Performance analysis on the geometric correction algorithms using GCPs - polynomial warping and full camera modelling algorithm

Dongseok Shin and Young-Ran Lee
Satellite Technology Research Center, KAIST
373-1 Kusung-dong, Yusung-gu, Taejon, KOREA (305-701)
dshin@krsc.kaist.ac.kr, yllee@krsc.kaist.ac.kr

Abstract

Accurate mapping of satellite images is one of the most important parts in many remote sensing applications. Since the position and the attitude of a satellite during image acquisition cannot be determined accurately enough, it is normal to have several hundred meters' ground-mapping errors in the systematically corrected images. The users which require a pixel-level or a sub-pixel level mapping accuracy for high-resolution satellite images must use a number of Ground Control Points (GCPs).

In this paper, the performance of two geometric correction algorithms is tested and compared. One is the polynomial warping algorithm which is simple and popular enough to be implemented in most of the commercial satellite image processing software. The other is full camera modelling algorithm using physical orbit-sensor-Earth geometry which is used in satellite image data receiving, pre-processing and distribution stations. Several criteria were considered for the performance analysis : ultimate correction accuracy, GCP representatibility, number of GCPs required, convergence speed, sensitiveness to inaccurate GCPs, usefulness of the correction results.

This paper focuses on the usefulness of the precision correction algorithm for regular image pre-processing operations. This means that not only final correction accuracy but also the number of GCPs and their spatial distribution required for an image correction are important factors. Both correction algorithms were implemented and will be used for the precision correction of KITSAT-3 images.

1. Introduction

The commercialization of 1m resolution satellite images has come to the very near future. The extraction of accurate positional information from a satellite image is critical to many remote sensing applications such as a large scale mapping, urban planning and military applications. The automatic change detection using multi-temporal image registration also requires high precision absolute/relative image mapping.

Raw satellite images contain severe geometric distortion due to orbit-attitude of the satellite, irregular Earth shape and its rotation, panoramic effects, and so forth. This distortion can be relieved effectively by the projection of a raw image to ground using a sensor-orbit-Earth geometric model. This projection using *a priori* information is called systematic correction. The result of the systematic correction, however, contains residual geometric errors inevitably due to the inaccuracy of *a priori* information, especially due to the inaccuracy in the satellite orbit and attitude determination during image acquisition. In order to achieve a very accurate image mapping, the usage of Ground Control Points (GCPs) is essential.

The most critical factor for accurate geometric correction is the accuracy of GCPs themselves. Practically no algorithm can achieve good geometric correction results by using poor GCPs. The geometric correction performance by using the same GCPs depends, however, heavily on the correction algorithm applied. In general, two methods have been applied for satellite image geometry correction : polynomial warping and full camera modelling.

The polynomial warping technique is very simple and popular enough to be implemented in most of the commercial satellite image processing software. However, it requires a large number of GCPs which should also be evenly distributed over the entire image frame. In order to obtain high accuracy, high-order polynomials can be applied resulting in high sensitivity to GCP errors. To overcome the poor performance of the polynomial warping technique, a full camera model has been used for the accurate geometric correction using a couple of GCPs. Although this algorithm has a complexity in development and implementation phase, the accuracy and the much less number of GCPs required has put this algorithm into satellite image ground station processing system in which an operational image correction is carried out.

The two geometric correction algorithms are briefly summarized in section 2. Their performance tests and results are described in section 3. This paper concludes with discussions in section 4.

2. Precision geometric correction algorithms

2.1 Polynomial warping technique

The polynomial warping (also called rubber sheeting) technique uses polynomial equations in order to relate target image (corrected image) coordinates to source image (raw image) coordinates as follows:

$$X = \sum_{j=0}^{m} \sum_{k=0}^{m-j} a_{jk} x^j y^k , \qquad Y = \sum_{j=0}^{m} \sum_{k=0}^{m-j} b_{jk} x^j y^k \tag{1}$$

where (X, Y) and (x,y) are the source image and the target image coordinates respectively (mth order polynomial). Using the source and target coordinates of GCPs, the polynomial coefficients (a_{jk}, b_{jk}) can be obtained by the least square estimation method. Although the optimal number of polynomial order (m) depends on the number, distribution and the accuracy of GCPs, high order polynomials are not used due to the cause of additional distortion. The least square estimation requires at least (m+1)(m+2)/2 GCPs (3 for the first order polynomial). In practice, however, more than 20 GCPs are used to achieve accurate geometric correction.

2.2 Full camera modelling

This technique converts the raw image coordinates (column, row) to the ground coordinates (map projection) by modelling sensor scanning geometry, satellite orbit and attitude geometry, and Earth shape and rotation. The coordinate transform is performed by using a vector projection technique with axes rotation (Figure 1).

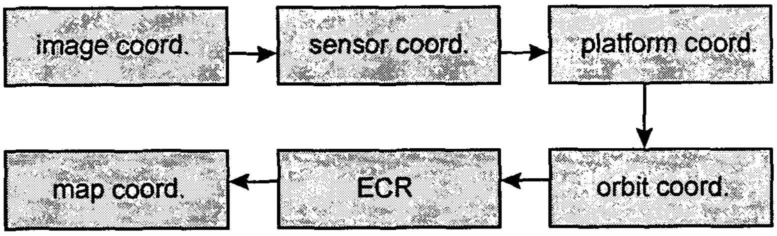

Figure 1. Coordinate transformation (sensor-orbit-Earth modelling)

The residual error sources after this systematic modelling are :

- Satellite position (along-track, across-track, radial)

- Satellite velocity (along-track, across-track, radial)
- Satellite attitude (pitch, roll, yaw)

The nine error source parameters described above are estimated by a non-linear extended Kalman filter. The GCPs (measurements) are applied recursively (one by one) to the Kalman filter and the nine parameters are inversely estimated resulting in an accurate camera model. Since the error range and GCP accuracy information is fed into the initial Kalman filter covariance matrix, this technique can achieve accurate geometric correction by using a couple of GCPs.

3. Experiments

The two precision correction algorithms were tested by using 33 GCPs which were extracted from a test image (SPOT Panchromatic) and 1:50,000 maps as shown in Figure 2. The GCPs were evenly distributed over a part of the test SPOT image - approximately 45km×30km.

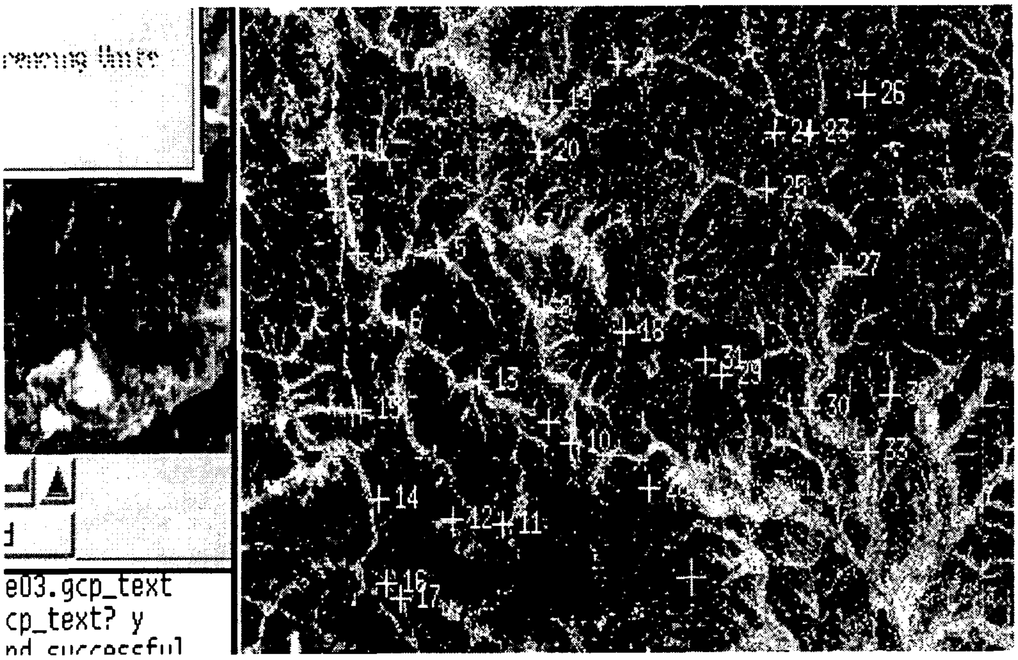

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Figure 2. Test image and GCPs © CNES

Since the GCPs were extracted from 1:50,000 maps, their RMS errors are estimated to be approximately 30-40 meters mainly due to the inaccuracy of the maps themselves. This relatively inaccurate GCPs prevented a high-order polynomial algorithm from being used. The first order polynomial warping algorithm was, therefore, applied for the precision correction of the test image.

The full camera modelling algorithm used *a priori* ephemeris data, scan mirror angle, and the mathematical model of the image scanning geometry. The accurate ephemeris and attitude values were estimated from the GCPs using an extended Kalman filter.

Both algorithms were applied by using n GCPs ($1 \le n \le 33$ for full model and $3 \le n \le 33$ for polynomial warping) which are called "reference GCPs". The performance was analyzed from the 33-n independent GCPs which were not used for the correction (called "test GCPs"). The accuracy of the test GCPs is much more important because the purpose of the precision correction is to correct all pixels in the image accurately by selecting several sample pixels with ground true values (reference GCPs).

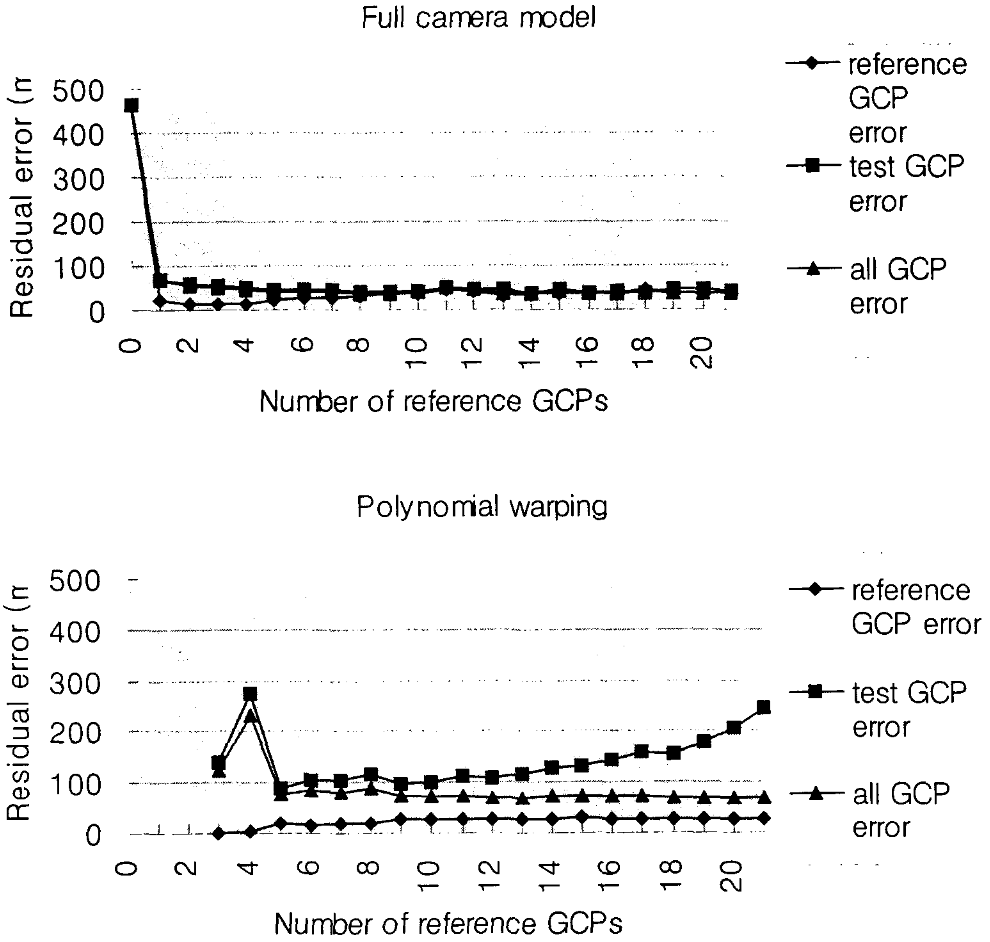

Figure 3. Performance test results

Figure 3 tells many things. The most important performance criteria is the representatibility of the reference GCPs. The comparison of the reference GCP error and the test GCP error gives that the reference GCPs used in the full camera modelling algorithm represent all pixels in the image very accurately. The polynomial warping algorithm generates very accurate polynomials only for the reference GCPs, but the polynomials cannot correct the rest of the pixels accurately (no better than 100m accuracy).

This representatibility of the correction algorithm is also related with the minimum number of GCPs required and their distribution requirement. While the full camera modellng algorithm can achieve the convergence of the residual error to ~40m in usage of 3~4 GCPs, the polynomial warping algorithm can never achieve the accuracy better than 100m using more than 20 GCPs. The full modelling algorithm can correct the whole image accurately by using the GCPs located in a part of the image because the GCP represents the pixels in another part of the image accurately. The polynomial warping algorithm is very sensitive to the location of the GCPs in the image, so that it requires many GCPs which are very evenly distributed over the image.

Another important factor is the usefulness of the auxiliary information obtained from the precision correction. The polynomial warping algorithm provides only the polynomial coefficients which cannot be used by any other fields than the correction itself. Since the full camera modelling algorithm, however, provides the accurate error source values (satellite position, velocity and attitude), the values can be used by many other fields such as:

- satellite attitude determination/control dynamics analysis
- orbit determination algorithm accuracy analysis
- sensor-platform mounting misalignment angle estimation
- precision correction of images from which GCPs cannot be obtained*

The full camera modelling algorithm can generate the accurate orbit model. This orbit model can be propagated to a new scene which was obtained in the same orbit pass. This means that an image from which no GCPs can be extracted can also be precision-corrected by the correction of the scene in the same orbit pass.

The performance of the two algorithms is summarized in Table 1.

	Full camera modelling	**Polynomial warping**
Ultimate correction accuracy	~40m	>100m
Minimum number of GCPs required	3~4	>20
Reference GCP distribution requirement	No	Evenly distributed
Sensitivity to GCP inaccuracy	Low (stable)	High (unstable)
Information acquired from correction	Useful	Useless
Implementation complexity	Complex	Simple
Processing time	Fast	Fast
Main purpose	Operational pre-processing	General image processing

Table 1. Performance comparison of two precision correction algorithms

4. Discussion

The full camera modelling correction algorithm has been developed and integrated in KIMS3 (KITSAT-3 Image Mosaic System) which is an operational pre-processing software for KITSAT-3 multi-spectral images. Although the algorithm depends much on each sensor, high-resolution linear pushbroom type sensors can be modelled in a similar way. The KIMS3 can therefore process not only the future KITSAT-3 images but also the currently available SPOT PLA/MLA and JERS-1 OPS/VNIR images.

To minimize the number of GCPs required for the correction is the most important factor for the operational pre-processing because the GCP extraction takes the most of the processing procedure. In this sense, KIMS3 has the capability of:

- the use of 239 1:50,000 scanned raster maps rather than paper maps on a digitizing table
- adding new GCPs to a database with image chips and their semi-automatic reuse
- entering external GCP information such as GPS measurements.

The reasons that users want to correct the image geometry by using the polynomial warping technique for themselves are (1) the high cost of the precision corrected images and (2) the reliability of the correction results. From the ground station's point of view, it is very wasteful for every user to collect and apply different GCPs. The image correction accuracy depends on each user and cannot be generalized. Therefore, Satellite Technology Research Center developed highly reliable and accurate precision correction algorithm and is trying to collect accurate GCPs using DGPS. By using centralized accurate GCP database and the full camera modelling correction algorithm showing high accuracy, the KITSAT-3 image users can obtain accurately corrected images and they don't have to spend long time for the GCP extraction.