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Geometric Modeling of Remotely Sensed Imagery Using a New Software Package (EMAN)

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ملخص:

يعد التصحيح الهندسي لصور الاستشعار عن بعد الصور خطوة ضرورية قبل استخدامها في تطبيقات الخرائط, وذلك لإزالة الأنواع المختلفة من التشوهات الهندسية الموجودة في تلك الصور. عادة ما تستخدم النماذج التجربية كبديل للنماذج الفزيائية لتمثيل العلاقة بين إحدثيات الصورة و الإحداثيات الأرضية. وقد تم إنشاء حزمة برمجية جديدة تعتمد على لغة الماتلاب للسماح بتنفيذ جميع النماذج التجريبية المتاحة لتحديد الدقة الهندسية لصور القمر الصناعي عالية الدقة. و تهدف هذه الدراسة هو تقييم البرنامج الجديد للتحقق من صلاحيته لإنشاء نموذج كثيرة الحدود النسبي لتصحيح الصور من خلال مقارنة النتائج التي تم الحصول عليها من EMAN مع تلك الناتجة من PCI Geomatica. و كذلك عمل مقارنة بين الدرجة الثالثة والثانية والأولى لنموذج كثيرة الحدود النسبي بإستخدام نقاط الربط الأرضية. ولإجراء هذه الدراسة تم إستخدام صورة القمر الصناعي ايكونوس تغطي مدينة فريدريكتون بولاية نيو برونزويك في كندا. و قد اظهرت النتائج صلاحية برنامج EMAN في اجراء التصحيح الهندسي للصورالرقمية للأقمار الصناعية لاستخدامها في تطبيقات الخرائط.

ABSTRACT

The geometric correction of remotely sensed imagery is an essential step before using them in mapping applications. Thus, to remove the different types of geometric distortions the images contain. The empirical models are traditionally employed, instead of the physical models, to describe the object-image geometry of remotely sensed images. A new software package has been developed based on MATLAB programming language to allow the implementation of all available empirical sensor models. The purpose of this paper is to examine and evaluate the new standalone software, which is called EMAN to check its validity for rectifying satellite images using Rational function models (RFMs). The results obtained using EMAN software was compared with those obtained using one of the most commonly used software commercially PCI from Geomatica, Canada. The purpose is extended to investigate the performance of third, second and first orders of RFM using different numbers of Ground Control Points (GCPs). An IKONOS panchromatic image covering the city of Fredericton, New Brunswick, Canada was used in this study. The results indicated that EMAN software is an effective standalone software that can be used to perform the geometric corrections for digital satellite image to be used in mapping application.

Keywords: Remotely sensed imagery, Geometric accuracy, IKONOS panchromatic images, Rational function model, Orthoimages

1. Introduction

Rapid changes in the ground and man activities require accurate and up to date spatial information in the shortest time and in the less expensive way. Therefore, the potentialities of remotely sensed imagery developed very fast in the last years. Nowadays commercial high-resolution satellite imagery offers the potential to extract useful and accurate spatial information for a wide variety of mapping and geographical information system (GIS) applications.

Remote sensing imagery contains several geometric distortions. The sources of these distortions can be grouped into two broad categories: the Observer or the acquisition system (platform, imaging sensor and other measuring instruments etc.) and the Observed (atmosphere and Earth) [1].

A geometric model is required to eliminate the image distortions resulting in a rectified image with metric features compatible with the mapping applications. A geometric model describes the geometric relationship between the object space and the image space, or vice versa. It relates 3D object coordinates to 2D image coordinates.

Physical models with the aid of ephemeris information can present the relationship between the image space and the ground space. Most high-resolution satellites, which have been recently launched, do not provide satellite ephemeris information to construct the physical sensor models. Alternatively, empirical models being independent of satellite ephemeris have to be used. In addition empirical models can be applied to different satellite sensors since they are time independent mathematical models. They are also independent of the sensor scanning system. Therefore, the expensive, most commonly used software packages utilize the empirical models to carry out the geometric corrections for remotely sensed images [2, 3, and 4].

This paper describes the main function of a new software called EMAN developed to perform the geometric correction for satellite images using all the available empirical models. Moreover, the performance of EMAN software was examined and evaluated against PCI image processing software from Geomatica, Canada. The effect of using different orders of RFMs on the obtained geometric accuracy was also investigated.

2. EMAN software package

EMAN is a new standalone software package that has been developed based on MATLAB programming language to allow the implementation of 36 empirical models for rectifying satellite images. These 36 empirical models can be categorized according to the following:

1. Model direction (forward models and inverse models)
2. Model type (rational function models, rational function models with equal denominators and polynomial models)
3. Model order (third order model, second order model and first order model)
4. Model dimensions (three dimensions model and two dimensions model).

EMAN software includes many tools to perform the different steps of rectification and orthoimage generation processes as follow:

1. Control points tool allows collecting control points from different sources such as manual entry, geocoded image or geocoded vectors.
2. Model selector allows selecting the model according to model directions, model dimension, model orders and model types.
3. Residuals tool displays ground control points (GCPs) residuals, GCPs root mean square errors (RMSEs), check points (CKPs) residuals and RMSEs.
4. Image transformation through which the geometrically corrected image is generated.

3. Mathematical model

The rational function model (RFM) is mathematically a generic form that can be used for many sensor models. RFM can perform in forward and inverse directions [5]. The forward RFM performs transformation from ground coordinates to image coordinates where the inverse RFM performs transformation from image coordinates to ground coordinates.

The forward RFM can be represented as the ratio of two polynomials, which describes the geometrical relationship between object space and image space as follows [6]:

$$p = \frac{F_1(X,Y,Z)}{F_2(X,Y,Z)} \tag{1}$$

$$p = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} a_{ijk} X^i Y^j Z^k \Bigg/ \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} c_{ijk} X^i Y^j Z^k \tag{2}$$

$$l = \frac{F_3(X,Y,Z)}{F_4(X,Y,Z)} \tag{3}$$

$$l = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} b_{ijk} X^i Y^j Z^k \Bigg/ \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} c_{ijk} X^i Y^j Z^k \tag{4}$$

Where,

(p,l) = The image coordinates.

(X,Y,Z) = The ground coordinates.

a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk} = The coefficients of each polynomial.

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 [7]. 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.

The inverse RFM can be expressed as the quotient of two polynomials, which is similar to forward RFM, but with change in the place of ground coordinates and image coordinates as follow [8]:

$$X = \frac{F_5(p,l,Z)}{F_6(p,l,Z)} \tag{5}$$

$$X = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} e_{ijk} p^i l^j Z^k \Bigg/ \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} g_{ijk} p^i l^j Z^k \tag{6}$$

$$Y = \frac{F_7(p,l,Z)}{F_8(p,l,Z)} \tag{7}$$

$$Y = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} f_{ijk} p^i l^j Z^k \Bigg/ \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} h_{ijk} p^i l^j Z^k \tag{8}$$

Where, e_{ijk}, f_{ijk}, g_{ijk}, h_{ijk} are the polynomial coefficients.

In the third order inverse RFM, each polynomial has the form:

$$\begin{aligned} F(p,l,Z) = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} e_{ijk} p^i l^j Z^k &= e_0 + e_1 p + e_2 l + e_3 Z + e_4 p\, l + \\ e_5 pZ + e_6 l\, Z + e_7 p^2 + e_8 l^2 + e_9 Z^2 + e_{10} p\, l\, Z &+ e_{11} p^2 l + e_{12} p^2 Z + \\ e_{13} l^2 p + e_{14} l^2 Z + e_{15} Z^2 p + e_{16} Z^2 l &+ e_{17} p^3 + e_{18} l^3 + e_{19} Z^3 \end{aligned} \tag{9}$$

Replacing equation (9) in equations (6) and (8) and eliminating the first coefficient in the denominator polynomial and putting the constant 1 instead, the third order inverse RFM form becomes [9]:

$$X = \frac{(1\ p\ \ l\ \ Z \ldots l^3 Z^3).(e_0 e_1 e_2 e_3 \ldots e_{18} e_{19})^T}{(1\ p\ \ l\ \ Z \ldots l^3 Z^3).(1 g_1 g_2 g_3 \ldots g_{18} g_{19})^T} \tag{10}$$

$$Y = \frac{(1\ p\ \ l\ \ Z \ldots l^3 Z^3).(f_0 f_1 f_2 f_3 \cdots f_{18} f_{19})^T}{(1\ p\ \ l\ \ Z \ldots l^3 Z^3).(1 h_1 h_2 h_3 \ldots h_{18} h_{19})^T} \tag{11}$$

There are 78 unknown coefficients in the third order inverse RFM. In other words, there are 39 unknown coefficients in each equation of the third order inverse RFM. In order to solve the third order RFM, at least 39 ground control points (GCPs) are required. The second order inverse RFM has 38 rational function coefficients (RFCs) and 19 RFCs in each equation as in equations (12) and (13). In such a case, 19 GCPs at least are required to determine the RFCs [9].

$$X = \frac{(1\ p\ \ l\ \ Z \ldots l^2 Z^2).(e_0 e_1 e_2 e_3 \ldots e_8 e_9)^T}{(1\ p\ \ l\ \ Z \ldots l^2 Z^2).(1 g_1 g_2 g_3 \cdots g_8 g_9)^T} \tag{12}$$

$$Y = \frac{(1\ p\ \ l\ \ Z \ldots l^2 Z^2).(f_0 f_1 f_2 f_3 \cdots f_8 f_9)^T}{(1\ p\ \ l\ \ Z \ldots l^2 Z^2).(1 h_1 h_2 h_3 \ldots h_8 h_9)^T} \tag{13}$$

The first order inverse RFM has 14 rational function coefficients and 7 RFCs in each equation as shown in equations (14) and (15). In such a case, 7 GCPs at least are required to determine the RFCs.

$$X = \frac{(1\ p\ \ l\ \ Z).(e_0 e_1 e_2 e_3)^T}{(1\ p\ \ l\ \ Z).(1 g_1 g_2 g_3)^T} \tag{14}$$

$$Y = \frac{(1\ p\ \ l\ \ Z).(f_0 f_1 f_2 f_3)^T}{(1\ p\ \ l\ \ Z).(1 h_1 h_2 h_3)^T} \tag{15}$$

4. Data sources

Fredericton test area covers a part of Fredericton, the capital of New Brunswick, Canada. Fredericton enjoys an amazing location on the banks of the Saint John River. Geographically Fredericton centered on 45°56′43″ N latitude and 66°39′56″W longitude. The altimetric variation of the study area is about 300 meters.

A subscene was cut out of a panchromatic IKONOS image acquired on October 01, 2001. The radiometric resolution of the subscene is 11 bit while the whole IKONOS image size is 13884 pixel by 19852 pixel. The subscene size is 6000 pixel by 6000 pixel with a ground resolution 1.0 meter. Figure (1) shows the IKONOS subscene of Fredericton study area. A Digital Topographic Data Bases (DTDB) available from Service New Brunswick (SNB) was used as a reference data.

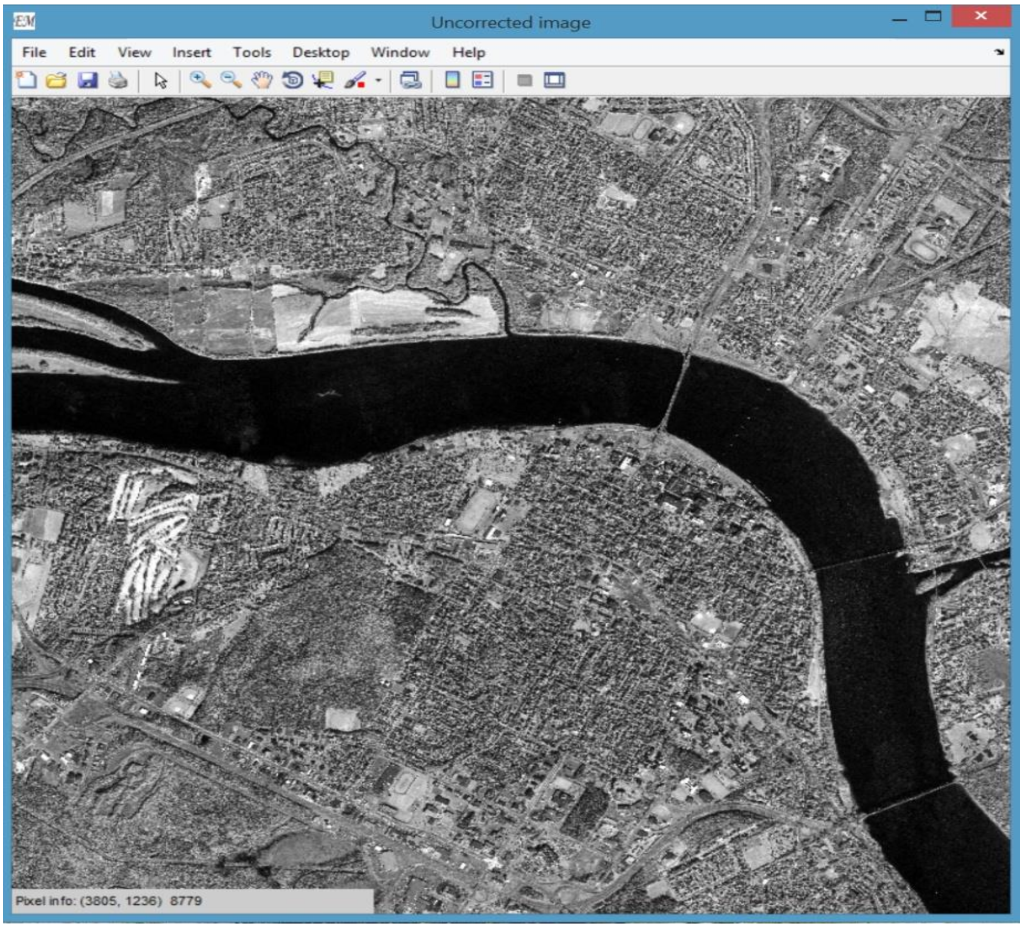

Figure (1): IKONOS subscene of Fredericton area

5. Results and analysis

In this study the RFMs were used to geometrically correct the IKONOS image. The third order RFM requires 39 GCPs to solve for the RFCs while the minimum number of GCPs required for the second order RFM is 19 points and for the first order RFM is 7 points.

All control points were collected by the aid of control points selection tool in EMAN software. The three dimensional coordinates of 63 control points were collected from Fredericton data set. Out of these 63 control points, 49 control points were chosen as GCPs for the determination of the model coefficients and the remaining 14 control points were used as check points (CKPs). 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 third, second and first order of RFM different numbers of GCPs were used starting at 49 points, and then the number was reduced till the minimum required number for each order is reached. Then these selected control points were entered to PCI Geomatica software to be ready for RFM computations and testing. The experiments were carried out using both EMAN and PCI softwares under the same conditions regarding the number, distribution and accuracy of the GCPs. Thus to enable the comparison of the obtained results of EMAN software with those resulted using PCI software.

The accuracy is expressed as the root mean square error (RMSE) of the residuals in X, and Y directions. The RMSE of CKPs in the inverse RFM can be derived by the following equations:

$$RMSE(X) = \sqrt{\frac{\sum_{i=1}^{n}(\Delta X_i)^2}{n-1}} \qquad RMSE(Y) = \sqrt{\frac{\sum_{i=1}^{n}(\Delta Y_i)^2}{n-1}}$$

$$RMSE(T) = \sqrt{\frac{\sum_{i=1}^{n}\left((\Delta X_i)^2 + (\Delta Y_i)^2\right)}{n-1}}$$

Where:

n = number of check control points

ΔX , ΔY = residual of ground coordinates of CKPs in X and Y direction

$RMSE(X)$ = root mean square error of CKPs in X direction

$RMSE(Y)$ = root mean square error of CKPs in Y direction

$RMSE(T)$ = total root mean square error of CKPs

Table (1) shows the RMSE of ground coordinates for 14 CKPs resulted using EMAN software for the three RFM orders using different numbers of GCPs. While table (2) shows the corresponding RMSE resulted using PCI software. The graphical representations of RMSE of CKPs resulted from using EMAN and PCI software packages versus the used number of GCPs were presented in figures (2), (3) and (4) for the third, second and first order RFM.

For the third order and second order RFM, the calculated RMSEs of check points due to using EMAN software is very close to those obtained using PCI software as shown in tables (1) and (3) and figures (2) and (3). For the first order RFM, the calculated RMSEs due to using the two software packages are almost similar as shown in figure (4).

From table (3) it is clear that the maximum difference of the planimetric RMSE between the corresponding results obtained using EMAN and PCI for the third order RFM is 0.02, for the second order is 0.018, and for the first order is 0.08. it is noticeable that although that maximum difference is reasonable (from 1% to 4%), it is usually occurs when using the minimum required number of GCPs as in the second order RFM or when using a large number of GCPs as in the first order RFM. this can be attributed to the very low or very high degree of redundancy

The previous analysis has proved the efficiency and capability of EMAN software to rectifying satellite images using RFMs with different orders. To investigate the effect of the rational function model orders on the accuracy of the resulted rectified image, the results obtained using only EMAN software was considered. Figure (5) shows the relationship between the RMSE of CKPs resulted using EMAN software and the used number of GCPs for the three RFM orders.

From the results in table (1) and figure (5), it can be noted that, the third order RFM gave the most accurate results since it provides the least RMSE of check points. It is followed by the second order, while the first order gave the least accuracy. This can be referred to that the higher the order of RFM the more types of distortions can be presented in the empirical models and consequently taken into account for correction.

Table (1): The RMSE of CKPs in meters from EMAN software

No. of GCPs	Third order RFM			Second order RFM			First order RFM		
	X	Y	T	X	Y	T	X	Y	T
49	0.78	1.17	1.40	1.36	1.11	1.76	1.12	1.87	2.18
45	0.80	1.12	1.38	1.01	1.13	1.52	1.24	1.75	2.14
40	0.73	1.03	1.26	0.96	1.03	1.40	1.45	1.63	2.18
39	0.74	1.05	1.28	0.98	1.04	1.42	1.46	1.57	2.14
35				1.01	1.07	1.47	1.38	1.60	2.11
30				2.03	1.06	2.29	1.34	1.58	2.07
25				1.96	1.51	2.48	1.35	1.59	2.09
20				2.88	2.79	4.01	1.19	1.53	1.94
19				2.88	3.26	4.35	1.21	1.52	1.94
15							1.14	1.70	2.05
10							2.05	1.76	2.70
7							2.99	1.64	3.40

Table (2): The RMSE of CKPs in meters from PCI software

No. of GCPs	Third order RFM			Second order RFM			First order RFM		
	X	Y	T	X	Y	T	X	Y	T
49	0.78	1.17	1.41	1.34	1.08	1.72	1.15	1.94	2.26
45	0.83	1.13	1.40	1.00	1.13	1.51	1.24	1.75	2.14
40	0.73	1.02	1.25	0.94	1.02	1.39	1.45	1.63	2.18
39	0.71	1.06	1.28	0.95	1.04	1.41	1.45	1.57	2.14
35				0.99	1.06	1.45	1.38	1.60	2.11
30				1.98	1.04	2.24	1.34	1.59	2.08
25				1.95	1.48	2.45	1.36	1.58	2.08
20				3.10	2.31	3.87	1.19	1.53	1.94
19				3.09	2.80	4.17	1.21	1.52	1.94
15							1.15	1.71	2.06
10							2.11	1.76	2.75
7							3.01	1.64	3.43

Table (3): The RMSE of CKPs in meters

No. of GCPs	Third order RFM		Second order RFM		First order RFM	
	T		T		T	
	EMAN	PCI	EMAN	PCI	EMAN	PCI
49	1.40	1.41	1.76	1.72	2.18	2.26
45	1.38	1.40	1.52	1.51	2.14	2.14
40	1.26	1.25	1.40	1.39	2.18	2.18
39	1.28	1.28	1.42	1.41	2.14	2.14
35			1.47	1.45	2.11	2.11
30			2.29	2.24	2.07	2.08
25			2.48	2.45	2.09	2.08
20			4.01	3.87	1.94	1.94
19			4.35	4.17	1.94	1.94
15					2.05	2.06
10					2.70	2.75
7					3.40	3.43

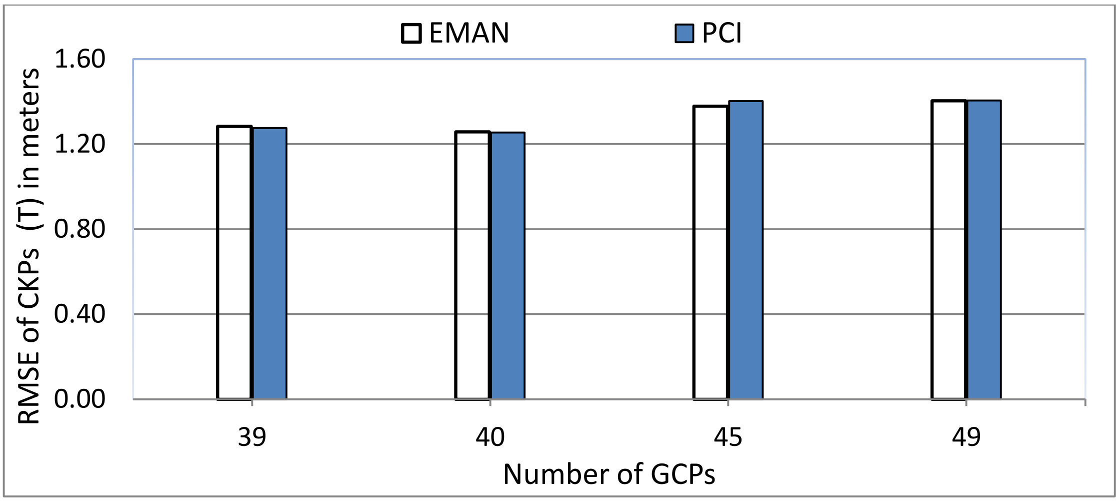

Figure (2): The RMSE of CKPs for third order RFM

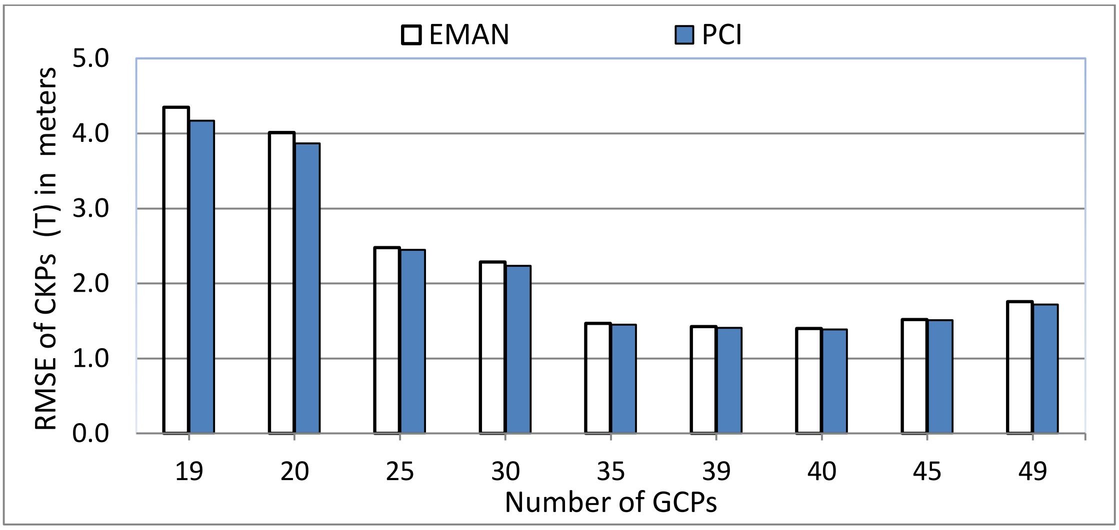

Figure (3): The RMSE of CKPs for second order RFM

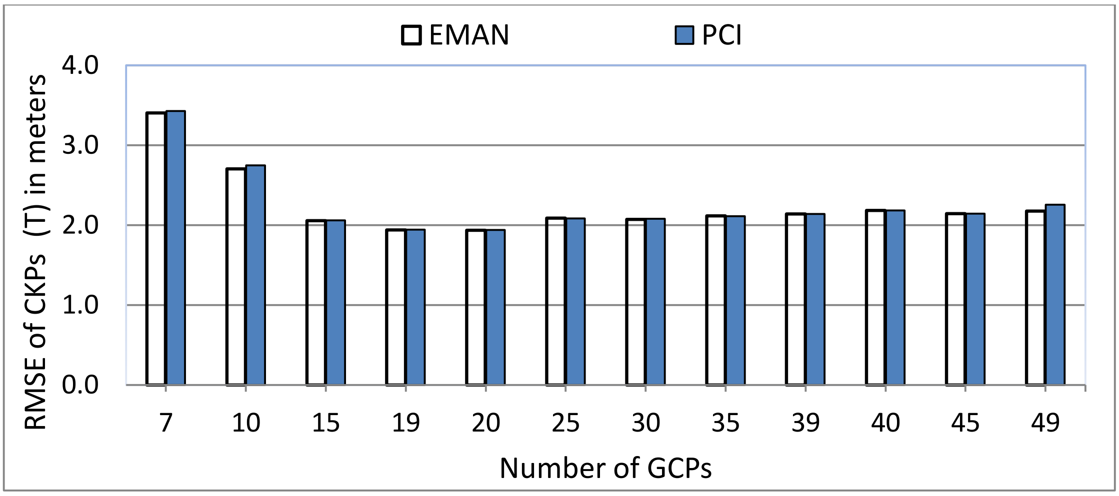

Figure (4): The RMSE of CKPs for first order RFM

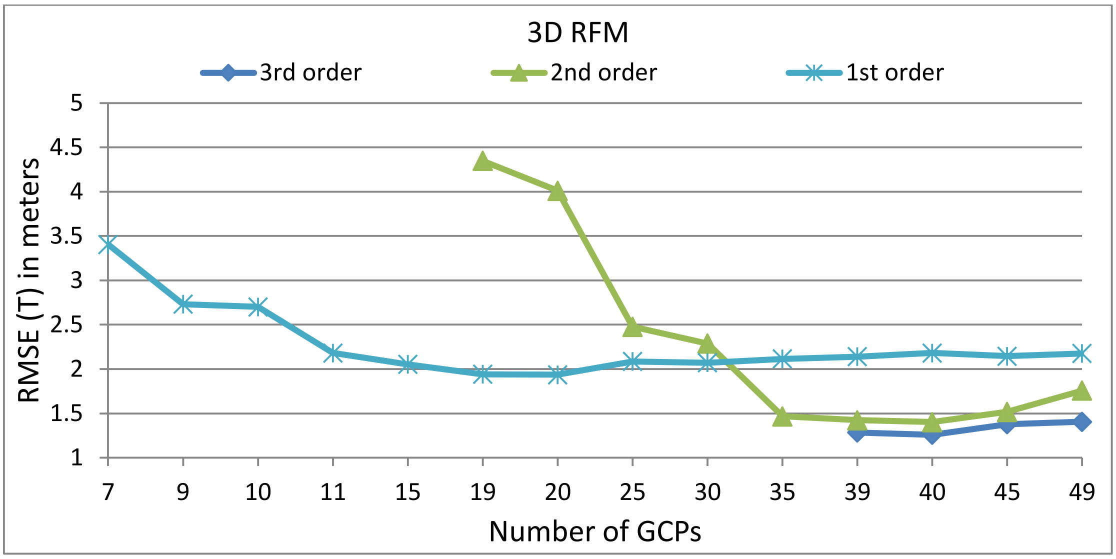

Figure (5): The RMSE of CKPs for three RFM orders at different numbers of GCPs

5. Conclusions

The standalone software package EMAN has proved its efficiency and capability to geometrically correct remotely sensed imagery using RFM where, in most cases of different RFM orders and different number of GCPs, the obtained RMSEs of CKPs using EMAN software are very close and comparable to those obtained using PCI software.

The maximum difference of the planimetric RMSE obtained using EMAN and PCI software for the corresponding experiments is at most less than 4% of RMSR (T) and in most cases ranges from 1% to 2% of the RMSR (T).

Regarding the order of the RFM, it was found that, the third order RFM has provided the superior stable accuracy rather than the second and first order models. This is due to the more suitability of the higher order terms involved in the third order RFM to accurately model different types of distortions.

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