Potential of mapping from IKONOS imagery

Hafez Abbas Afify
Public Work Eng. Dept., Faculty of Eng., Tanta University, Tanta, Egypt

Technological developments in spatial resolution of remotely sensed data have opened new important perspectives regarding space cartography. IKONOS satellite has provided the world with high spatial resolution 1-m panchromatic images. Not only the high spatial resolution, but also the high spectral, radiometric and temporal resolutions of IKONOS imagery make it ideally suited for mapping applications. The Rational Polynomial Model (RPM) is traditionally employed, instead of the physical model, to describe the object-image geometry of IKONOS. The purpose of this study is to evaluate the point positioning accuracy of IKONOS imagery and to compare the performance of third and second orders of RPM using different numbers of Ground Control Points (GCPs). The potential of using IKONOS panchromatic images for generating orthoimages of large scale has been also investigated. In this study, an IKONOS panchromatic image covering the city of Fredericton, New Brunswick, Canada was used. Processing steps were executed using PCI Geomatica version 9.1 OrthoEngine module. The results indicated that using third-order RPM and well-distributed number of GCPs the geometric accuracy of IKONOS images is less than 1.5 m, which is compatible for producing and updating topographic maps of scale 1:5,000.

إن التطورات التقنية الموجودة حالياً للقوة التحليلية الفراغية لصور الأقمار الصناعية فتحت آفاقاً جديدة في المساحة الكارتوجرافية من الفضاء، ويمدنا القمر الصناعي "إيكونوس" IKONOS بصور لها قوة تحليلية أرضية تساوي ١ متر. ومن مميزات هذه الصور أيضا القوة التحليلية الطيفية والقدرة على اكتساب بيانات لنفس المنطقة وعلى فترات زمنية قصيرة مما جعلها مناسبة للتطبيقات الخاصة بإنتاج الخرائط. ويستخدم نموذج كثيرة الحدود النسبي لتمثيل العلاقة بين إحداثيات الصورة والإحداثيات الأرضية، وتهدف هذه الدراسة إلى تقييم دقة الإحداثيات الأرضية المستنبطة من صور "إيكونوس"، وكذلك عمل مقارنة بين الدرجة الثالثة والدرجة الثانية لنموذج كثيرة الحدود النسبي باستخدام أعداد مختلفة من نقط الربط الأرضي. كما يهدف البحث إلى إجراء تطبيق لإنتاج الصور المعدلة orthoimages من صور "إيكونوس" وتحديد الدقة البلانيمترية لها، ولإجراء هذه الدراسة تم استخدام صورة تغطي مدينة فريدريكتون بولاية نيو برانزويك في كندا. وقد أظهرت النتائج فاعلية صور القمر الصناعي "إيكونوس" لإنتاج وتحديث الخرائط الطبوغرافية بمقياس رسم ١: ٥,٠٠٠ وكذلك تحليل مزايا استخدام نموذج كثيرة الحدود النسبي من الدرجة الثالثة عن الدرجة الثانية وتوضيح سلوك كلاً من درجتي النموذج نتيجة استخدام أعداد مختلفة من نقط الربط الأرضي.

Keywords: High-resolution imagery, Geometric accuracy, IKONOS panchromatic images, Rational polynomial model, Orthoimages

1. Introduction

Since its launch in September 1999, IKONOS satellite has been consistently providing high-resolution satellite images with 1-meter in panchromatic mode and 4-meter in multispectral mode. The off-nadir viewing capability is also an important characteristic of IKONOS since it improves the revisit rate to between two and three days and also enables the acquisition of stereo images which are essential for generating Digital Terrain Models (DTMs). The availability of such high-resolution data from IKONOS whether panchromatic or multispectral, single or stereo images have opened a new era heralding a promising future for producing and updating medium and large scale topographic databases. More details about IKONOS orbital properties and sensor characteristics can be found in [1], and [2].

The orbit and sensor information during the scene acquisition time is not provided with IKONOS images and thus potentially precludes the application of the rigorous physical-reality model in the geo-correction process. Instead, a Rational Polynomial Model (RPM) is used to describe the object-image geometry. Several investigations have been already carried out on the geometric correction of IKONOS imagery, for example [3, 4, 5]. These studies were based on third-order RPM to set up the relationship between the three-dimensional object-space and the two-dimensional image-space. In [6] a 3D affine transformation was applied to refine the ground positions calculated from the RPM. This combined model which consists of the vendor-provided RPM coefficients and the 3D affine transformation is referred to as the "RPM + 3D Affine" model. In [7] it was stated that, the biases inherent in RPM derived without the aid of ground control could be compensated during spatial intersection by two additional parameters in image space that effect a translation of image coordinates.

This paper is devoted to investigate the suitability of IKONOS data for mapping applications. Specifically, evaluating the point positioning accuracy of IKONOS imagery and comparing the performance of the third and second orders of RPM using different numbers of Ground Control Points (GCPs). The potential of using IKONOS data for generating orthoimages of large scale has been also investigated.

In this study, Rational Polynomial Model (RPM) was applied as an empirical model to geometrically correct an IKONOS image covering the city of Fredericton, New Brunswick, Canada. Different stages of geometric correction and orthoimage generation processes have been described. The analysis was performed by the aid of PCI EASI/PACE package version 9.1 from Geomatica, Ottawa, Canada.

2. Mathematical model

To geometrically correct IKONOS data, it is essential to apply a mathematical model that relates pixel-coordinates in image space to ground-coordinates in object space. The orbital information and ephemeris data during the scene acquisition time are not provided with IKONOS images. Therefore it is not possible to apply the physical reality model for the geo-correction process. Instead, a Rational Polynomial Model (RPM) is applied. This model is a non-parametric model (empirical model). It performs the transformation between image space and object space through mathematical functional relations, which do not require aprioristic knowledge of the parameters describing the platform, the sensor, or the projection system [8].

The RPM is constituted by four polynomial functions; the ratio of two polynomial functions is used to calculate row pixel (i) positions, and the ratio of the other two functions is used to calculate column pixel (j) positions. The general formula of the Rational Polynomial Model (RPM) is as follows:

$$i = \frac{P_1(X,Y,Z)}{P_2(X,Y,Z)} \quad j = \frac{P_3(X,Y,Z)}{P_4(X,Y,Z)}, \tag{1}$$

where (i, j) are the (column, row) of each image point and (X, Y, Z) are the longitude and latitude (in degrees, WGS84) and ellipsoidal height (in meters, WGS84) of the corresponding ground point [6]. In order to improve the numerical stability of equations and minimize the computational errors, all the image and ground coordinates are normalized to the range [-1,1] by offsetting and scaling [9].

The maximum power of each ground coordinate is typically limited to 3; and the total power of all ground coordinates is also limited to 3. In such a case, the third-order polynomial function is of the form:

$$\begin{aligned} P(X,Y,Z) = {} & a_0 + a_1X + a_2Y + a_3Z + a_4X^2 + a_5XY + \\ & a_6XZ + a_7Y^2 + a_8YZ + a_9Z^2 + a_{10}X^3 + \\ & a_{11}X^2Y + a_{12}X^2Z + a_{13}XY^2 + a_{14}XYZ + \\ & a_{15}XZ^2 + a_{16}Y^3 + a_{17}Y^2Z + a_{18}YZ^2 + a_{19}Z^3 \end{aligned} \tag{2}$$

Replacing eq. (2) in eq. (1) and eliminating the first coefficient in the denominator polynomial and putting the constant 1 instead, the third-order RPM form becomes:

$$i = \frac{(1XYZ\ldots YZ^2Z^3)(a_0a_1a_2a_3\ldots a_{18}a_{19})^T}{(1XYZ\ldots YZ^2Z^3)(1a_1a_2a_3\ldots a_{18}a_{19})^T}, \tag{3}$$

$$j = \frac{(1XYZ\ldots YZ^2Z^3)(c_0c_1c_2c_3\ldots c_{18}c_{19})^T}{(1XYZ\ldots YZ^2Z^3)(1d_1d_2d_3\ldots d_{18}d_{19})^T}. \tag{4}$$

As shown there are 39 unknown coefficients for each equation of the model, 20 in the numerator and 19 and the constant 1 in the denominator. In order to solve for the Rational Polynomial Coefficients (RPCs), at least 39 ground control points are required. RPCs are different in number, depending on the degree of the polynomial function. For the second-order RPM the number of the RPCs is 19: ten in the numerator and nine and the constant one in the denominator as shown in eqs. (5) and (6). In such a case, 19 GCPs at least are required to determine the RPCs [10,11].

$$i = \frac{(1XYZ...YZ\,Z^2)(a_0 a_1 a_2 a_3..a_8 a_9)^T}{(1XYZ...YZ\,Z^2)(1 b_1 b_2 b_3..b_8 b_9)^T}, \qquad (5)$$

$$j = \frac{(1XYZ...YZ\;\;Z^2)(c_0 c_1 c_2 c_3..c_8 c_9)^T}{(1XYZ...YZ\;\;Z^2)(1 d_1 d_2 d_3..d_8 d_9)^T}. \qquad (6)$$

The RPCs can be provided by the agency that distributes the images, or they can be calculated indirectly, through a number of GCPs equal to (2n-1) where n is the number of terms in each polynomial function.

3. Case study

3.1. Data sources

The study area is located in Fredericton, province of New Brunswick, Canada. It is characterized by an extensive road network, which makes it easy to locate enough number of GCPs as road intersections. Saint John River flows through the study area and urban dwellings, with different population densities, found on its sides. The altimetric variation of the study area is about 300 meters.

A subscene covering the study area was cut out from a panchromatic IKONOS image acquired on October 01, 2001. Table 1 summarizes the technical characteristics of the used IKONOS scene. A full resolution part of the subscene is shown in fig. 1. The subscene size is 13000 pixel by 11000 pixel and the ground resolution is 1.0 meter. The circular error (CE90) of this IKONOS product type is about 12.0 m.

Table 1
Characteristics of IKONOS image

Item	IKONOS scene
Date of acquisition	01-10-2001
Sensor azimuth	353.3126°
Sensor elevation	60.92489°
Sun angle azimuth	166.9543°
Sun angle elevation	40.07225°
Radiometric resolution	11 bit
Geometric resolution	1.0 meter
Map projection	UTM- zone (19)
Datum	WGS 84
Resampling method	Cubic convolution
Dimensions	13884 *19852 pixel

Fig. 1. A full resolution part of the study area.

The ground coordinates of control and check points were derived from Digital Topographic Data Bases (DTDB) provided by Service New Brunswick (SNB). These databases contain vector maps and Digital Terrain Models (DTMs) for New Brunswick. They are produced in 1996 based on New Brunswick double stereographic projection and ATS77 reference ellipsoid. SNB has stated that the planimetric and altimetric accuracy of the DTDB is 2.5 m expressed as root mean square error of point coordinates. ArcView GIS software version 3.0 was used to transform the original reference databases to Universal Transverse Mercator (UTM) and WGS84 reference ellipsoid. Coordinates of the ground points were then extracted from the transformed DTDB files.

3.2. Results and analysis

In this study the third-order and second-order rational polynomial models were used to geometrically correct the IKONOS image. The third-order RPM requires 39 GCPs to solve for the RPCs while the minimum number of GCPs required for the second-order RPM is 19 points. The three dimensional coordinates of 60 GCPs were collected from the transformed DTDB (vector maps and DTMs). The GCPs were selected so that they are well distributed and spaced uniformly throughout the study area. The projection system of the coordinates is Universal Transverse Mercator (UTM) and the reference ellipsoid is WGS84.

For both orders of RPM different numbers of GCPs were used starting at 60 points, and then the number was reduced 5 GCPs each time till the minimum required number for each order is reached.

To assess the accuracy of point positioning, the coordinates of an independent set of 15 check points were also collected from the transformed DTDB. The residuals between the computed and the collected coordinates of check points were determined. The accuracy is expressed as the root mean square error of the residuals in x, and y directions. Table 2 shows the RMS error and the maximum residuals of the calculations for the two RPM orders using different numbers of GCPs.

The National Map Accuracy Standards (NMAS) has stated the planimetric accuracy requirements for a certain map scale as follows:

RMS (P) = 0.3 mm * scale factor.

This means that a root mean square error of planimetric coordinates equals to 1.5 meter must be realized for the production of maps scale 1:5000. In table 2 column 4 the obtained RMS(P) using the third-order RPM is generally less than 1.5 m. In column 9 where the second-order RPM and 25 GCPs (or more) were used the RMS(P) is also less than 1.5 m. Regarding these results, the suitability of IKONOS data for generating and updating maps of scale 1:5000 was realized.

From table 2 it can be easily noticed that the results obtained using third-order RPM are more accurate and stable with increased number of GCPs than those obtained using second-order RPM. This is due to that the third-order terms inherent in the third-order RPM can model and represent some distortions with high order components such as camera vibration, which could not be adequately represented by the second-order RPM.

Table 2
RMS error and maximum residuals of check points in meters

No. of GCPs	Third-order RPM					Second-order RPM				
	RMS of check points			Max. residuals		RMS of check points			Max. residuals	
	(*X*)	(*Y*)	(*P*)	(*X*)	(*Y*)	(*X*)	(*Y*)	(*P*)	(*X*)	(*Y*)
60	0.58	0.79	0.98	1.33	1.51	0.96	0.92	1.33	2.63	1.65
55	0.58	0.78	0.97	1.36	1.53	0.94	0.88	1.29	2.61	1.61
50	0.62	0.86	1.06	1.60	1.94	0.90	0.86	1.24	2.37	1.54
45	0.73	0.75	1.05	1.24	1.53	0.86	0.80	1.17	2.06	1.41
40	0.71	0.78	1.05	1.24	1.67	0.76	0.87	1.16	1.60	1.87
39	0.75	0.79	1.09	1.23	1.55	0.76	0.89	1.17	1.56	1.83
35						0.85	0.93	1.26	1.49	1.86
30						0.87	0.91	1.26	1.52	1.78
25						0.98	1.01	1.41	1.57	1.85
20						1.21	1.10	1.64	1.92	2.08
19						1.30	1.44	1.94	2.32	3.28

The graphical presentation of the results in fig. 2 indicated that, in case of using the second-order RPM, the planimetric accuracy passes through three stages with increasing the number of GCPs. In the first stage increasing the number of GCPs from 19 points to 30 points resulted in a significant improvements in the obtained accuracy. The second stage from 30 to 40 GCPs, the improvements are marginal and the geo-positioning accuracy is considerably stable. In the third stage increasing the number of GCPs from 40 to 60 points resulted in a slight deterioration in the obtained accuracy. This can be attributed to artificial errors introduced to the ground coordinates due to using too many GCPs.

3.3. Efficiency of orthoimage production

As a final stage of this study, an orthoimage of the study area was generated using the third-order RPM (created with 39 GCPs) and the transformed DTM. Overlaying the vector map (DTDB) on the created orthoimage has indicated an excellent consistence. For numerical assessment of the planimetric accuracy of the created orthoimage, a comparison between the coordinates of 20 points extracted from the orthoimage, and the coordinates of the same points extracted from the reference DTDB was performed. The RMS errors of the residuals were found to be 0.96 m, and 1.08 m in x, and y directions respectively, which means that, the planimetric accuracy of the orthoimage created from IKONOS panchromatic data expressed by a RMS error of the residuals is 1.45 m.

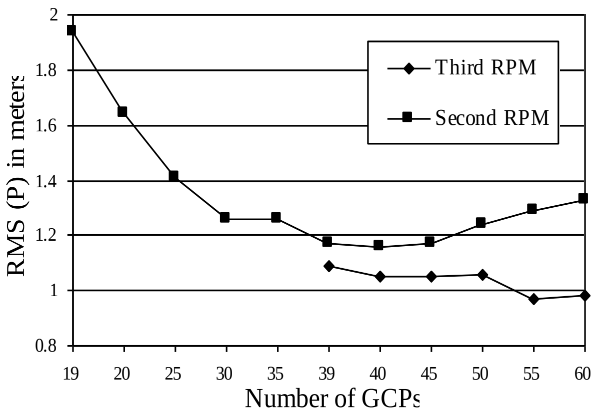

Fig. 2. RMS (P) using different numbers of GCPs.

4. Conclusions

Implementation of Rational Polynomial Model (RPM) for IKONOS images has demonstrated a very high potential for mapping applications. Comparing with the National Map Accuracy Standards (NMAS), which specify a planimetric RMS error of 1.5 meter for maps of scale 1:5000, the production and revision for these maps is feasible using IKONOS panchromatic images.

Regarding the order of the polynomial it was found that, the third-order model has provided more accurate and stable results than the second-order model. This is due to the more suitability of the third-order terms involved in the third-order RPM to accurately model different types of distortions.

The most appropriate number of GCPs to be used with second-order RPM should lie between 30 and 40 points. The geometric accuracy proved to be stable within this range. Moreover, using more than 40 GCPs may introduce artificial errors to ground coordinates which consequently reduce the point-positioning accuracy.

Acknowledgements

The author wishes to thank professor Yun Zhang and the Department of Geodesy and Geaomatics, University of New Brunswick, Canada for providing advise, assistance, and tools used in this study, including labs, hardware, data, and software.

The author also feels indebted to the Egyptian Missions Department and Tanta University for financing his research grant in Canada in summer 2005.

References

[1] Grodecki Jacek and Gene Dial, "IKONOS Geometric Accuracy Validation", Pecora 15/ Land Satellite Information IV / ISPRS Commission I /FIEOS conference Proceedings (2002).

[2] Toutin Thierry and Philip Cheng, "Demystification of IKONOS", Earth Observation Magazine, Vol. 9 (7) pp. 17-21 (2000).

[3] Grodecki Jacek and Gene Dial, "Block Adjustment of High Resolution Satellite Images Described by Rational Polynomials", Photogrammetric Engineering and Remote Sensing, Vol. 69 (1) pp. 59-68 (2003).
[4] Dial Gene and Jacek Grodecki, "Application of IKONOS Imagery", Proceedings of ASPRS Annual Convention, 2003, Anchorage, Alaska, (2003).
[5] R.G. Amato, D. Dardanelli, V. Emmolo, M. Franco, P. Lo Brutto, P. Midulla, B. Orlando, Villa, "Digital Orthophotos at Scale of 1:5000 from High Resolution Satellite Images", Proceedings of XXth ISPRS Congress, 2004, Istanbol, Turkey, commission IV, WG IV/7 pp. 12-23 (2004).
[6] Kalchang Di, Ma Ruijin, Li Rongxing, "Geometric Processing of IKONOS Stereo Imagery for Coastal Mapping Applications", Photogrammetric Engineering and Remote Sensing, Vol. 69 (8) pp. 873-879 (2003).
[7] S. Fraser, B. Clive and Harry Hanley, "Bias Compensation in Rational Functios for IKONOS Satellite Imagery", Photogrammetric Engineering and Remote Sensing, Vol. 69 (1) pp. 53-57 (2003).
[8] R. Passini K. and Jacobsen, "Accuracy Analysis of Digital Orthophotos from Very High Resolution Imagery", Proceedings of XXth ISPRS Congress, July 2004, Istanbol, Turkey, commission IV, WG IV/7 pp. 12-23 (2004).
[9] NIMA (National Imaging and Mapping Agency), "The Compendium of Controlled Extensions (CE) for The National Imagery Transmission Format (NITF)", version 2.1,www.ismc.nima.mil/ntb/superceded/STDI0002_v2.1 (2000).
[10] Kalchang Di, Ma Ruijin, Li Rongxing, " Rational Functions and Potential for Rigorous Sensor Model Recovery", Photogrammetric Engineering and Remote Sensing, Vol. 69 (1) pp. 33-41, (2003).
[11] C.V. Tao, and Y. Hu, "A Comprehensive Study of The Rational Function Model for Photogrammetric Processing", Photogrammetric Engineering and Remote Sensing, Vol. 67 (12) pp. 1347-1357 (2001).

Received October 30, 2005
Accepted November 30, 2005