Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (39) No. (3) july, 2017

Potential of Mapping from GeoEye Imagery

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ملخَّص:

إن التطورات التقنية الموجودة حالياً للقوة التحليلية الفراغية لصور الأقمار الصناعية فتحت أفاقاً جديدة في المساحة الكارتوجرافية من الفضاء, ويمدنا القمر الصناعي "جيو آي" GeoEye بصور لها قوة تحليلية أرضية تساوي 0,41 متر. ومن مميزات هذه الصور ايضا القوة التحليلية الطيفية والقدرة على اكتساب بيانات لنفس المنطقة وعلى فترات زمنية قصيرة مما جعلها مناسبة للتطبيقات الخاصه بإنتاج الخرائط. ويستخدم نموذج كثيرة الحدود النسبي لتمثيل العلاقة بين احداثيات الصورة والاحداثيات الارضية, وتهدف هذه الدراسة الى تقييم دقة الأحداثيات الأرضية المستنبطة من صورة "جيو آي", وكذلك عمل مقارنة بين الدرجة الثالثة والثانية والأولى لنموذج كثيرة الحدود النسبي باستخدام أعداد مختلفة من نقط الربط الأرضي. كما يهدف البحث الى إجراء تطبيق لإنتاج الصور المعدلة ortho images من صور "جيو آي" وتحديد الدقة البلانيمترية لها, ولإجراء هذة الدراسة تم استخدام صورة تغطي مدينة طنطا بمحافظة الغربية في مصر. وقد أظهرت النتائج فاعلية صور القمر الصناعي "جيو آي" لإنتاج وتحديث الخرائط الطبوغرافية بمقياس 1 : 5000 وكذلك تحليل مزايا إستخدام نموذج كثيرة الحدود النسبي من الدرجة الثالثة عن الدرجة الثانية والأولى وتوضيح سلوك درجات النموذج نتيجة استخدام أعداد مختلفة من نقط الربط الأرضي.

ABSTRACT

Technological developments in spatial resolution of remotely sensed data have opened new important perspectives regarding space cartography. GeoEye satellite has provided the world with high spatial resolution 0.41-m panchromatic images. Not only the high spatial resolution, but also the high spectral, radiometric and temporal resolutions of GeoEye 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 GeoEye.

The purpose of this study is to evaluate the point positioning accuracy of GeoEye imagery and to compare the performance of third, second and first orders of RPM using different numbers of Ground Control Points (GCPs). The potential of using GeoEye panchromatic images for generating ortho images of large scale has been also investigated. In this study, an GeoEye panchromatic image covering the city of Tanta, El Gharbia, Egypt was used. Processing steps were executed using PCI Geomatica version 10.3 OrthoEngine module. The results indicated that using third-order RPM and well-distributed number of GCPs the geometric accuracy of GeoEye images is less than 1.5 m, which is compatible for producing and updating topographic maps of scale 1:5,000.

Keywords: *High resolution imagery, Geometric accuracy, GeoEye panchromatic images, Rational polynomial model, Orthoimages*.

1. Introduction

Since its launch in April 2008, GeoEye satellite has been consistently providing high-resolution satellite images with 0.41-meter in panchromatic mode and 1.65-meter in multispectral mode. The off-nadir viewing capability is also an important characteristic of GeoEye since it improves the revisit rate is three days or less, depending on the required look angle 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 GeoEye 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 GeoEye 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 GeoEye 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 GeoEye imagery, for example [3, 4]. 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.

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

In this study, RPM was applied as an empirical model to geometrically correct a GeoEye image covering the city of Tanta, El Gharbia, Egypt. 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 10.3 from Geomatica, Ottawa, Canada.

2. Mathematical model

To geometrically correct GeoEye 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 GeoEye images. Therefore it is not possible to apply the physical reality model for the geo correction process. Instead, 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 [5].

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:

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

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. 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 [6].

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:

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

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:

$$i = \frac{(1XYZ \ldots YZ^2Z^3)(a_0a_1a_2a_3 \ldots\ldots a_{18}a_{19})^T}{(1XYZ \ldots YZ^2Z^3)(1b_1b_2b_3 \ldots\ldots b_{18}b_{19})^T}, \quad (3)$$

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

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 [7, 8].

$$i = \frac{(1XYZ \ldots YZ\,Z^2)(a_0a_1a_2a_3 \ldots\ldots a_8a_9)^T}{(1XYZ \ldots YZ\,Z^2)(1b_1b_2b_3 \ldots\ldots b_8b_9)^T}, \quad (5)$$

$$J = \frac{(1XYZ \ldots YZ\,Z^2)(c_0c_1c_2c_3 \ldots\ldots c_8c_9)^T}{(1XYZ \ldots YZ\,Z^2)(1d_1d_2d_3 \ldots\ldots d_8d_9)^T}, \quad (6)$$

For the first-order RPM the number of the RPCs is 7: four in the numerator and three and the constant one in the denominator as shown in eqs. (7) and (8). In such a case, 7 GCPs at least are required to determine the RPCs [7, 8].

$$i = \frac{(1XYZ \ldots YZ\,)(a_0a_1a_2a_3 \ldots\ldots a_6a_7)^T}{(1XYZ \ldots YZ\,)(1b_1b_2b_3 \ldots\ldots b_6b_7)^T}, \quad (7)$$

$$J = \frac{(1XYZ \ldots YZ\,)(c_0c_1c_2c_3 \ldots\ldots c_6c_7)^T}{(1XYZ \ldots YZ\,)(1d_1d_2d_3 \ldots\ldots d_6d_7)^T}, \quad (8)$$

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 test site covers the city of Tanta, El Gharbia, Egypt. It is approximately 7.5 km^2 (2.5 km east west direction and 3 km north south direction). Extensive urban features, heavy traffic network and residential buildings are found in the study area.

A subscene covering the study area was cut out from a panchromatic GeoEye image acquired on September, 2012. Table 1 summarizes the technical characteristics of the used GeoEye scene. The full resolution subscene is shown in fig. 1. The subscene size is 4844 pixels by 5916 pixels and the ground resolution is 0.41 meter. The circular error (CE90) of this GeoEye product type is about 12.0 m.

Table 1. Characteristics of GeoEye image.

Item	GeoEye scene
Date of acquisition	5-9-2012
Sensor azimuth	357.3406 degrees
Sensor elevation	61.97565 degrees
Sun angle azimuth	126.0481 degrees
Sun angle elevation	69.80911 degrees
Radiometric resolution	11 bit
Geometric resolution	0.41 meters
Map projection	UTM – zone (36)
Datum	WGS 84
Resampling method	Cubic convolution
Dimensions	4844 *5916 pixel

The ground coordinates of control and check points were derived from digital topographic map of scale 1: 5000, produced by the Egyptian General Survey Authority (EGSA). The planimetric coordinates (X and Y) for ground and check points were taken from this digital map

Fig.1.The full resolution subscene.

3.2. Results and analysis

In this study the third-order, second order and first order rational polynomial models were used to geometrically correct the GeoEye 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 and for the first order RPM is 7 points. The three dimensional coordinates of 45 GCPs were collected from the digital map. 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 the three orders of RPM different numbers of GCPs were used starting at 45 points, and then the number was reduced till the minimum required number for each order is reached.

To assess the accuracy of point positioning, the coordinates of an independent set of 12 check points were also collected from the digital map. 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 three 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:

$$\textbf{RMS (P) = 0.3 mm * scale factor}$$

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 table 2 column 9 the obtained RMS(P) using the second-order RPM is generally less than 1.5 m. In table 2 column 14 the obtained RMS(P) using the first-order RPM is generally less than 1.5 m. Regarding these results, the suitability of GeoEye data for generating and updating maps of scale 1:5000 was realized.

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

No. of GCPs	3rd order RPM					2nd order RPM					1st order RPM				
	RMS of ch. Points			Max. res.		RMS of ch. points			Max. res.		RMS of ch. Points			Max. res.	
	(X)	(Y)	(P)	(X)	(Y)	(X)	(Y)	(P)	(X)	(Y)	(X)	(Y)	(P)	(X)	(Y)
45	0.72	0.81	1.08	1.25	1.50	0.75	0.89	1.16	1.54	1.25	0.79	0.93	1.22	1.41	1.45
44	0.72	0.81	1.08	1.25	1.56	0.73	0.89	1.15	1.25	1.37	0.81	0.91	1.22	1.21	1.54
42	0.72	0.82	1.09	1.27	1.49	0.76	0.86	1.15	1.55	1.25	0.80	0.92	1.22	1.17	1.43
40	0.74	0.81	1.10	1.33	1.52	0.77	0.86	1.15	1.57	1.12	0.81	0.91	1.22	1.41	1.38
39	0.66	0.87	1.09	1.34	1.51	0.69	0.90	1.13	1.54	1.40	0.79	0.93	1.22	1.40	1.51
38						0.69	0.91	1.14	1.54	1.44	0.80	0.93	1.23	1.40	1.54
36						0.70	0.91	1.15	1.49	1.46	0.83	0.94	1.25	1.22	1.56
34						0.71	0.91	1.15	1.45	1.54	0.84	0.96	1.28	1.36	1.34
32						0.73	0.89	1.15	1.24	1.77	0.88	0.92	1.27	1.45	1.16
30						0.69	0.86	1.18	1.49	1.60	0.86	0.97	1.30	1.37	1.53
28						0.68	0.98	1.19	1.55	1.98	0.87	0.98	1.31	1.30	1.49
26						0.70	0.96	1.19	1.28	1.59	0.88	0.98	1.32	1.43	1.56
24						0.72	0.96	1.20	1.52	2.06	0.90	1.00	1.35	1.38	1.84
22						0.70	1.04	1.25	1.74	1.55	0.89	1.04	1.37	1.67	1.44
20						0.74	1.06	1.29	1.32	2.27	0.90	1.03	1.37	1.54	2.21
19						0.74	1.05	1.28	1.57	1.82	0.81	1.05	1.33	1.62	1.47
18											0.82	1.06	1.34	1.62	1.40
16											0.83	1.02	1.32	1.51	1.98
14											0.83	1.00	1.30	1.75	1.52
12											0.89	0.98	1.32	1.49	1.83
10											0.88	0.94	1.29	1.88	1.91
7											0.87	0.94	1.28	1.86	1.89

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 and first-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.

The graphical presentation of the results in fig. 2 indicatedthat, 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 26 points resulted in a significant improvement in the obtained accuracy. The second stage from 26 to 39 GCPs, the improvements are marginal and the geo-positioning accuracy is considerably stable. In the third stage increasing the number of GCPs from 39 to 45 points resulted in a slight deterioration in the obtained accuracy. Andin case of using the first-order RPM, the planimetric accuracy is worst than using the second and the third RPM. And the improvement in planimetric accuracy results can be noticed from the first to the third degree.

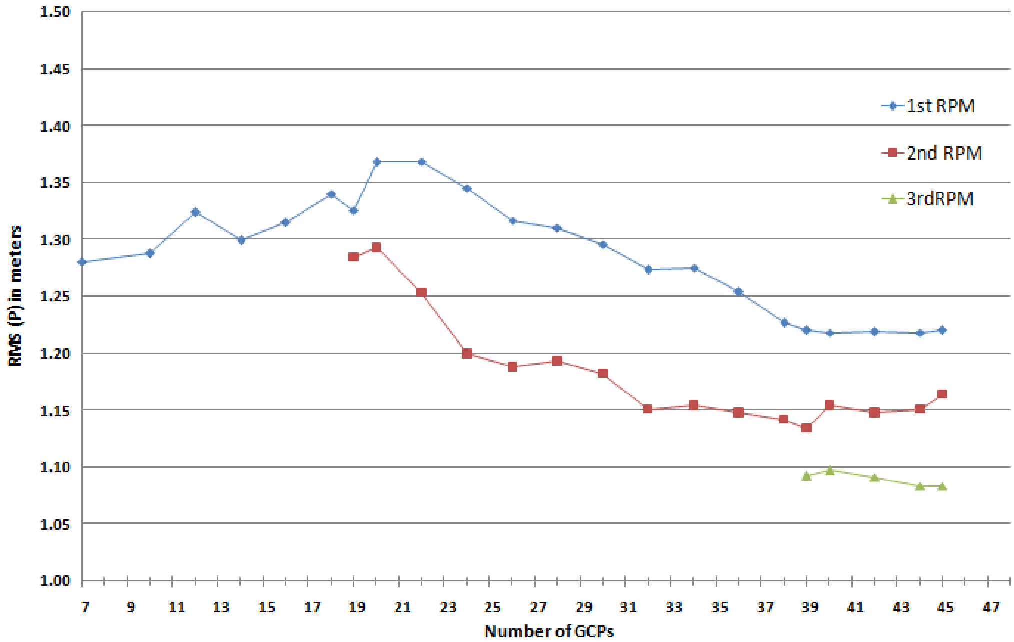

Fig. 2. RMS (P) of check points using different numbers of GCPs.

4. Conclusions

Implementation of Rational Polynomial Model (RPM) for GeoEye 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 GeoEye 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 and first-order models. 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 28 and 39 points and with first-order RPM should lie between 20 and 40 points. The geometric accuracy proved to be stable within this range. Moreover, using more than 38 GCPs with second-order RPM and 38 GCPs with first-order RPM may introduce artificial errors to ground coordinates which consequently reduce the point positioning accuracy.

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