, in this paper we propose a simple and robust algorithm to meet this demand.

In the next section, a detailed description of the methodology for registration will be provided. In section 3, an experiment with real datasets is performed to demonstrate the feasibility of this approach. Conclusions and future works are discussed in section 4.

2. METHODOLOGY

The registration activity may be defined as a process aiming at combining multiple datasets acquired by different sensors in order to achieve better accuracy and enhanced information of the environment. In general, a registration methodology must deal with three issues: First, a decision should be made regarding the choice of registration primitives considering the datasets. Secondly, the choice of transformation functions for registration should be considered to relate the datasets mathematically. Finally, a similarity measure should be devised to ensure the coincidence of conjugate primitives after applying the appropriate transformation function (Brown, 1992).

In connection to these issues, a brief overview and developed techniques are presented in the following sub-sections.

2.1 The choice of registration primitives

To register IKONOS-2 imagery by using ALS data, the common conjugate features have to be extracted. The chosen primitives will be subsequently used as registration primitives. It is known that they greatly influence the whole registration process, and hence, it is crucial to determine which primitives should be used for establishing the transformation between the datasets under consideration (Habib et al. 1999).

In the registration process using spatial data, the three fundamental kinds of primitives are mainly used. They are points, lines, and area features. While point features are used for this purpose in traditional photogrammetric activities, it is almost impossible to identify conjugate laser footprints in ALS data due to the irregular nature of ALS data. Moreover, even when intensity data are captured by the ALS system, identifying conjugate points in the generated intensity images will be contaminated by errors of the same magnitude as the average sampling distance in the acquired data. Therefore, point features are not applicable for registration process using ALS data (Kager et al.,, 2004; Filin et al., 2004; Habib et al., 2005) and so points such as corners and center points are used instead (Lee, 2003). It should be noted that the approaches using those points as registration primitives experience difficulties in extracting the features because these points are extracted by intersecting three ALS patches. Consequently, line and area features are the other potential primitives that can be more suitable for datasets involving ALS data. Area features such as lakes, roofs, and homogeneous regions can be extracted from ALS data using classification or segmentation algorithms. However, area features are not suited for photogrammetric datasets because there are no established procedures for deriving area feature of object space from corresponding feature in the image space. Based on this argument, the linear features were considered as the best primitives for the registration because of their abundant availability in nature and the simplicity of the extraction algorithm. For the complete description of the choice of the registration primitives for registration between image and range datasets, refer to the reference (Habib et al., 2004). Figures 1 and 2 show linear features extracted from ALS data and IKONOS-2 satellite imagery respectively. In these figures, linear features are represented by points along the line, which is the most convenient representation of linear features in the photogrammetric view (Habib et al., 2002).

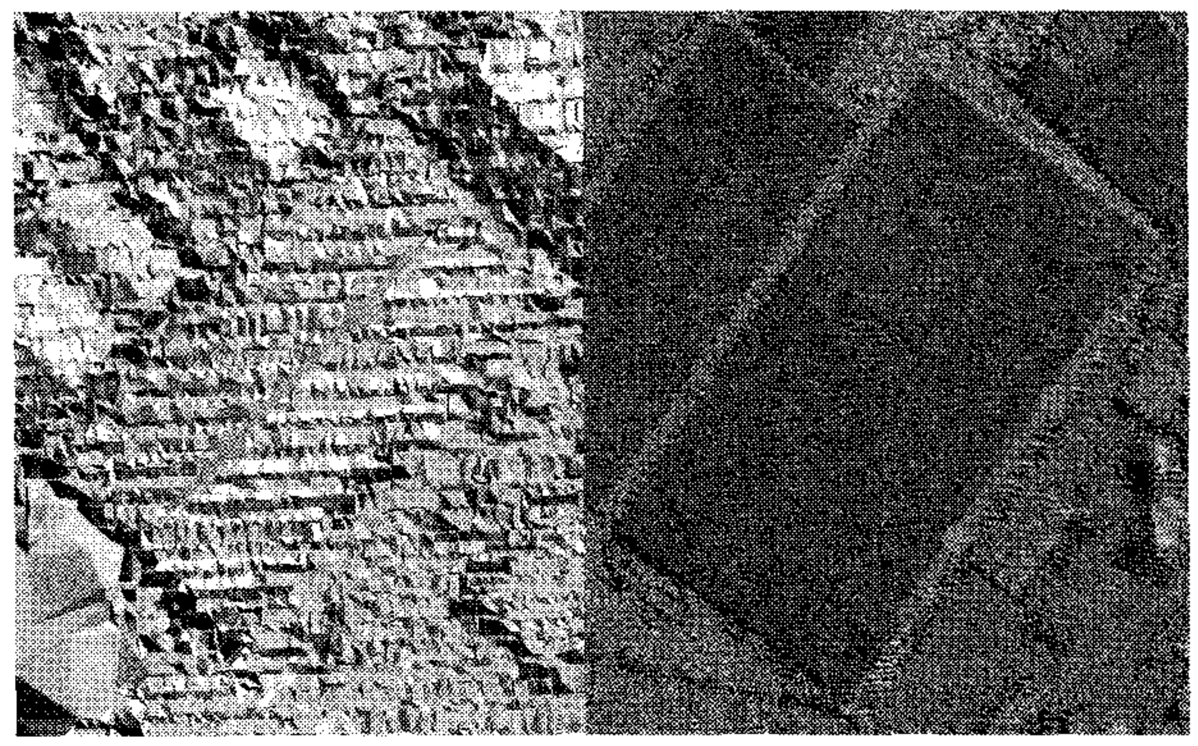

Figure 1. Linear features extracted from ALS data

Figure 2. Linear features extracted from IKONOS-2 satellite imagery

2.2 The choice of transformation function

For the registration of IKONOS-2 satellite imagery with RPC models, an elegant and efficient transformation function model was proposed by Grodeki et al. (2003).

$$\begin{aligned} Line_i^{(j)} &= \Delta p^{(j)} + p^{(j)}(\phi_k, \lambda_k, h_k) + \varepsilon_{Li} \\ Sample_i^{(j)} &= \Delta r^{(j)} + r^{(j)}(\phi_k, \lambda_k, h_k) + \varepsilon_{Si} \end{aligned} \quad (1)$$

where,

$Line^{(j)}_i$ and $Sample^{(j)}_i$ are measured (on image j) line and sample coordinates of i^{th} image point, corresponding the k^{th} ground control with object space coordinates (Φ_k, λ_k, h_k)

$\Delta p^{(j)}$ and $\Delta r^{(j)}$ are the adjustable functions expressing the differences between the measured and the nominal line and sample coordinates of ground control for image j

$p^{(j)}$ and $r^{(j)}$ are the given line and sample, denormalized RPC models for image j

ε_{Li} and ε_{Si} are random unobservable errors.

As demonstrated by Grodeki et al. (2003), only few parameters are required to adjust systematic errors in RPC models of IKONOS-2 satellite imagery. A line offset parameters absorbs effects of orbit, attitude, and residual interior orientation errors in the line direction and the sample offset parameter absorbs the same effects in the sample direction. Also, for images shorter than 50 km, the adjustment model becomes simply $\Delta p=a\_0$ and $\Delta r=b\_0$. Furthermore, the image-space adjustment models defined in image-space coordinate was used because it is much more closely related to the geometric properties of the physical camera model. For complete descriptions of adjustment models for IKONOS-2 satellite imagery, please refer to the reference (Grodecki et al., 2003).

2.3 Similarity measure

The role of the similarity measure is to set up the necessary constraints for ensuring the coincidence of corresponding features extracted from ALS data and IKONOS-2 imagery. As described in section 2.2, the linear features extracted from ALS data are projected on image space by using the RPC model and then, the parameters of transformation function are determined with constraints. In the paper, it is used as a constraint that the linear feature from IKONOS-2 imagery should be laid on the corresponding linear feature from ALS data. Using this constraint and transformation function (Eq. (1)), the observation equation can be expressed as

$$\frac{Line_A^{(j)} - Line_B^{(j)}}{Sample_A^{(j)} - Sample_B^{(j)}} = \frac{p^{(j)}(\phi_k, \lambda_k, h_k) + a^{(j)}{}_0 - Line_B^{(j)}}{r^{(j)}(\phi_k, \lambda_k, h_k) + b^{(j)}{}_0 - Sample_B^{(j)}} \quad (2)$$

where, $_A$ and $_B$ indicate the points representing a linear feature and $a^{(j)}{}_0$ and $b^{(j)}{}_0$ are parameters of the adjustment model of jth image.

One should be note that the linear features are represented by the points along them and the points of corresponding ALS and IKONOS-2 image linear features need not be conjugated. This makes the extraction process of linear features easier.

3. EXPERIMENTS AND ANALYSIS

The experiments are designed to address the following issues.

1) The feasibility of developed methodologies for registration of IKONOS-2 imagery using ALS data
2) The number of linear features used for the registration
3) The distribution of linear features used for the registration

Stereo pair of IKONOS-2 imagery and one ALS dataset are included in this study. IKONOS-2 imagery was collected on 19th November 2001 with 1 m spatial resolution and over 9.6 km × 9.6 km. It is the Geo-level panchromatic image and its nominal positional accuracy is 25 m (RMS 1 m). ALS dataset was collected on 15th May 2005 using the OPTECH ALTM-2700 laser scanning sensor. According to the specifications, the point density of the dataset is 2.2 points/m^2 and the horizontal and vertical accuracy are expected 30 cm and 15 cm respectively. 30 linear features for adjustment are extracted from two IKONOS-2 images and ALS dataset. Also, to test the accuracy of IKONOS-2 satellite imagery after registration, 30 GCPs are collected using GPS surveying techniques. Figure 3 shows one of IKONOS-2 images and distribution of linear features used for controls.

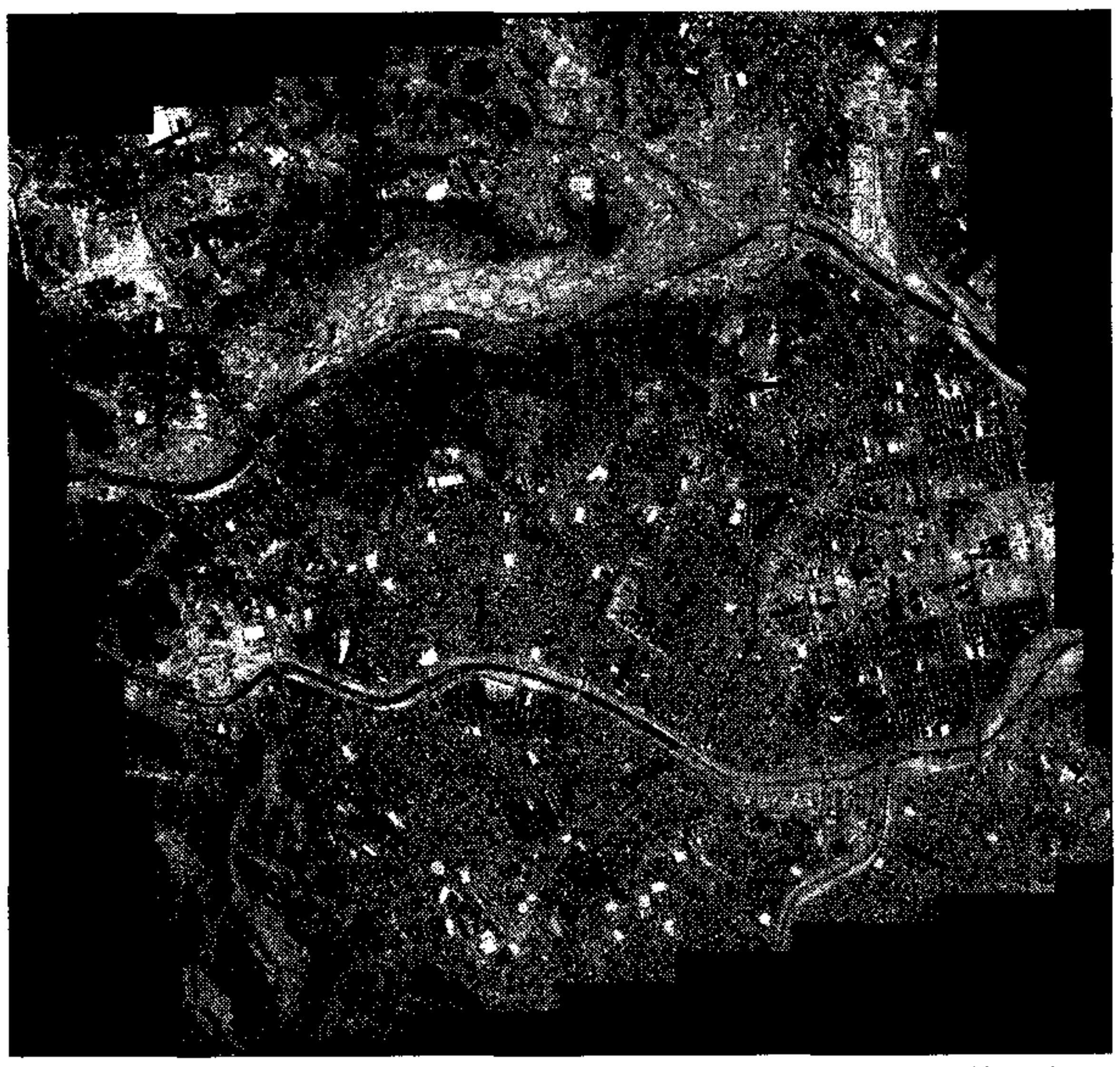

Figure 3. One of IKONOS-2 images and distribution of linear features

Table 1 shows the adjustment results. The average errors without control linear features were 5 m, 5 m, and 7 m in longitude, latitude, and height. This illustrates IKONOS-2 geo-positioning accuracy without ground control. The addition of 5 ground control points reduced the average error to 0.5 m, 0.5 m, and 0.5 m in longitude, latitude, and height, respectively. Meanwhile additional linear features further reduced average errors, the standard deviation remained virtually unchanged at 1 m in longitude, latitude, and height.

We next conducted a hypothesis test to examine whether the results are statistically significant. Using the paired comparison method, the differences between errors in longitude, latitude, and height before and after registration were examined to determine if they are significantly large from a statistical viewpoint. The test statistic was set up as follows:

$$T = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_{1,i} - X_{2,i}) - \delta_0}{S_D / \sqrt{n}} \quad (3)$$

$$S_D^2 = \frac{1}{n-1}\sum_{i=1}^{n}[(X_{1,i} - X_{2,i}) - \frac{1}{n}\sum_{i=1}^{n}(X_{1,i} - X_{2,i})]^2$$

where

indicates the pooled standard deviation, $X_{1,i}$ and $X_{2,i}$ denote the value of i^{th} the normal vectors before and after transformation, respectively, and n indicates the number of normal vectors. In this case, δ_0 is zero. The corresponding hypothesis is:

$$H_0 : \mu_1 = \mu_2, \quad H_1 : \mu_1 > \mu_2 \quad (4)$$

where μ_1 and μ_2 are the population means of the normal vectors before and after transformation, respectively.

Table 1. Adjustment results *Standard Deviation

Linear features	Error Longtude Mean(SD*)	Error Latitude Mean(SD*)	Error Height Mean(SD*)
None	-3.661 (±1.060)	-9.985(±1.246)	-14.481(±1.330)
5	0.299(±0.869)	-0.245(±1.215)	0.763(±0.747)
7	-0.169(±0.869)	0.522(±1.215)	0.370(±0.747)
10	-0.148(±0.869)	0.453(±1.215)	0.671(±0.747)
15	-0.318(±0.869)	0.300(±1.215)	-0.329(±0.747)
20	-0.318(±0.870)	0.300(±1.215)	-0.329(±0.747)
30	-0.241(±0.869)	0.331(±1.215)	-0.234(±0.747)
9 in upper left corner	-0.168(±0.868)	0.200(±1.215)	0.896(±0.747)
9 in lower left corner	0.618(±0.869)	-0.575(±1.215)	0.178(±0.747)
9 in upper right corner	-0.243(±0.870)	0.298(±1.215)	0.713(±0.747)
9 in lower right corner	-0.272(±0.870)	0.312(±1.215)	-0.672(±0.747)

The test results for all the transformations rejected the null hypothesis at the 99% significance level. For example, the t-values when using 10 linear features were 5.462 in the X-direction, 9.692 in the Y-direction and 12.218 in the Z-direction, which rejects the null hypothesis at the significance level (99%, at which the t-value is 2.364). This result clearly indicates that the developed methodology is valid for the registration of IKONOS-2 satellite imagery using ALS data.

4. CONCLUSIONS

We have presented a generally applicable algorithm that uses linear features to register IKONOS-2 imagery using ALS data. The algorithm explicitly formulates step-by-step methodologies. The results clearly shows that using the proposed approach result in a statistically significant reduction in biases of RPC models of IKONOS-2 imagery, and that the registration methodology using linear features is valid.

Future research will focus on the full automation of our proposed algorithm; including tasks such as extracting linear features and matching conjugate features using their directional vectors and relative distances.

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