The Automatic Extraction of DEM Using Modified RFM of IKONOS Stereo Imagery

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Abstract

The launch of extremely high-resolution sensor satellites has paved the way for many researchers to explore the potential gain in producing Digital Elevation Model (DEM) from stereo imagery. This paper deals with the issue of extracting DEM automatically from IKONOS stereo-pair of imagery using modified the Rational Function Model (RFM). Since high-resolution satellite imagery companies do not provide precise sensor information and orbit parameters for various reasons. Thus, the use of RFM as a generic sensor model has become an alternative to accurate sensor models. This model uses the Rational Polynomial Coefficients (RPCs) provided with the images describing the relationship between ground space and image space. However, the RPCs supplied by the vendors may not always represent well the true imaging process and this affects the accuracy of DEM. Therefore, RPCs modification is a better choice for obtaining DEM with reasonable accuracy.

The study was conducted on a stereo pair of IKONOS imagery over an area in the North of Khartoum (Sudan), covering about 30 sq-km. A well-distributed set of 12 ground points was selected over stereo images and then surveyed using Differential Global Positioning System (DGPS) static technique, these points are divided into control and checkpoints to assess the accuracy. DEM generation automatically depends on a series of processes within the Imagine Photogrammetry software package that were used in this research with the modified RFM.

The results of the experiment showed that the accuracy of extracting DEM by modifying RFM has a very good consistency and within a 2 m-level using a few Ground Control Points (GCPs). Finally, the results of this paper are mainly motivating for professionals from different disciplines who need to use a DEM for planning and transportation issues as well as using high-resolution stereo images to replace the traditional aerial photography in generating DEM, which limits the cost and time-consuming.

Keywords*: DEM, RFM, RPCs, GCPs, IKONOS, Imagine Photogrammetry Software*

1. Introduction

With the current growth in demand for high-resolution satellite imagery to derive high-accurate 3D information, it is first essential to identify the type of model used by that sensor. In general, there are physical sensor models and generic sensor models. Physical sensor models are more rigorous and provide better accuracy, but this information is not always available, especially for images from commercial satellites (e.g., IKONOS). Hence, the use of generic sensor models has become very common in the remote sensing community. A Rational Function Model (RFM) based on Rational Polynomial Coefficients (RPCs) is one of the common models used instead of rigorous models. The RPCs are typically provided by imagery vendors and were utilized for transformation from image to object space coordinates in a geographic reference system.

Because the orientation of the sensor is directly observed, there would be some systematic errors in the orientation parameters and this is also another problem besides the physical models. Therefore, there is a need to modify RPC to generate DEM using IKONOS. But it is difficult for end-users to create model parameters on their own because RFM has a lot of coefficients, so it is necessary to have a lot of GCPs to solve the sensor model's function. For these reasons, the research question revolves around how to update RPC with a few additional GCPs for generating DEM with high precision from IKONOS satellite imagery.

2. Methodology

2.1. Rational Function Model

The RFM is one of the generic models that uses a ratio of two polynomial functions to calculate the line (*l*) and sample (*s*) coordinates in the image, as recommended by Open GIS Consortium (OGC) (Kottman, 1999). The internal and external orientation parameters of the image can be obtained by solving the RFM if sufficient GCPs are available, expressed in equations (1) and (2) (Grodecki & Dial, 2003).

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

$$\begin{aligned} P(X,Y,Z) = {} & a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6YZ + a_7X^2 + a_8Y^2 + a_9Z^2 \\ & + a_{10}XYZ + a_{11}X^3 + a_{12}XY^2 + a_{13}XZ^2 + a_{14}X^2Y + a_{15}Y^3 + a_{16}YZ^2 \\ & + a_{17}X^2Z + a_{18}Y^2Z + a_{19}Z^3 \end{aligned} \tag{2}$$

Where *l* and *s* are the image coordinates, X, Y, and Z are the ground coordinates. P_1, P_2, P_3, and P_4 are the polynomial coefficients RPCs, normally a third-order polynomial with 20 coefficients for each function (Total of 80).

In many cases, a few GCPs are available, and the end-user wants to improve RPC parameters of IKONOS imagery for getting better quality. As such, two methods are tested and proposed for update IKONOS RPC with additional a few numbers of GCPs.

2.2. Adding Parameters to Image Space

This method proposes a first-order polynomial transformation that is defined in the image space to correct the bias, in which Δl and Δs are added to the original RFM for computing the differences between the nominal and the measured image coordinates, described in equations (3) and (4) (Fraser & Hanley, 2013). Correction parameters are estimated based on the availability of sufficient GCPs by applying the least-squares method through a prototype software developed by the author in a MATLAB environment. Equation (5) expresses the matrix form of observation equations with a minimum number of GCPs to solve the parameters.

$$l+\Delta l=\frac{\mathrm{P}_1\left(\mathrm{X_n},\mathrm{Y_n},\mathrm{Z_n}\right)}{\mathrm{P}_2\left(\mathrm{X_n},\mathrm{Y_n},\mathrm{Z_n}\right)} \qquad s+\Delta s=\frac{\mathrm{P}_3\left(\mathrm{X_n},\mathrm{Y_n},\mathrm{Z_n}\right)}{\mathrm{P}_4\left(\mathrm{X_n},\mathrm{Y_n},\mathrm{Z_n}\right)} \tag{3}$$

$$\begin{aligned}\Delta l&=A_0+A_1 l+A_2 s\\ \Delta s&=B_0+B_1 l+B_2 s\end{aligned} \tag{4}$$

$$\begin{bmatrix}1 & l_1 & s_1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & l_1 & s_1\\ 1 & l_2 & s_2 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & l_2 & s_2\\ 1 & l_3 & s_3 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & l_3 & s_3\end{bmatrix}\begin{bmatrix}A_0\\A_1\\A_2\\B_0\\B_1\\B_2\end{bmatrix}=\begin{bmatrix}\Delta l_1\\ \Delta s_1\\ \Delta l_2\\ \Delta s_2\\ \Delta l_3\\ \Delta s_3\end{bmatrix}+\begin{bmatrix}v_{l1}\\v_{s1}\\v_{l2}\\v_{s2}\\v_{l3}\\v_{s3}\end{bmatrix} \tag{5}$$

2.3. Adding Parameters to Object Space

In the second proposed method, a first-order polynomial transformation defined in the domain of object space was used to correct the ground coordinates derived from RPCs provided by satellite image vendors. The goal is to find out in which domain the bias compensation could achieve a better result using ground control information. Because there are known ground coordinates was observed by GPS, a set of equations can be established, as in equation (6) (Xiong & Zhang, 2013), to calculate the optimal estimates of transformation parameters by a least-squares approach. Next, the transformation parameters are used in computing the optimized coordinates of other points to assess the suitability of the model by calculating the Root Mean Square Error (RMSE) value based on the differences between coordinates of RFM derived and known in checkpoints.

$$
\begin{aligned}
X^{GPS} &= a_0 + a_1 X^{RFM} + a_2 Y^{RFM} + a_3 Z^{RFM} \\
Y^{GPS} &= b_0 + b_1 X^{RFM} + b_2 Y^{RFM} + b_3 Z^{RFM} \\
Z^{GPS} &= c_0 + c_1 X^{RFM} + c_2 Y^{RFM} + c_3 Z^{RFM}
\end{aligned} \tag{6}
$$

Where X^{GPS}, Y^{GPS}, Z^{GPS} are the observed ground coordinates; X^{RFM}, Y^{RFM}, Z^{RFM} are the ground coordinates derived from the RPCs; and a_i, b_i, c_i are the correction parameters.

3. Automatic DEM Generation

Many factors greatly affect the production of DEM from satellite imagery such as image resolution, availability of sensor parameters, number and distribution of GCPs, the topography of study area and final DEM application. Figure (1) shows the workflow of the DEM generation automatically. After pre-processing image quality, mathematical models are used to geo-reference of stereo images. In this study, a modified RFM was used for geo-referencing. It follows, creating epipolar images that reduce the time to find corresponding points in image matching. During the image matching, common points in the overlapped area of the stereo-pairs are identified and measured. Finally, the accuracy of the resulting DEM is evaluated by comparing the checkpoints of the DEM and checkpoints of the study.

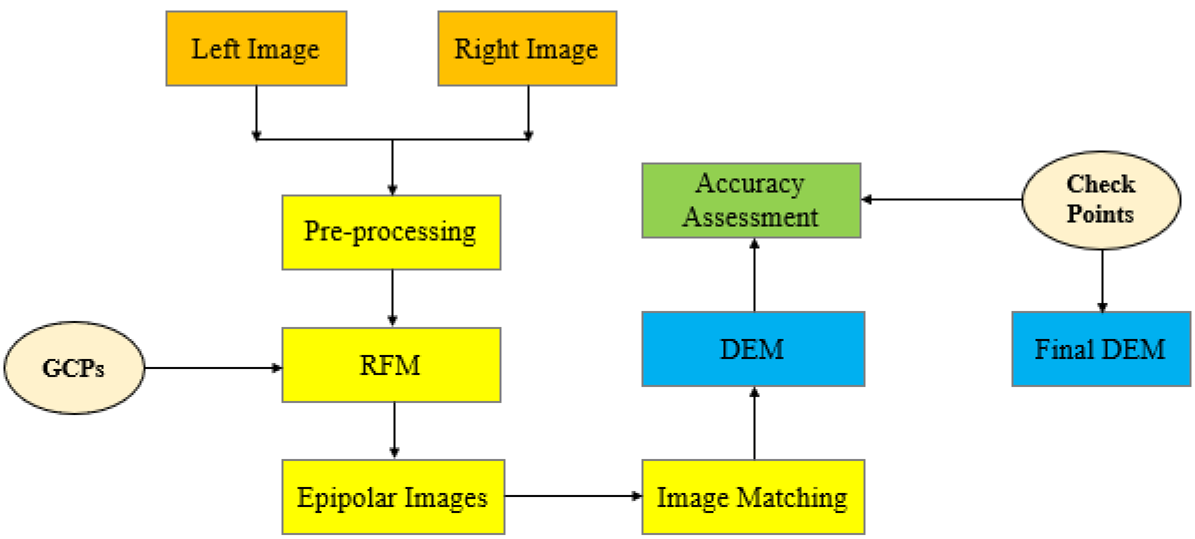

Figure (1) Procedure for automatic DEM generation.

4. Discussion and Conclusion

A maximum of 7 additional GCPs were used for testing the proposed methods while 5 checkpoints were used to verify the accuracy of the modified RFM solution. Each method was tested using the minimum allowable additional GCPs and then added one point at a time to solve the parameters. Result, Table (1) shows the possibility of improving RFM if an additional few numbers of GCPs are available. Accordingly, both were consistent with the results published by Space Imaging for Reference Stereo products which are 3.0 m horizontal accuracy and 6.4 m vertical accuracy (Grodecki & Dial, 2003). Regardless number of points used, the accuracy of the RPCs of IKONOS imagery can be improved 50% or more using these methods. At last, the DEM obtained from IKONOS stereo images using modified RFM, based on Imagine Photogrammetry commercial software. Figure (2) depicts a shaded relief of the Extracted DEM.

Table (1) Ground Coordinates Residuals at Check Points (Unit: meters): Using Adding Parameters to Image Space and Object Space.

No. of GCPs	Image space			Object space		
	RMSE					
	X	Y	Z	X	Y	Z
0	7.5	3.4	16.9	7.5	3.4	16.9
3	2.4	1.0	1.2	---	---	---
4	0.9	1.0	1.6	1.9	1.0	4.3
5	0.8	1.2	1.4	1.8	1.2	3.3
6	0.8	1.1	1.5	1.6	1.1	2.7
7	0.7	1.1	1.5	1.3	1.2	1.7

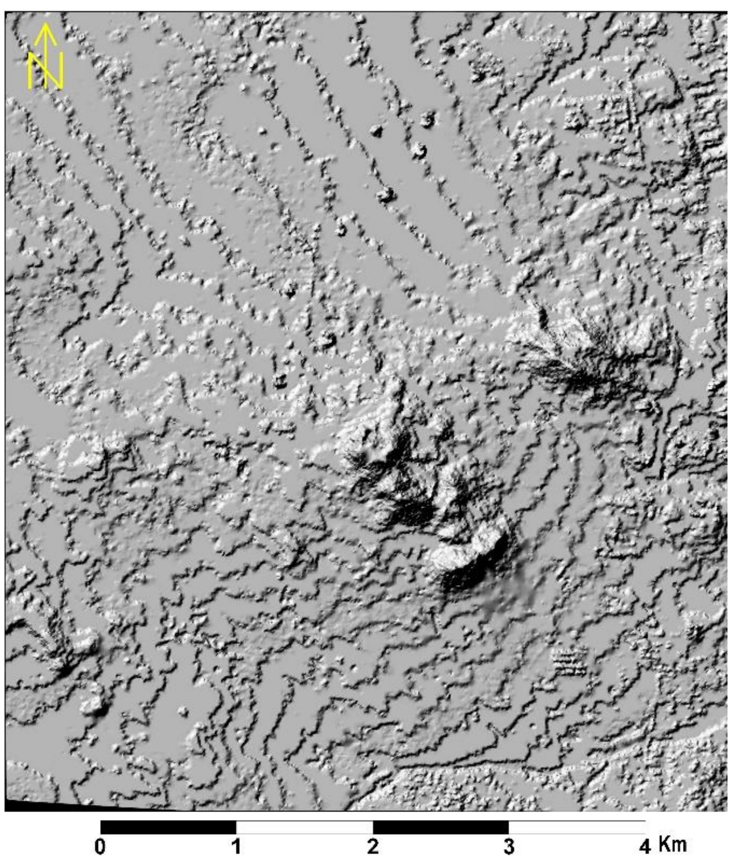

Figure (2) A shaded relief of the Extracted DEM by modified RFM.

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Tamer Saleh received the B.Sc. in surveying and geodesy from the Benha University, Engineering Shoubra, Egypt, in 2012; and the M.Sc. in photogrammetry and remote sensing from the University of Benha, Engineering Shoubra, Egypt, in 2018. He works as an assistant lecturer with the Banha University, Department of Surveying Engineering from 2012 to 2018. He is currently a PhD researcher at State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS), Wuhan University, China. His research interests include mathematical modeling of digital images and GNSS positioning, digital photogrammetry and computer vision, Feature Extraction and Change Detection, Artificial Intelligence and Deep Learning.