

# CAPABILITY ASSESSMENT OF HIGH RESOLUTION SATELLITE IMAGERY FOR 3D RECONSTRUCTION USING RPC PARAMETERS

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## ABSTRACT:

Connection of 2D image space coordinates of linear sensor array satellite data and 3D object space coordinates performs by RPC models. As these models are fast and accurate enough for the purposes of mapping such as image exploitation, 3D extraction and reconstruction and DEM generation and also the extraction of physical parameters from these models are difficult, so the vendors of satellite systems consider them as a replacement of physical sensor models and provide them to the users of image products and by this strategy, the information regarding physical sensor models can be hidden. The main disadvantage of these models is the lack of ground control and other image constraints to improve the accuracy of imagery described by RPC coefficients so that the ground controls which are reconstructed directly with the use of these models, do not satisfy the user's desired accuracies. In recent years, many practices for improvement and correction of RPC models have been investigated by different researchers. In this paper, these models are corrected by the aid of an adjustment model with parameters related to geometric properties of object space. This method is implemented to the RPC models of IRS-P5 stereo images and the 3D reconstruction of object space coordinates is fulfilled by using the modified model. The results confirm the high potential of the proposed method in correction of RPC parameters and 3D reconstruction of object space.

## 1. INTRODUCTION

Sensor models are required to establish the relation between the image space and object space. These models are used in 3D reconstruction of object space, ortho-rectification of images, DEM generation, 3D extraction, etc. these models are classified into two categories: physical and generalized sensor models. The choice of a sensor model depends on the required performance and accuracy and the availability of camera and control information (McGlone, 1996). By physical sensor models, the physical imaging geometry of sensors with respect to ground is reconstructed and the parameters of these models describe the position and orientation of sensors at the time of imaging. These models are rigorous and yield sub-pixel accuracies. In these models, parameters are uncorrelated and each parameter has a physical significance (Tao and Hu, 2001a).

Generic sensor models are independent of sensor platform and type. In a generic sensor model, the 3D relation between image space and object space is performed by some general function without modeling the physical imaging process. These models can be of several forms such as polynomials, rational functions, etc. Accuracy of general sensor models depend on the number and distribution of ground control points and no relation between the coefficients of these models exist and interior and exterior orientation parameters can be hardly discovered from them. These coefficients are independent of the geometry of imaging process. The vendors of high resolution satellite data have adopted the rational polynomial camera (RPC) as a replacement of physical sensor model and provide them with satellite images instead of physical sensor parameters to end users of photogrammetric processing for image exploitations

and 3D reconstruction. This strategy helps vendors to keep the information about their sensors confidential because it is difficult to derive the sensor parameters from the RPCs. However, it is not possible for end users to perform their own block adjustment with these parameters because the quality of results using this method only satisfy the desired accuracy in ground stations of satellite vendors (Tao and Hu, 2002).. For these limitations, many investigators have proposed methods to improve the capability of these models. In our research, one of these methods is implemented and evaluated. Here, we first implement and assess a correction method by applying an adjustment model to image space coordinates of RPC functional model and modifying the RPC parameters. After correction of RPC parameters, we then use these parameters for 3D reconstruction.

### 1.1 RPC Geometry

Vendors of high resolution satellites provide an image geometry model (IGM) in RPC format with ortho-kit and stereo image products. For this, images of a region altogether are block adjusted in a ground station and the RPC data are calculated to describe the relation of object space to image space. The ortho-kit images comprising a mono image taken from a high elevation angle and RPC data, can be orthorectified with a proper DEM (Dial and Grodecki, 2002).

The RPC model relates object to image space coordinates. Here, the object space coordinates are in the form of geodetic latitude, longitude and height where latitude and longitude are expressed in degrees, height is above the WGS-84 ellipsoid in meters and image space coordinates are in pixel (line and sample) unit.

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In RPC functional model, the coordinates should be first normalized by the normalizing parameters that are included in RPC data.

**1.2 Data Characteristics**

For the analysis of 3D reconstruction of object space using RPC models, a stereo model of IRS-P5 high resolution satellite and their relating RPC data of Arak are used. Before the reconstruction process, the bias and drift parameters of RPC model are first should be calculated and compensated using 3-4 control points on each image.

**1.2.1 IRS-P5 (CartoSAT-1) Satellite Data:** This Indian remote sensing satellite has been launched in 2005 into its polar orbit. This satellite has two panchromatic cameras that can be used in flight stereo viewing or wide swath mode acquisition (about 54 kilometers swath) (IRS-P5 Cartosat-1, 2007).

Some of the characteristics of this satellite are:

1. High spatial resolution (2.5 meters for each camera)
2. Extended image size (swath width of about 30 kms)
3. Tilt angle of 26 degrees for front and -5 degrees for after views
4. Ability of target positioning with high accuracy

General characteristics of this satellite are represented in Table 1.

Characteristic	PAN Fore Camera	PAN After Camera
Tilt Along Track	+26 deg	-5 deg
Spatial Resolution	2.5 m	2.5 m
Swath-width	30 km	27 km
Radiometric Resolution, Quantization	10 bit	10 bit
Spectral Coverage	500-850 nm	500-850 nm
Focal Length	1945 mm	1945 mm
CCD Arrays (no. of arrays × no. of elements)	1 × 12000	1 × 12000
CCD Size	7 μm × 7 μm	7 μm × 7 μm
Integration Time	0.336 ms	0.336 ms
Spatial Resolution	2.5 m	2.5 m

Table 1. General characteristics of IRS-P5 (CartoSAT-1) satellite

**2. RPC CORRECTION MODEL**

RPC parameters are a replacement of physical sensor models of the high resolution satellites. Users are able to perform terrain and feature extraction, ortho-rectification and 3D reconstruction by using these parameters. The only limitation of using these models is that the parameters directly relate to camera interior and exterior orientation parameters and the accuracy on reconstructed object coordinates by RPC parameters are below the needs of users. Because of this difficulty, many investigators have proposed methods to improve the capability of these models. (Dial and Grodecki, 2002) have added bias and drift terms to the a-priori rational functions to capture the discrepancies between the a-priori and the measured image space coordinates. (Tao and Hu, 2001b) have considered RPC parameters as initial estimates and then updated the initial

values by discrete Kalman filtering using new control information and (Fraser, 2004) has proposed and evaluated a bias correction approach for RPC rational functions.

In our paper, we implement a correction method by adding an adjustment model to the left side (image space coordinates) of RPC functional model and modifying the RPC parameters by the resulting corrections. The mathematical form of this concept is in the form of Equation 1:

$$\begin{aligned}
 x + \Delta x &= \frac{P_1(X, Y, Z)}{P_2(X, Y, Z)} \\
 y + \Delta y &= \frac{P_3(X, Y, Z)}{P_4(X, Y, Z)}
 \end{aligned}
 \tag{1}$$

where (X, Y, Z) = 3D coordinates of object space  
 (x, y) = corresponding image coordinates  
 Δx, Δy = correction terms

These correction terms are in the form of a shift parameter:

$$\begin{aligned}
 \Delta x &= a_0 \\
 \Delta y &= b_0
 \end{aligned}
 \tag{2}$$

where  $a_0, b_0$  = unknown coefficients of the adjustment model

This model is fast, simple and linear and the parameters has physical significance. Parameter  $a_0$  absorbs all in-track effects causing offsets in the line direction including in-track ephemeris, satellite pitch attitude, cross-array principal point and cross-array detector positions. Parameter  $b_0$  absorbs all cross-track effects causing offsets in the sample direction including cross-track ephemeris, satellite roll attitude, along array principal point and along array detector positions (Dial and Grodecki, 2002).

**3. 3D RECONSTRUCTION OF OBJECT SPACE**

The first step in reconstruction is the normalization of both image space and object space coordinates. The parameters of this normalization process are provided by high resolution satellite vendors. The coordinates of left and right images of a stereo-pair are usually normalized by different parameters and also the normalization parameters of object space are different for each image. Several methods for object space reconstruction using satellite images are evaluated by different researchers. (Tao and Hu, 2000) presented a non-linear least square method to reconstruction of object space by non-linear rational models. Accuracy assessment of RPC models as replacement of rigorous sensor models are provided by (Dowman and Dollof, 2000; Tao and Hu, 2001 a, b). 3D reconstruction based on rational models in digital photogrammetric systems is implemented by (Pederes et al, 1989; Greve et al, 1992; Madani, 1999). In (Yang, 2000) an iterative approach for 3D reconstruction by RPC models is presented. In this method, an inverse form of rational models in which the planimetric coordinates are functions of image coordinates and ground elevations is used to compute the object space coordinates. 3D

reconstruction by forward form of rational functions is evaluated by (Di et al, 2001; Tao and Hu, 2002). As the forward methods of reconstruction using RPC models result higher accuracies than inverse methods (Tao and Hu, 2002), in our research, this strategy of reconstruction is implemented.

**3.1 3D Reconstruction Based on Forward RPC Models**

The forward form of rational models used in 3D reconstruction is expressed in Equation 4 (Tao and Hu, 2002):

$$\begin{aligned}
 x_l &= \frac{P_{1l}(X, Y, Z)}{P_{2l}(X, Y, Z)} & \text{and} & & x_r &= \frac{P_{1r}(X, Y, Z)}{P_{2r}(X, Y, Z)} \\
 y_l &= \frac{P_{3l}(X, Y, Z)}{P_{4l}(X, Y, Z)} & & & y_r &= \frac{P_{3r}(X, Y, Z)}{P_{4r}(X, Y, Z)}
 \end{aligned}
 \tag{4}$$

where  $(x_l, y_l)$  = normalized coordinates in left image  
 $(x_r, y_r)$  = normalized points in right image

For linearization of Equation 4, the Taylor expansion of x, y coordinates towards the object space coordinates is always used. The matrix form of linearized equations is given in Equation 5.

$$\begin{bmatrix} v_{sl} \\ v_{yl} \\ v_{sr} \\ v_{yr} \end{bmatrix} = \begin{bmatrix} \partial x_l / \partial Z / Z_{sl} & \partial x_l / \partial Y / Y_{sl} & \partial x_l / \partial X / X_{sl} \\ \partial y_l / \partial Z / Z_{sl} & \partial y_l / \partial Y / Y_{sl} & \partial y_l / \partial X / X_{sl} \\ \partial x_r / \partial Z / Z_{sr} & \partial x_r / \partial Y / Y_{sr} & \partial x_r / \partial X / X_{sr} \\ \partial y_r / \partial Z / Z_{sr} & \partial y_r / \partial Y / Y_{sr} & \partial y_r / \partial X / X_{sr} \end{bmatrix} \begin{bmatrix} \Delta Z_u \\ \Delta Y_u \\ \Delta X_u \end{bmatrix} - \begin{bmatrix} x_l - \hat{x}_l \\ y_l - \hat{y}_l \\ x_r - \hat{x}_r \\ y_r - \hat{y}_r \end{bmatrix}
 \tag{5}$$

In above equation, the coordinates are normalized according to Equation 6:

$$X = \frac{X_u - X_o}{X_s}, \quad Y = \frac{Y_u - Y_o}{Y_s} \quad \text{and} \quad Z = \frac{Z_u - Z_o}{Z_s}
 \tag{6}$$

where  $(X_u, Y_u, Z_u)$  = object space coordinates before the normalization  
 $(X_o, Y_o, Z_o)$  = offset values for normalization

$(X_s, Y_s, Z_s)$  = scale values for normalization

These normalization parameters are also provided by satellite vendors. In Equation 5, the first order derivatives are calculated in the form of Equation 7:

$$\frac{\partial r}{\partial Z} = \frac{\partial P_1 / \partial Z \cdot P_2 - P_1 \cdot \partial P_2 / \partial Z}{P_2 \cdot P_2}
 \tag{7}$$

and the remaining derivatives are similarly calculated. The least square adjustment is presented in equation (8):

$$X = [\Delta Z_u \quad \Delta Y_u \quad \Delta X_u]^T = (A^T W A)^{-1} A^T W l
 \tag{8}$$

where W = weight matrix for the image points

The total reconstruction procedure that can be used to compute the object point coordinates from a pair of corresponding points, is summarized (Tao and Hu, 2002):

1. Determine the initial approximate values  $X_u, Y_u$  and  $Z_u$  using a DLT transformation made of RPC parameters
2. Calculate the correction terms by Equation 8 and add them to  $X_u, Y_u$  and  $Z_u$  in each iteration
3. Repeat step (2) until  $X_u, Y_u$  and  $Z_u$  converge or the specified number of iteration has been reached

**4. RESULTS AND EVALUATION OF RPC COEFFICIENT CORRECTIONS**

In this research, IRS-P5 high resolution satellite stereo data are used. The data contain stereo images, RPC parameters and normalization coefficients for all images and object coordinate points.

For each of the images, three to five control points are considered for bias estimation and the residuals and total RMSEs of check points are presented.

In Table 2 the maximum values of residuals and total RMSEs in both x and y directions before the RPC corrections are illustrated.

Table 3 illustrates the maximum residual values and total RMSEs on check points for each image after the RPC corrections using Equation 3.

Image	Maximum Residual (x)	Maximum Residual (y)	RMSE (x)	RMSE (y)
IRS-P5- Band A	63.96	13.53	61.94	10.36
IRS-P5- Band F	11.59	19.52	9.34	16.07

Table 2. Maximum residuals and total RMSE in x and y directions on IRS-P5 satellite images before the RPC corrections (unit: pixel)

Image	Maximum	Maximum	RMSE (x)	RMSE (y)
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	Residual (x)	Residual (y)	Residual (z)	Total RMSE
IRS-P5- Band A	0.94	1.06	0.55	0.58
IRS-P5- Band F	0.74	0.82	0.37	0.48

Table 3. Maximum residuals and total RMSE in x and y directions on utilized images after applying the correction terms of Equation 3 (unit: pixel)

The results impress that the bias compensated model is suitable for the correction of RPC models of the data set. Therefore, for 3D reconstruction of object points using RPC models, these corrected parameters are used. Figures 4 and 5 show the error

vectors of back projected check points on each of the four satellite images before and after the RPC corrections. These vectors are drawn with 100 times exaggeration.

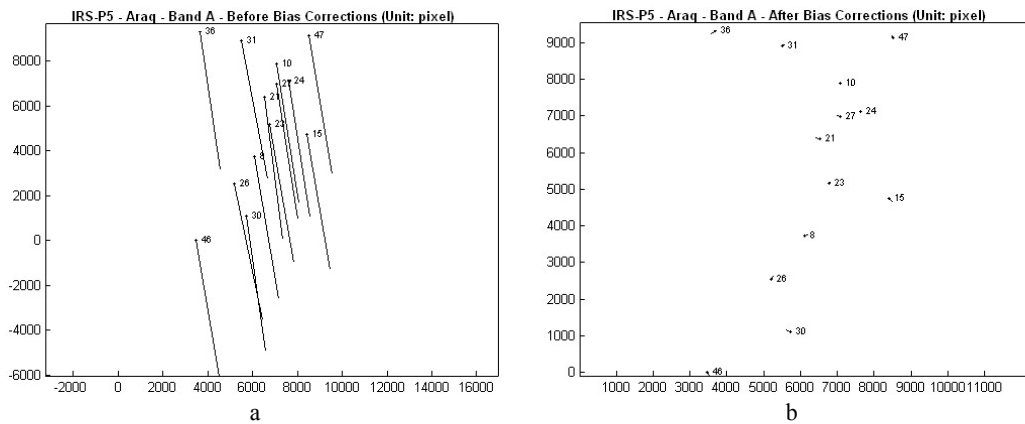


Figure 4. Error vectors of check points on IRS-P5 Band A image. a) before RPC corrections, b) after RPC corrections (exaggeration: 100 times)

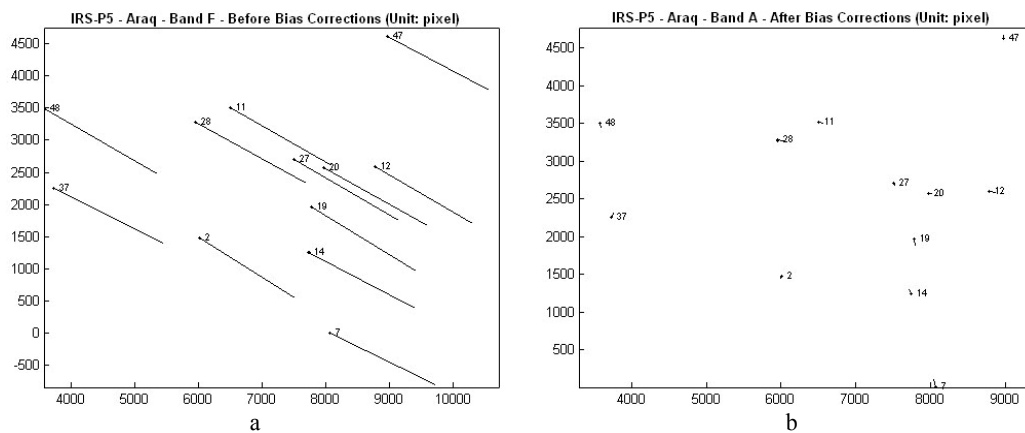


Figure 5. Error vectors of check points on IRS-P5 Band F image. a) before RPC corrections, b) after RPC corrections (exaggeration: 100 times)

### 5. RESULTS AND EVALUATION OF 3D RECONSTRUCTED POINTS OF OBJECT SPACE USING THE CORRECTED RPC MODELS

Referring to the results of RPC correction models of IRS-P5 stereo images, the corrected RPCs are used for 3D reconstruction. The reconstruction procedure is performed by the bias compensated RPC models on some carefully observed conjugate points in the overlapping area of the left and right images of IRS-P5 satellite and the accuracies of reconstructed points are provided in the form of RMSEs and maximum

residuals in X, Y and Z directions of object coordinate system (Table 6).

In Figure 7 the error vectors of reconstructed points using RPC parameters before and after the correction of RPC models with 100 times exaggeration are illustrated.

RPC Model	Maximum Residual (X)	Maximum Residual (Y)	Maximum Residual (Z)	RMSE (X)	RMSE (Y)	RMSE (Z)
Before Correction	95.701	14.883	33.265	89.888	8.663	24.204
Bias Corrected Model	3.396	2.868	3.102	1.498	1.252	1.562

Table 6. Maximum residuals and total RMSEs of reconstructed points in X, Y and Z directions on utilized images before the correction of RPC parameters (unit: meters)

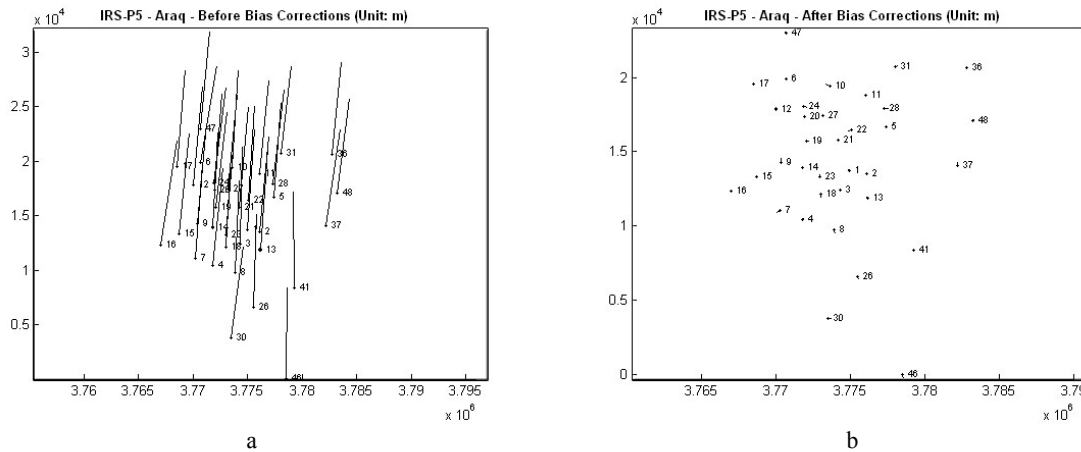


Figure 7. Error vectors of reconstructed points by IRS-P5 stereo images (Arak). a) before RPC corrections, b) after RPC corrections (exaggeration: 100 times)

## 6. CONCLUDING REMARKS

In this paper, a procedure of 3D reconstruction of object space using generic sensor model of high resolution satellite data was presented. The utilized generic model is the RPC functional model which is provided by satellite vendors. Before the reconstruction stage, the bias terms of RPC parameters should be compensated. In our investigation, we applied the shift parameters in image space of RPC functional model and the achieved results show that the bias corrected model provides acceptable results for the utilized model. The reconstruction was performed by the bias compensated RPC models of the IRS-P5 satellite stereo images.

The comparison of results of reconstructed points before and after the RPC correction confirm the high potential of the utilized method for 3D reconstruction of object points using high resolution satellite imagery based on RPC rational function models.

We believe that this method of reconstruction that handle RPC parameters for different high resolution sensors can be used to develop a software package (for example Softcopy) – if the RPC coefficients and normalization parameters are provided – for mapping purposes. For example if a high resolution satellite image with a set of RPC parameters were available, users will be able to perform the photogrammetric processing tasks without knowing the physical sensor models.

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