Approximate approaches for geometric corrections of High Resolution Satellite Imagery

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ABSTRACT

Remote sensing data becomes one of the main sources of comprehensive and most current basic information required for mapping and different applications. Successful exploitation of the high accuracy potential of HRSI systems depends on accurate mathematical models for the satellite sensor. However, in the absence of sensor calibration and satellite orbit information for most of the new HRSI, empirical methods have been adopted. In this paper, the exploitation of different non-rigorous mathematical models as opposed to the satellite rigorous models is discusses for geometric corrections and topographic/thematic maps production of HRSI. Furthermore, the paper focuses on the effects of the number of GCPs and the terrain elevation difference within the area covered by the images on the obtained ground points accuracy. From the research findings, it is obvious that non-rigorous orientation and triangulation models can be used successfully in most cases for 2D rectification and 3D ground points determination without needing a camera model or the satellite ephemeris data. In addition, accuracy up to the sub-pixel level in plane and about one pixel in elevation can be achieved with a modest number of GCPs.

KEYWORDS: Remote Sensing, Rectification, Polynomials, High-Resolution

1. INTRODUCTION

With the launch of various commercial high-resolution earth observation satellites, such as Indian Remote Sensing Satellite IRS-1C/1D, the Space Imaging IKONOS system, SPOT 5 and Digital Globe QUIKBIRD system, precise digital maps generated by satellite imagery are expected in the spatial information industry. For last decades, airborne photography is the primary technique employed in producing national map products due to its high accuracy and flexible schedule (Li, 1998). However, it cannot map areas where airplanes cannot reach and its mapping frequency is constrained by the limits of flight planning (Li, 2000). Now with the high-resolution satellites era, accuracy required by medium and small-scale maps are achievable, with the possibility to frequently map an area without the special flight planning and scheduling required using aerial photographs. Successful exploitation of the high accuracy potential of these systems depends on accurate mathematical models for the satellite sensor.

In the last decade, many studies and researches performed with rigorous and non-rigorous mathematical models to rectify the satellite line scanner imagery such as SPOT, MOMS-02 and IRS-1C. One of the main goals of these researches is to find an appropriate mathematical model with precise and accurate results. The geometric accuracy of data products is terminated by the knowledge of precise imaging geometry, as well as the capability of the imaging model to use this information. The precise imaging geometry in its turn is established by knowledge of orbit, precise attitude, precise camera alignments with respect to the spacecraft and precise camera geometry (Srivastava and Alurkar, 1997).

Rigorous mathematical models for geometric corrections of any images can be defined as the models, which can be precisely, present the relationship between the image space and the object space. Perspective geometry and projection performs the basis of the imaging model frame cameras as well as other sensors. For any point in the space, there is a unique projective point in the image plane, however, for any point in the plane there are infinite number of corresponding points in the space, Mikhail et al. 2001. Due to this fact, an additional constrain is needed to define the point in the 3D space. Collinearity equations are the rigorous model, which describe this projection relation between 2D image space and 3D object space.

Unlike ordinary photogrammetric photography, high-resolution satellites are a line sensing imaging systems where every line is imaged at different time. That may help to understand the need of a special treatment of the sensor model, Makki, 1991. In general, the rigorous time dependent mathematical models are based on the collinearity equations, which relate image coordinates of a point to its corresponding ground coordinates. Published studies reported to date on IKONOS and other satellites focus in two main aspects, the accuracy attainable in ortho-image generation and DTM extraction concerning 3D positioning from stereo spatial intersection using rigorous and non-rigorous sensor orientation models. Due to some limitations, most of the new High Resolution Satellite Imagery (HRSI) vendors hide the satellite orbit information and calibration data from the customers community such as for IKONOS and QUICKBIRD imagery. This means that other alternative models should be used to solve practically this problem and calculate the imagery parameters. Therefore, these empirical approaches can be applied to determine the ground point coordinates in either 2D or 3D.

For IRS imagery, despite the satellite ephemeris data and information about sensor model are available, practical approaches are preferred. The rigorous sensor model usually has some disadvantages such as the complexity of the model, the need for changing real time mathematical model for each different image sensor and the difficulties for selecting specialized proper software for multi sensor triangulation. In addition, the very long principle distance and the narrow angle of view comparing to the aerial photographs may make an orbital resection unstable (Li et al., 2000). Due to these difficulties, practical approaches are preferred for geometric corrections of HRSI and extracting accurate 2D and 3D terrain information.

Adoption of such models instead of the collinearity equations is also necessary with the new HRSI due to the absence of a camera model and precise ephemeris data, which are withheld from the user community. Hanley and Fraser (2001), Fraser et al. (2002a), Shaker et al. (2002) and Shi and Shaker (2003) conducted experiments, which proved that the metric integrity of the IKONOS imaging system is in accordance with expectations gained from experience with medium resolution push-broom satellite sensors. The work applied to the mathematical models of 2D and 3D images to object space transformation; the results showed that accuracy of 0.3 to 0.5 m in 2D geo-positioning and about 1 m in height is achievable with tools and a modest number of ground control points.

This part of the research discusses the exploitation of different non-rigorous mathematical models as opposed to the satellite rigorous models for geometric corrections and topographic/thematic maps production of HRSI. Different orders of polynomials, projective and affine model were used with different numbers of GCPs in different cases. Sophisticated programs were developed based on the previous models to check the capability of the models with IKONOS images.

2. HIGH-RESOLUTION SATELLITES

2.1 IRS 1C/1D technical specifications

As primary objectives of IRS satellites is to provide systematic and repetitive acquisition of data, IRS operates in a circular, sun-synchronous, near polar orbit with an inclination of 98.69° (Eurimage, 2002). With the stereo capabilities, the satellite can image the earth by a rotation of the whole PAN-camera up to ±26° across track viewing and with minimum five days revisit time. The swath width varied between 70, 141 and 804 km at nadir view for PAN, LISS-III, and WiFS images respectively. The imaging with the PAN camera consists of almost 12000 pixels from three CCD lines. One main reason for the imaging with PAN camera is separated to three CCD-lines that there is no available CCD-line with 12000 pixels and 7 micron meter pixel size (Jacobsen, 1998). Each CCD-line has 4096 pixels with a small overlap between the three CCD-lines, which make the effective size of the whole combination to be 12000 pixels. In general, the full PAN scene is delivered in three separated files, one file for each original CCD-sensor. Full details about the IRS-1C satellite and its camera system, which is similar to IRS/1D, can be found in Joseph, et al., (1996) and Kasturirangan, et al., (1996).

2.2 IKONOS technical specifications

IKONOS satellite imageries are available within ±85° latitudes with two different levels of geometrically corrections. First is Geo product, which is imaged above 50° elevation angle for fast revisit time with pan Ground Sample Distance (GSD) up to 1.2m. Second are the Geo Ortho kit products, which has an elevation angle above 75° with pan GSD below 1m, and includes Polynomial Rational coefficients (PRC) data as opposed to the rigorous mathematical model of the satellite. Table1 illustrates IKONOS product names and the corresponding accuracies in terms of Circular Error at 90% probability (CE90) and Root Mean Square error (RMS). These errors are not including effects of terrain displacement that depends on geometry and elevation uncertainly and can amount to several hundred meters (Space Imaging, 2002).

The Rational Polynomial Coefficients RPCs (also termed Rational Polynomial Camera model (RPCM) or Rational Function Model (RFM)) is used by Space Imaging (SI) Company as opposed to the rigorous mathematical model. SI specifications showed that without ground corrections the horizontal accuracy is 50m CE90% or 23.6m RMS; however, when using RPCs model with GCPs the accuracy can be improved to 4m CE90% or 1.8m RMS.

With the high stereo capability, IKONOS stereo principle based on along track technique as well as a capability of cross track, which can be rolled at distances of 725 km on either side of the ground track. Stereo pairs created from forward and backward looking (along track) ensure high quality collections because images are acquired under nearly the same conditions (Zhou and Li, 2000). However, cross track technique provide opportunity to enhance the revisit frequency of the satellite up to daily frequency. More details about the satellite technical features and specifications are included in Table2.

Table 1: IKONOS products accuracy

Product Name	CE90	RMS	Associated map scale
Geo	50.0 m	23.6 m	1:100,000
Reference	25.4 m	11.8 m	1:50,000
Pro	10.2 m	4.8 m	1:12,000
Precision	4.1 m	1.9 m	1:4,800
Precision Plus	2.0 m	0.9 m	1:2,400

2.3 QUICKBIRD technical specifications

By the end of the year 2001, high-resolution satellite market place watched the launch of the highest resolution satellite of any currently available or planned commercial satellite. Digital Globe's QuickBird satellite provides a highest resolution (0.61 m and 2.44 m in PAN and Multispectral modes respectively) and the largest swath width (16.5 km at nadir) as well as largest on-board storage. Different processing levels are offered ranging from raw data to orthorectified image maps. QuickBird imagery products are mainly delivered at two processing levels; Basic imagery (Level 1) with the minimum amount of processing, and Standard imagery (Level 2) with standard radiometric and geometric corrections, which are delivered in a map projection.

Basic imagery or Level 1 products are the least processed product with only radiometric and sensor corrections. In this level, the Ground Sample Distance (GSD) which presents the image resolution is varied between 61-centimeter (at nadir) to 72-centimeter (at 25° off-nadir look angle) for PAN mode and 2.44-centimeter (at nadir) to 2.88-centimeter (at 25° off-nadir look angle) for multispectral (QuickBird imagery product, product guide). However, the Basic imagery is geometrically raw, a horizontal accuracy of 14 m RMSE (23 m CE90%) may be achieved when the data are processed and this accuracy does not account the topographic displacement effects. On the other hand, Standard imagery products are radiometrically corrected, sensor corrected, geometrically corrected, and map projected. The GSD are presented as 70-centimeter with uniform pixel size. All Standard products are supposed to have the same accuracy as in Basic imagery products after processing. More information about the satellite can be seen in Table 2.

2.3 Technical comparison between different HRSI specifications

Many differences between IKONOS, QuickBird and IRS satellite systems can be presented such as differences in the coverage area, stereo technique, revisit time and resolution; however, the main differences between the IKONOS-QuickBird systems and IRS system can be summarized in three main points. First, the inflexibility of the payload steering mechanism of IRS system comparing to IKONOS and QuickBird systems led to limited acquisition of stereo IRS images. Second, the limited radiometric range (Gray value) of the PAN sensor of IRS (only 6-bit) compared to IKONOS and QuickBird sensors (11-bit) may led to saturation problems as will be discussed. Finally, the difference of the IRS satellite sensor architecture, which is composed of three linear arrays next to each other, than IKONOS system with one linear array provide some difficulties for image triangulation process. Table 2 illustrates summary of the technical specifications of the two satellite systems.

Table 2: Different HRSI technical specifications.

Sensor	IKONOS	IRS-1D	QuickBird	SPOT 5
Spatial Resolution: Panchromatic Multispectral	0.8-1.2m, resampled to 1m 3.3m, resampled to 4m	5.8m, resampled to 5m 23.5m	0.61 to 0.72m 2.44 to 2.88m	2.5m - 5m 10m
Radiometric Resolution	11 bit	6 bit	11 bit	8 bit
Swath Width	11 km (one strip)	70 km (3 strips)	16.5km	60 km
Altitude (km)	681	874 - 824	450	822
Location accuracy	23.6m (RMSE)	-------	23m (14m RMSE)	50m
Stereo Imaging	Along-track, with cross-track possible	Cross-track	Along track cross-track possible	Along track
Viewing Angle (degree)	26 ° (Forward – Backward)	+/- 26 °	25 °(Forward – Backward)	20 ° (Forward – Backward)
Image Processing Level	Standard Geometrically Corrected	Standard Geometrically Corrected (Radiometric corrections only are also available)	Basic imagery (no geometric correction) Standard imagery (Standard Geometrically Corrected)	Different level of processing including radiometric and geometric corrections

3. TEST FIELD

In research work, simulated data used to be utilized for the judgment of the mathematical model performance as a part of developing or establishing a new model; however, the conclusions on the performance of the model can only be made after using real data. The simulated imageries can be used in the first stages for model validation but it is not enough for solid conclusions because they themselves are created by the same model or by user assumptions that may not represent the real situation. Thus, the use of the real data is indeed necessary when we are talking about developing of mathematical models.

3.1 Hong Kong IKONOS images

Data set used in this paper as an example from our research work comprises two IKONOS satellite images for Hong Kong region with different terrain types. The Hong Kong test field area is located in the central part of Hong Kong. Two images were available for this area, image 1 (Figure 1) covered an area of 11.60x10.28 km over a part of Hong Kong Island and Kowloon district, and image 2, in the same region covered an area of 6.62x10.18 km and has a 2.5x10.0 km overlap with the first image. The max ground elevation difference in the tested area is about 500 m. The central parts of the two images are nearly flat, while the northern and southern parts are mountainous. Table 3 presents the main characteristics of the two acquired images.

The two images were not sold originally as stereo pair but as two single images. It means that the images did not delivered with the rational function models but the company submitted it with its Meta data files only. However, from the azimuth and elevation angles of the two images, it is obvious that the images were captured in along track and can be used as a stereo pair for the overlap area. From the two images specifications, base to height ratio (B/H) can be calculated and we found that it is equal to 0.87, which give us indication that the two images can be used geometrically as a stereo pair. Hong Kong test field has special characteristics due to the very tall buildings and high difference in elevation. These unique characteristics lead to some problems due to relief displacement and shadow from buildings. Therefore, in our scope of work, we just consider the terrain surface regardless the buildings and all GCPs/checkpoints were chosen on the terrain surface and quite far from the residential areas. Figure 1 presents the covered area and the GCPs distribution on the two images.

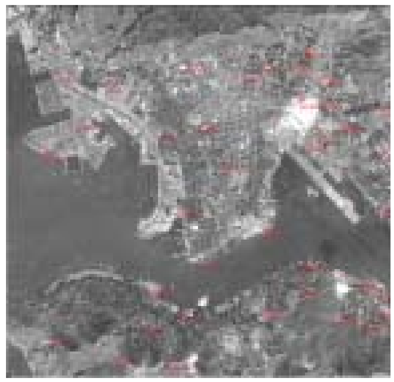


Figure 1: Ground points distribution and test field of Hong Kong data set.

Table 3: Technical specifications of the IKONOS images used in the experiment

Field	Image 1	Image2
Processing Level	Standard Geometrically Corrected	Standard Geometrically Corrected
Image Type	PAN	PAN
Acquired Nominal GSD: Cross Scan Along Scan	 0.86 m 0.91 m	 0.92 m 1.01 m
Stereo	Mono	Mono
Datum	WGS84	WGS84
Map Projection	UTM	UTM
Zone Number	50 N	50 N
Nominal Collection Azimuth	346.7620 °	160.9128 °
Nominal Collection Elevation	70.9734 °	62.66803 °
Sun Angle Azimuth	156.4342 °	149.7458 °
Sun angle Elevation	43.99996 °	49.42814 °
Acquisition date	2000-11-23	2000-10-29

3.2 Hong Kong GPS works

Up to data, the most traditional source of GCP for satellite imagery rectification has been to use topographic maps and digitized tablet (Smith and Athinson, 2001); however, the launch of high-resolution satellites may change it to use other alternative methods. In general, accurate rectification of the remote sensing imagery to a map projection relies on accurate source of ground control points. At the same time, accuracy of ground control points should match the resolution of the digital image (Smith and Athinson, 2001). In Hong Kong, 1:1000 topographic digital scale maps are available, which means that accuracy of 0.5 to 1.0m can be achieved from extracting GCPs and it may match the images resolution. However, it was not useful for us to use it in our research work because in many cases we cannot find and match GCP position on the image and the digital maps. In addition, 1.0 m accuracy from the extracted GCP can't be achieved when the source of the elevation values are one contour layer with major contour interval of 10m and minor contour intervals of 2.0m. These facts and principles lead us to use GCPs acquired by GPS instead of those acquired from digitized topographic maps due to its high accuracy.

For this project, a reference receiver located over one of Hong Kong Polytechnic University buildings was used as a base station when a rover receiver were moved for collecting the GCPs. Thirty-eight well-distributed ground control points were established by using two GPS Trimble sets system 4000 SSI and applying differential GPS techniques. As a first step, the images were divided into several areas of interest. Alternative points were chosen in each area so that they were well distributed across the images and the stereo model. The natures of the observed points were landmarks, road intersections, road-canal intersections, and some well-known features that can be identified easily on the image. All the GPS ground points were chosen to be located on the ground surface. Figure 2 shows how the GPS ground control points were chosen, defined, and collected in the field. Table 4 present more details about the GPS field work.

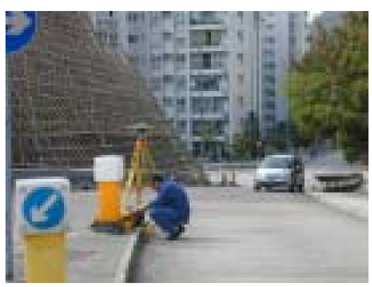


Figure 2: GCPs identification on field.

The final accuracy of all points is estimated to be of the order of 5cm in X and Y directions and 10cm in Z direction. It is worth mentioning that there is one concern should be pointed out regarding GPS work; that "the international error introduced into the GPS by the Department of Defence for the purpose of degrading signal accuracy, was turned off in early 2000, eliminating the primary source of positional error that requires differential corrections" (Smith and Athinson, 2001). For some satellite images, rectification process will need just one to two meters positional accuracy by single frequency GPS unit without differential corrections. However, necessity to base station triangulations will still be compulsory for very high accuracy.

Table 4: Hong Kong GPS fieldwork information

Number of points planed to collect	40 Points
Number of points collected	38 Points
Number of working days	6 Days
Number of points in HK Island District	14 Points
Number of points in Kowloon District	24 Points
Working Time	35 hours
Occupation time for each points	15 - 25 minutes
The longest base line	6258.907 m
The shortest base line	1250.098 m
Elevation Mask	10 Degrees
Intervals	5 Sec
Processing Time	6 Hours

4. MODELS USED

Based on previous research on IKONOS satellite, it is possible to assume that the sensor moves linearly in space, and that the attitude is almost unchanged. Furthermore, if the WGS84 UTM system is adapted as a reference system, the orientation angles can be regarded as constant and the flight path of the satellite as approximately straight. These characteristics let one abridge the collinearity equations between the satellite imagery and the ground points to simple formulas. For 2D transformation, five models were studied in this research using different numbers of ground control points. These models are generally available within most of remote sensing image processing systems. These models can be used to provide sufficient insight about the ground elevation effects on the metric integrity of the rectified images. The five 2D transformation models adopted for testing were four orders of 2D polynomials and eight-parameter projective model. The following sections discuss the models characteristics.

4.1 Polynomial models

Polynomial models usually used in the transformation between source file coordinates and map coordinates. The needed transformation can be expressed in different orders of the polynomials based on the distortion of the image, the number of GCPs and terrain type. A 1st-order transformation is a linear transformation, which can change location, scale, skew, and rotation. In most cases, first order polynomial used to project raw imagery to a planar map projection for data covering small areas. Transformations of the 2nd-order or higher are nonlinear transformations that can be used to convert Lat/Long data to planar or correct nonlinear distortions such as Earth curvature, camera lens distortion. The following equations are used to express the general form of the polynomial models.

Two-dimensional general polynomials

$$x = a_0 + a_1 X + a_2 Y + a_3 X^2 + a_4 Y^2 + a_5 XY + ... \quad (1)$$

$$y = b_0 + b_1 X + b_2 Y + b_3 X^2 + b_4 Y^2 + b_5 XY + ... \quad (2)$$

Three-dimensional general polynomials

$$x = a_0 + a_1 X + a_2 Y + a_3 Z + a_4 X^2 + a_5 Y^2 + a_6 Z^2 + a_7 XY + a_8 XZ + a_9 YZ + ... \quad (3)$$

$$y = b_0 + b_1X + b_2Y + b_3Z + b_4X^2 + b_5Y^2 + b_6Z^2 + b_7XY + b_8XZ + b_9YZ + ... \quad (4)$$

where (a,b) are the model coefficients, (X,Y) are model parameters.

4.2 Eight-parameter Projective model

Eight-parameter projective model expresses the relationship between two planes based on perspective projection concepts. The basic elements of the perspective projection consist of the point of the perspective center, bundle of arrays through this point and two different planes cut the bundle of arrays and do not contain perspective center. These two planes can be defined in our work as image plane and the ground projected plane. The relationship between the two planes can be written the following formula:

Eight-parameter transformation model:

$$x = (a_1X + a_2Y + a_3)/(a_4X + a_5Y + 1) \quad \textbf{(5)}$$

$$y = (a_6X + a_7Y + a_8)/(a_4X + a_5Y + 1) \quad \textbf{(6)}$$

where a_i is the model coefficient, (x, y) are the image coordinates and (X, Y) are the object plan coordinates.

As was shown in Shaker et al. (2002), Shi and Shaker 2003, and can be seen from the analyses, it is necessary in most cases to project the ground coordinates onto a compensation plane for the fact that the object control points lie at different elevations, especially in cases such as Hong Kong imagery with about 450 m difference in height. The following two equations are used for the corrections in easting coordinates (ΔX) and northing coordinates (ΔY).

$$\Delta X = \Delta Z \sin\alpha / \tan\varepsilon \quad (7)$$

$$\Delta Y = -\Delta Z \cos\alpha / \tan\varepsilon \quad (8)$$

where (α) is the azimuth angle, (ε) is the elevation angle of the satellite and ΔZ is the height difference with the plane of control.

4.3 Affine model

In this research, the straightforward eight-parameters affine model was used to confirm that it could produce accuracy equivalent to the one produced by rigorous sensor models. Adoption of an affine model as opposed to perspective projection model for satellite line-scanner imagery has been previously considered for both SPOT and MOMS-02 imagery and results showed that the affine model is quite robust and stable for image orientation and triangulation. The noteworthy point is that using the affine model can save at least thirty percent on image prices by ordering stereo images without the need for the rational functions. Each observation of a GCP will give rise to a set of two affine condition equations derived from the relationship between the image coordinates and the GCP coordinates in the geocentric system. The two affine condition equations are as follows:

$$x = A_1X + A_2Y + A_3Z + A_4 \quad (9)$$

$$y = A_5X + A_6Y + A_7Z + A_8 \quad (10)$$

where (x, y) are the image coordinates and (X, Y, Z) are the ground coordinates.

5. RESULTS ANALYSIS

5.1 2D Image to object space transformation

In this part, five 2D transformation models, four orders of polynomials and the projective model, were used in this report due to their simplicity and availability within most of the remote sensing software packages to check its applicability for HRSI rectification. Furthermore, the use of a compensation plane with 2D transformation models is further studied when accurate planimetric results are sought and there is a difference in the terrain elevations, such as in Hong Kong case study

To determine the errors in the image geo-referenced coordinates, the observed GPS WGS84 UTM ground coordinates were compared with the corresponding measured geo-referenced image coordinates. The absolute planimetric errors for all points was found between 1 to 111 m in Y direction and from 3 to 32m in X direction, depending on the points elevations. As can be seen from the variation values in X and Y direction, Y direction contains the large amount of error as can be expected due to along track capturing technique. The transformation process involved two main steps: a) model parameters were determined by using different numbers of GCPs and the least square technique, and then b) the transformed coordinates were calculated based on the determined parameters. Since the two images in Hong Kong data set are quite similar with respect to the X and Y accuracy results, this report presents the results of applying the 2D transformation models to image1.

The 2D transformation comprised two tests. Firstly, the GCPs were utilized without being projected to a compensation plane. The number of GCPs used varied from 6 to 18 GCPs, while the remaining points were used as checkpoints. The results showed that in all cases, the total RMS errors ranged from 5.83 to 8.34m in X direction and from 14.47 to 38.27m in Y direction, and the projective model presented the best results. However, it can be seen that these 2D transformation models improve image accuracy but cannot verify accepted results accuracy. In a second test, all 3D ground point positions were projected to their equivalent positions on a compensation plane at an elevation of 200m, which presented the mean elevation of the tested area, and with the aim of the azimuth and elevation angles of the sensor. The projected coordinates were applied to the 2D models to check their accuracy. For control configurations starting from six up to eighteen GCPs and using the remaining points as checkpoints, the 2nd order polynomial produced best RMS errors with results of 0.46 – 0.29 m and 0.49 – 0.46 m in X and Y directions respectively. However, the fourth order polynomial yielded slightly better results than the second order but it required at least sixteen GCPs. In all cases, the RMS error discrepancy values are less than one pixel in both X and Y directions.

From these findings, it is remarkable that no significant effects in the total RMS errors were achieved when increasing gradually the number of the GCPs from 6 to 18. This provided a conclusion that the most important factor is GCP quality rather than quantity for 2D rectification. The third and fourth order polynomials offered results similar to the second order polynomial, but with more GCPs (at least 10 and 16 GCPs respectively).

5.2 3D ground points determination using Affine model

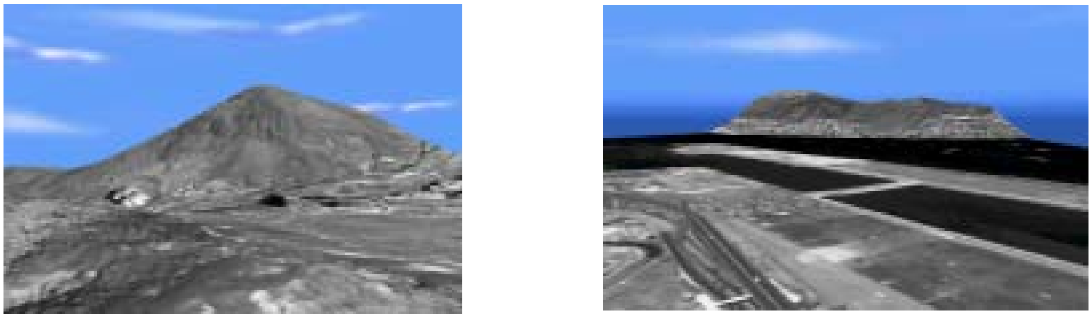
This research has an attempt to evaluate the potential of IKONOS panchromatic sensor data using non-rigorous models. In the implementation of these models for orientation and triangulation process, sophisticated programs were developed for 3D ground point determination. The programs comprises (i) a space resection, which is applied individually to each of the images making up the stereo pair; and (ii) a space intersection procedure, which generates the ground coordinates of the images with the aid of the least square adjustment. The least square solution solves the models equations to determine the orientation parameters of the left and right images. Stereo intersection is implemented independently to calculate the ground coordinates of conjugate points. Multiple sets of well-distributed GCPs were applied when the rest of the ground points were utilized as checkpoints.

In the implementation of the affine model for the IKONOS orientation and triangulation process, a particular program was developed which comprises object to image space transformation in forward (resection) and inverse (intersection) forms. Multiple sets of four, six, eight, ten and twelve well-distributed GCPs were applied when the rest of the eighteen points were utilized as checkpoints.

In general, it can be seen from the results that the total RMS errors in X, Y and Z directions considerably decrease with the increase of the number of GCPs. For the control configuration of four well-distributed GCPs and fourteen checkpoints, the affine model produced 1.38, 1.98, 3.20 m RMS errors in X, Y and Z directions respectively, whilst the RMS error results improved significantly to 0.58, 0.63m in X, Y directions and 0.98 m in Z direction when twelve GCPs were used. The accuracy of the model achieved by applying different sets of six to ten GCPs confirms the gradual improvement of the RMS errors of the checkpoints. In all cases the maximum residuals for the GCPs in the least square adjustment process was less than 5 cm, while it varied between 0.5 to 2.0 m in X, Y directions and from 0.6 to 3.5 m in Z direction for the checkpoints. The results obtained obviously showed that it is consistent with the expectation from photogrammetry experience. In addition, the effect of the along track images can be identified when most of Y direction results are slightly worse than X direction.

An additional test was performed to examine the accuracy of the ground coordinates determination using the affine based program by generating DEM based on some extracted points and by comparing it with an existing one, produced from 1:5000 scale maps. More than 300 well-defined points were digitized in the model region with the accuracy of image coordinates of more than half pixel. The measured points were applied to the affine program to compute its X, Y and Z ground coordinates using all available GCPs. When the generated DEM was compared with the existing one, the absolute height residuals varied between zero to five meters for the most part of the flat area on the image, while they ranged between zero to three meters for the hilly and mountainous areas. In order to treat the shortcomings of using the affine model in flat areas, some constraints, such as the seashore, were added to the model. The DEM was generated from all calculated (measured and constraint) points using the Kriging interpolation method and again was compared with the existing one. The resulting values of the latest DEM surpass those from the previous one in terms of height accuracy.

Finally, as indicated in Figure 5a, b surface was generated to present the results obtained from the affine model and the performed DEM. The 3D surface visualization was used for 3D modeling and presentations.



(a) (b)

Figure 5: 3D surface from generated DEM based on IKONOS images

7. CONCLUSIONS

From the findings obtained for the 2D rectification and 3D ground points determination of HRSI some encouraging conclusions can be drawn about the mapping potential of the IKONOS imagery. Conclusions can be summarized in the following; there is a distortion in the planimetric Geo-reference image coordinates delivered from the satellite depending on the ground point elevation level as can be expected from the imagery specifications. Care about the ground points elevation shall be done even we just rectify the image in 2D directions. The accuracy of the rectified coordinates is heavily affected by the elevation difference of the ground points. An accuracy of 0.5m can be achieved utilizing most of 2D transformation models after projecting the ground coordinates into a compensation plane. 3D Affine model can be used successfully in most cases for 3D ground points determination without needing a camera model or the satellite ephemeris data. Accuracy up to the sub-pixel level in X-Y directions and about one pixel in Z direction can be achieved by using the eight-parameter affine model and a modest number of GCPs. Increasing the number of GCPs significantly improves the accuracy of the results when the affine model is applied for an area with different terrain types.

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