



Assessment of geometric correction of remote sensing satellite images using RPC versus GCP

Original Article

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Abstract

Geometric distortions are common problems when dealing with remote sensing satellite images. Therefore, geometric correction is a necessary process for preparing remote sensing satellite images for many applications. Physical sensor model is formed by integrating the geometry of imaging sensor and positioning sensors as GPS and star trackers with system calibration parameters. Physical sensor model is not available in common but a Rational Polynomial Coefficient (RPC) model is provided as an alternative representation of sensor model. The RPC model is used for geometric correction of satellite image to get the spatial data of image features. The accuracy of the resultant image depends on the accuracy of RPC model which is not known as common. The research objective is to assess the accuracy of geometric correction of the satellite image using RPC model versus geometric correction using Ground Control Points (GCPs), along with their effect on the final accuracy of the output spatial features. The available data is IKONOS-2 image with its RPC file and seven GCPs with high accuracy obtained from ground survey for the study area. The input image is corrected using two available data separately. First degree of polynomial is used for transformation process for the case of GCPs. Bilinear interpolation technique is used to determine the pixel value of the newly resultant corrected images for the two cases. GCPs is preferred when available because the resultant image with RPC geometric correction has 15.0 meters average linear error while 3.0 meters error in case of GCPs geometric correction.

I. INTRODUCTION

The problem with all satellite images is that they contain geometric distortions. Geometric distortion is defined as incorrect positions of features in the image with respect to their correct positions in the ground^[1, 2].

Distortions in remotely sensed imagery can be classified into two main types, systematic and random distortions^[2, 3, 4]. Systematic distortions may be identified and corrected during pre-launch or in-flight platform ephemeris. This type requires priori knowledge about the orbit parameters, the nature and the magnitude of the sources of distortion during the scene acquisition time. Non Systematic distortion (Random) cannot be defined easily, so it is corrected by establishing mathematical relations between the coordinates of pixels in an image space and the corresponding coordinates of those points on the ground space using well defined marks known as ground control point (GCP).

Geometric correction is a preprocess for analyzing analysis the remotely sensed data in order to remove geometric distortions as well as making each individual element in the image (pixel) in their correct planimetric (x, y) location^[5]. So, geometric correction is an important process for producing georeferenced remote sensing images that can be used to extract accurate spatial data about features as distances, areas and coordinates, which are necessary for many applications as change detection, object tracking, feature measurements and environment surveillance^[2, 6].

Since the Ikonos-2 satellite was launched in September 1999, the vendors of satellite systems hide the information regarding physical sensor models and they provide users with Rational Polynomial Coefficient (RPC) models to be used in correction process. The vendors consider RPC as replacement of physical sensor models^[7]. RPCs are widely used in the processing of high-resolution satellite

images, as it can be used in geometric correction process, producing digital elevation models (DEM) and also for 3-D feature extraction applications such as terrain extraction and determination of building height^[8].

A. Rational Polynomial Coefficient (RPC) Model

The term RPC typically refers to the Rational Polynomial Coefficient, or Rational Polynomial Camera Coefficient also, defined as Rapid Positioning Capability^[9, 10].

RPC parameters are generated from physical sensor parameters, so it can be considered as a replacement of physical sensor models for the high resolution satellites. RPCs construction depends on exterior and interior orientation parameters of the on board satellite imaging and positioning sensors, which in most cases contain biases and random errors this may reflect on the accuracy of the constructed RPC.

RPC model is a mathematical function that relates object space coordinates (latitude, longitude, and height) (U, V, and W) to image space coordinates (line and sample) (l_n, s_n) through a form of a ratio of two cubic polynomial functions of object space coordinates as shown in equation (1)^[11, 7, 10, 12].

The object space coordinates are in the form of geodetic (latitude, longitude and height), which expressed in degrees and meters, while image space coordinates are (line and sample), which expressed in pixel unit. Then, the coordinates of RPC functional model should be first normalized by the normalizing parameters that are included in RPC data, which produce 10 scales and offset terms as shown in equation (2)^[7, 13, 14].

$$F1 = l_n = \frac{Num_l(U, V, W)}{Den_l(U, V, W)} \quad (1)$$

$$F2 = s_n = \frac{Num_s(U, V, W)}{Den_s(U, V, W)}$$

Where:

(l_n, s_n) are the image coordinates

(U, V, W) are the ground coordinates

$$l_n = \frac{l - LineOffset}{LineScale}$$

$$s_n = \frac{s - SampleOffset}{SampleScale}$$

$$U = \frac{\phi - LatitudeOffset}{LatitudeScale} \quad (2)$$

$$V = \frac{\lambda - LongitudeOffset}{LongitudeScale}$$

$$W = \frac{h - HightOffset}{HightScale}$$

Where

(l_n, s_n) are normalized image coordinate.

(l, s) are un-normalized image coordinate.

(U, V, and W) are normalized ground coordinate.

(φ, λ, h) are un-normalized ground coordinate.

The four polynomials Num_l(U,V,W), Den_l(U,V,W), Num_s(U,V,W) and Den_s(U,V,W) have the forms as shown in equation (3). Each one of the polynomials can be expanded as shown in equation (4), which contains 20 coefficients. So, RPCs coefficients are 80 coefficients with 10 extra scale and offset terms^[13]. The construction of IKONOS RPC file is listed in TABLE I

$$Num_l(U, V, W) = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} a_{ijk} U^i V^j W^k$$

$$Den_l(U, V, W) = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} b_{ijk} U^i V^j W^k$$

$$Num_s(U, V, W) = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} c_{ijk} U^i V^j W^k \quad (3)$$

$$Den_s(U, V, W) = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} d_{ijk} U^i V^j W^k$$

Where:

a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk} are the polynomial coefficient.

0 ≤ m₁, m₂, m₃ ≤ 3; furthermore the maximum powers of each ground coordinate (m, m2 and m3) are limited to 3.

$$\begin{aligned}
 Num_1(U, V, W) = & a_1 + a_2V + a_3U + a_4W + a_5VU + a_6VW \\
 & + a_7UV + a_8V^2 + a_9U^2 + a_{10}W^2 \\
 & + a_{11}UVW + a_{12}V^3 + a_{13}VU^2 + a_{14}VW^2 \\
 & + a_{15}V^2U + a_{16}U^3 + a_{17}UVW^2 + a_{18}V^2W \\
 & + a_{19}U^2W + a_{20}W^3
 \end{aligned} \quad (4)$$

Where

($a_0 : a_{20}$) are the coefficient of the polynomial

Table 1: Construction of KONOS available RPC file

LINE_OFF: +006910.00 pixels	
SAMP_OFF: +006195.00 pixels	
LAT_OFF: +30.11490000 degrees	
LONG_OFF: +091.40650000 degrees	
HEIGHT_OFF: +0097.000 metres	
LINE_SCALE: +006911.00 pixels	
SAMP_SCALE: +006196.00 pixels	
LAT_SCALE: +00.08330000 degrees	
LONG_SCALE: +000.06540000 degrees	
HEIGHT_SCALE: +0270.000 metres	
----- so on till 20	
LINE_NUM_COEFF_1: -3.818058928442891E-04	
LINE_NUM_COEFF_2: -1.273831558318368E-02	
----- so on till 20	
LINE_NUM_COEFF_19: -4.2441979451900991E-05	
LINE_NUM_COEFF_20: +2.878557422608012E-08	
----- so on till 20	
LINE_DEN_COEFF_1: +1.000000000000000E+00	
LINE_DEN_COEFF_2: -1.257973104690039E-02	
----- so on till 20	
LINE_DEN_COEFF_19: -3.620543095201914E-10	
LINE_DEN_COEFF_20: +1.273349786092016E-08	
----- so on till 20	
SAMP_NUM_COEFF_1: -1.291292122551020E-03	
SAMP_NUM_COEFF_2: +1.017030314332401E+00	
----- so on till 20	
SAMP_NUM_COEFF_19: -7.901236399378392E-08	
SAMP_NUM_COEFF_20: -1.993044474915829E-07	
----- so on till 20	
SAMP_DEN_COEFF_1: +1.000000000000000E+00	
SAMP_DEN_COEFF_2: +1.257973104690039E-02	
----- so on till 20	
SAMP_DEN_COEFF_19: -3.620545095201914E-10	
SAMP_DEN_COEFF_20: -1.273349786092016E-08	

B. Polynomial Model

Polynomial correction model is considered as the most common transformation model used for geometric correction because of many advantages such as simple form, moderate flexibility of shapes, well-known, understood properties and ease of computationally^[6]. There are different researches applied the geometric corrections using mapping polynomial. Hosseini *et al.* (2005) applied non-rigorous mathematical models in two

dimensional (2D) polynomial and three dimensional (3D) polynomial cases of study for geometric corrections^[1]. Hamza *et al.* (2009) applied a third order polynomial using ten GCPs and studied the effect of the selected location of GCPs and the way of distribution of the selected GCPs over the distorted image area on geometric correction accuracy^[2]. S.Santhosh Baboo *et al.* (2011) applied image to map geo-correction using polynomial transformation using sixteen GCPs through ERDAS Imagine 9.1 software^[3]. S. Santhosh Baboo *et al.* (2014) applied a new approach hybrid model, by applying a global polynomial first and then apply projective transformation, to improve the accuracy of correction process^[15]. El Amin *et al.* (2016) applying polynomial for testing different numbers of CGPs with different densifications for geometric correction of aerial image, the researchers investigated that three GCPs with specific distribution and densification are the minimum for geometrical correction of aerial images^[16].

Polynomial model transformation depends on establishing mathematical relationships between the addresses of pixels in the distorted image and the corresponding coordinates of those points on the ground using well defined marks known as ground control points (GCP) as shown in equation^[5] in order to produce transformation parameters this process known as spatial interpolation. General form of polynomial transformation equation for a t-order is shown in equation^[6].

Depending on the used, order polynomial the minimum number of selected GCPs can be identified. The relations between the order of the polynomials; the minimum required number of GCPs; and number of coefficients of the used polynomials, are given in equation^[7] and equation^[8].

$$\begin{aligned}
 U &= f(x, y) \\
 V &= g(x, y)
 \end{aligned} \quad (5)$$

where:

(x, y) is the location of points in the ground (GCP)

(U, V) is the location of pixels in the source (distorted) image.

[f & g] the pair of mapping functions.

$$\begin{aligned}
 U &= \sum_{i=0}^t \sum_{j=0}^t a_k x^{i-j} y^j \\
 V &= \sum_{i=0}^t \sum_{j=0}^t b_k x^{i-j} y^j
 \end{aligned} \quad (6)$$

where:

(x, y) is the location of points in the ground (GCP)

(U, V) is the location of pixels in the source (distorted) image

t is the order of the polynomial

a_k & b_k are the polynomial coefficients

$$N = \frac{(t + 1)(t + 2)}{2} \quad (7)$$

$$M = (t + 1)(t + 2) \quad (8)$$

Where:
 N is the minimum number of GCPs
 t is the order of the polynomial
 M is the number of coefficients

The accuracy of overall transformation process that is used to calculate transformation parameters is determined by calculating Root Mean Square (RMS) errors for each GCP, which is calculated as shown in equation^[9]; also the total root mean square (TRMS) errors for all the used GCPs, which is calculated as shown in equation^[10]. RMS and TRMS errors are expressed in pixel widths.

$$R_i = \sqrt{XR_i^2 + YR_i^2} \quad (9)$$

Where:
 R_i = the RMS error for GCP_i; XR_i = the X residual for GCP_i;
 YR_i = the Y residual for GCP_i

$$T = \sqrt{\frac{1}{n} \sum_{i=1}^n XR_i^2 + YR_i^2} \quad (10)$$

Where:
 T = total RMS error; n = the number of GCPs; i = GCP number; XR_i = the X residual for GCP_i; YR_i = the Y residual for GCP_i

After spatial interpolation is performed by using polynomial transformation model, the image grid is commonly orientated from grid coordinate of input image as shown in Fig. 1.

To solve this problem and determine the new Digital Number (DN) a value for cells (pixels) of the newly corrected image, the resampling process is applied, which is known as the intensity interpolation. Generally, three techniques are usually considered as; Nearest neighbor technique in which the output pixel uses the value of the closest pixel as shown in Fig. 1 (a); Bilinear interpolation

in which the output pixel uses the data file values of four pixels in a (2* 2) window as shown in Fig. 1 (b); Cubic convolution in which the output pixel uses the data file values of sixteen pixels in a (4 *4) window as shown in Fig. 1 (c).

The selection of used interpolation technique depends on the nature of features in input image, the required specifications of output image, the degree of data smoothing of used interpolation technique and the processing time^[17]. So, Nearest Neighbor will be a good choice if the user wants to preserve the original DN value to use images for classification process after correction process; and Bilinear interpolation can be used to produce a smoothing final corrected image with more spatial accuracy; finally, the produced image from using cubic convolution are enhanced with some contrast in the corrected image and with noise smoothing.

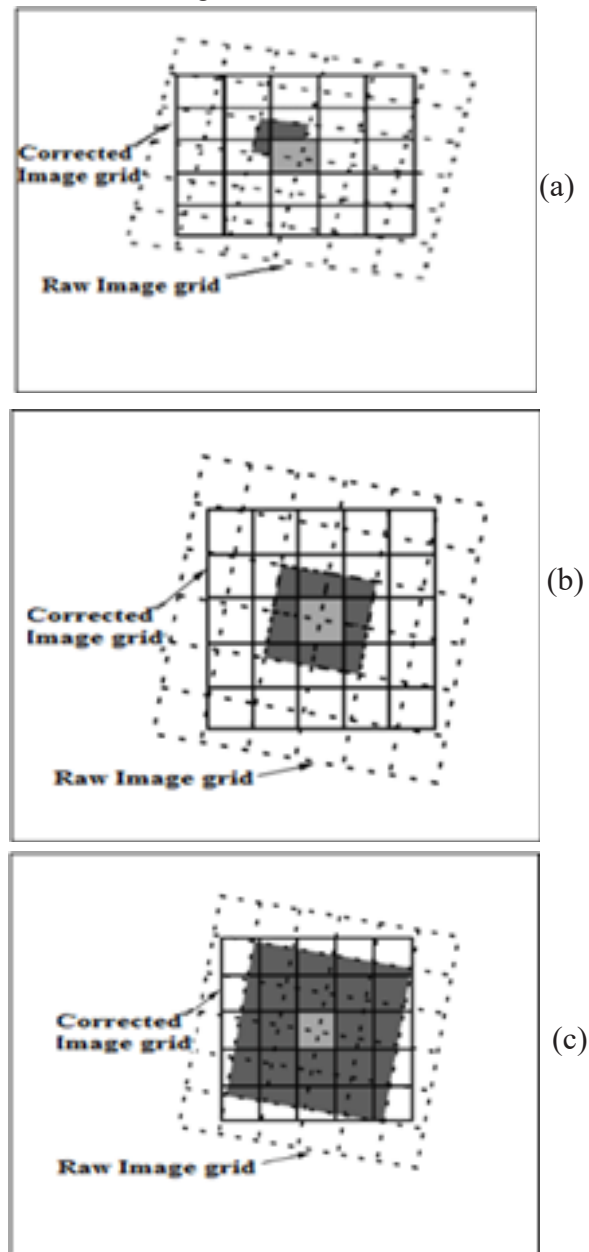


Fig. 1: Resampling Process; (a) Nearest Neighbor technique; (b) Bilinear Interpolation technique; (c) Cubic Convolution technique

II. Area of study

The study area is located in Cairo, Egypt; The input raw image is one scene acquired by remote sensing satellite IKONOS-2 with dimension (12*13) km at (2004-02-12 on 08:49 GTM), with bounded coordinates as the upper left corner coordinates are (31o 20\ 36.4727\ E, 30o 10\ 31.7373\ N) and the lower right corner coordinates are (31o 28\ 6.1432\ E, 30o 03\ 11.9254\ N) as shown in Fig. 2. The image data contains its RPC file and metadata file. Also, Seven Ground Control Points (GCPs) are available from ground survey for the same area of study with WGS84 datum and Latitude and Longitude projection with accuracy of sub pixel. The seven GCPs coordinate are as listed in TABLE II. The distribution of seven GCPs on the study area is shown in Fig. 3. .



Fig. 2 : The input raw image from IKONOS-2 Satellite

Table 2 : List of ground control points

GCP	E (Longitude)			N (Latitude)		
GCP # 1	31°	23\	06.19\	30°	08\	39.30\
GCP # 2	31°	25\	39.63\	30°	08\	18.65\
GCP # 3	31°	22\	53.24\	30°	07\	43.85\
GCP # 4	31°	26\	02.24\	30°	07\	52.44\
GCP # 5	31°	22\	46.90\	30°	06\	36.69\
GCP # 6	31°	24\	58.42\	30°	06\	58.65\
GCP # 7	31°	23\	53.42\	30°	05\	59.60\



Fig. 3: Distribution of seven ground control points

III. GEOMETRIC CORRECTION EXPERIMENTAL RESULTS

The experimental work is applied using Earth Resources Data Analysis System (ERDAS) Imagine Software 2014. Geometric correction is applied using two methods, one by using RPC file to correct the image distortion, and the other method using 1st Order polynomial (Affine transformation) with four specific distribution that gives better results regarding to the previous research^[6], the used GCPs IDs are (1, 2, 3 and 6). Then, applying bilinear resampling method to calculate the new pixels intensity values of the rectified output image because it gives more spatially accurate result than nearest neighbors and the resultant output images are smoother, without the stair-stepped effect that is possible with nearest neighbor^[18].

Again, using the seven available GCPs for accuracy assessment to determine the positioning errors (Linear Errors) in each point for the two cases (case of using RPC file and case of using 1st order polynomial with 4 GCPs). Linear errors can define as the difference between the measured coordinate of point in the corrected image and the corresponding coordinate of the GCP; which is simply determined as in equation^[11]. This can be done by applying MATLAB function to convert the discrepancy in reference (Latitude, Longitude) and measured (Latitude, Longitude) for each ground control point to errors in meter. The research work flow is shown in Fig. 4

$$\begin{aligned}
 & \text{Linear Error} \\
 & = \sqrt{((X_{Measured} - X_{Reference})^2 + (Y_{Measured} - Y_{Reference})^2)} \quad (11)
 \end{aligned}$$

Where:
 $X_{Measured}, Y_{Measured}$ = Coordinate of point in the corrected image.
 $X_{Reference}, Y_{Reference}$ = Coordinate of GCP.

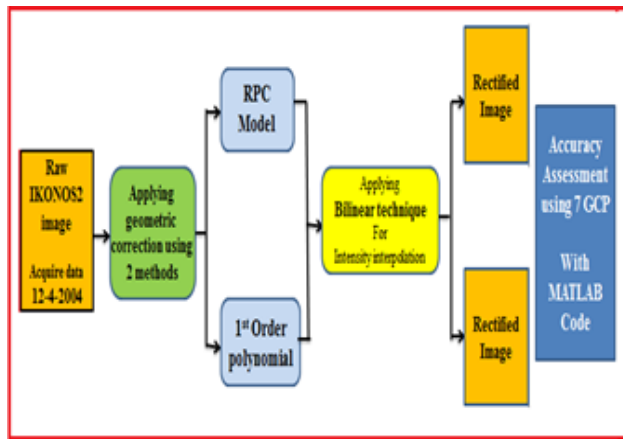


Fig. 4: Work flow of that research

The objective of that research is to make assessment to the accuracy of correction process when using RPC file versus the correction process when using GCPs.

A. Results In Case of using RPC file for geometric correction process.

The available data is raw IKONOS-2 satellite images with area (12*13) km; the correction process is applied using RPC file of that image and then applying bilinear technique for intensity interpolation to calculate the new DN values of the newly corrected image from the original pixel values. After generating the newly corrected image, the accuracy assessment of geometric correction process, can be checked through using the seven available (GCP). Positioning errors in each point are listed in TABLE III, and linear errors magnitude and direction in each point in this case is illustrated with scale100 in Fig. 5

Table 3: Errors in each GCP in case of using RPC file for correction process

GCP ID	X measured	Y measured	Errors (m)
1	31° 23\ 06.67\	30° 08\ 39.39\	13.07
2	31° 25\ 39.52\	30° 08\ 18.63\	3.05
3	31° 22\ 53.64\	30° 07\ 43.93\	10.86
4	31° 26\ 02.96\	30° 07\ 52.41\	11.33
5	31° 22\ 46.04\	30° 06\ 36.70\	3.64
6	31° 24\ 58.17\	30° 06\ 58.61\	6.72
7	31° 23\ 53.02\	30° 05\ 59.59\	10.73

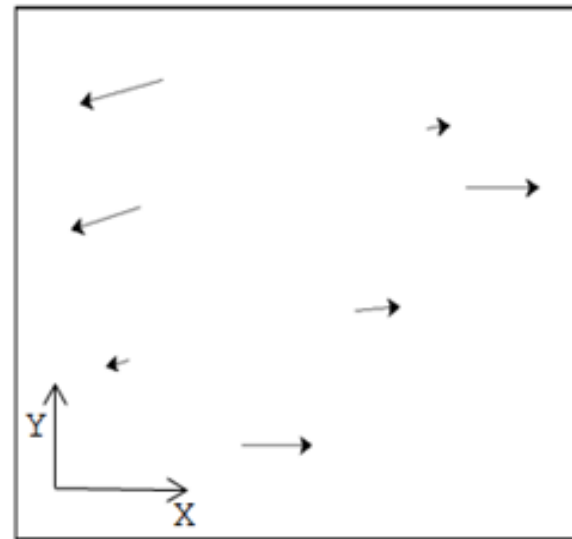


Fig. 5: Linear Errors magnitude and direction with 100 scales

B. Results In Case Of Using 1st Order Polynomial for Geometric Correction Process

Similarly, the same available data is geometrically corrected by applying 1st order polynomial for transformation process with using four GCP with IDs (1, 2, 3, and 6) which gives best results in our previous research [6] and its distribution is shown in Fig. 6. Then bilinear technique is used for intensity interpolation to calculating the new DN values of the corrected image from the original pixel values. Root mean square (RMS) errors in X and Y coordinates for each point of the four GCPs used in transformation process, also total RMS (TRMS) for all used GCPs are listed in TABLE IV.

After generating the new corrected image, the accuracy assessment is checked through using the seven available (GCP). The errors in each point are listed in TABLE V. In addition, errors magnitude and direction in each point in this case is illustrated with scale100 in Fig. 7.

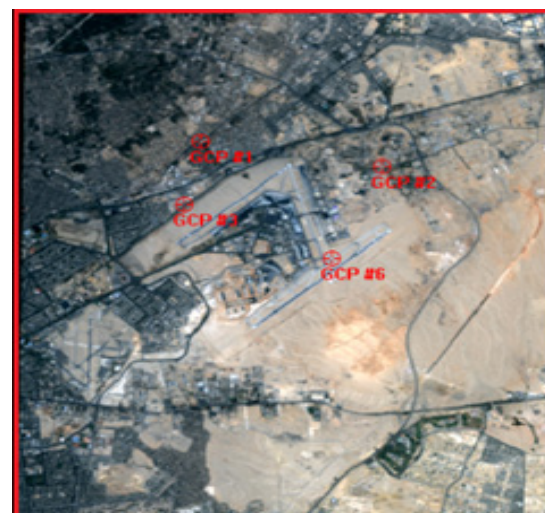


Fig. 6: The distribution of the four used GCPs

Table 4: RMS errors in each point and TRMSE for case of 1st order polynomial

(TRMSE) : 0.0139		(Total X Residual) : 0.0099		
		(TRMSE) : 0.0139		
GCP ID	X Residual	Y Residual	RMSE	Contrib.
1	-0.011	-0.011	0.016	1.124
2	0.007	0.007	0.010	0.712
3	0.012	0.012	0.017	1.241
6	-0.008	-0.008	0.012	0.83

Table 5: Errors in each GCP in case of applying polynomial for correction process

GCP ID	X measured		Y measured		Errors (m)
1	31° 23'	06.151\	30° 08'	39.303\	1.07
2	31° 25'	39.59\	30° 08'	18.669\	1.15
3	31° 22'	53.27\	30° 07'	43.88\	1.25
4	31° 26'	02.18\	30° 07'	52.436\	5.46
5	31° 22'	46.91\	30° 06'	36.697\	0.36
6	31° 24'	58.39\	30° 06'	58.63\	0.92
7	31° 23'	53.27\	30° 05'	59.64\	4.17

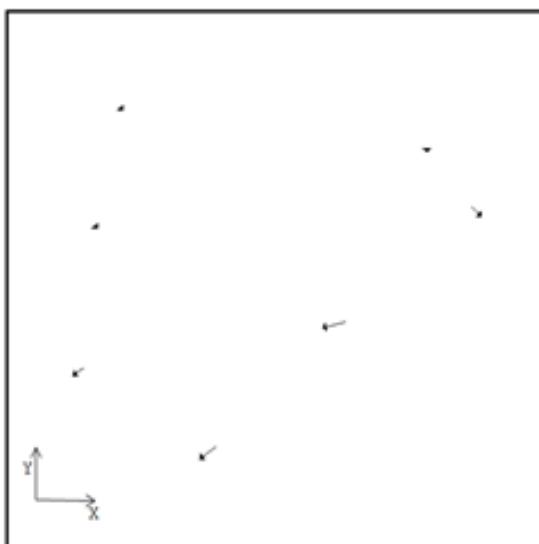


Fig. 7: Errors magnitude and direction with 100 scales

IV. CONCLUSION

Geometric correction is considered as a preprocessing for remotely sensed image to improve the quality and remove errors due to distortions. The RPC geometric correction of IKONOS image produced a resultant image of 15.0 meters average linear error while 3.0 meters in case of GCPs geometric correction. Then, the results of practical test conclude that the accuracy of correction process when applying polynomial transformation with four GCPs with accuracy of sub pixel from ground survey is better than the accuracy of correction process when using RPC file in case of IKONOS images as a general conclusion, and specially with study are as close as possible to our study area.

The research ended up with the correction process using GCPs, when they are available, is the best choice but the accuracy of the resultant image depends on the accuracy and distribution of the used GCPs.

Although the geometric correction using RPC file does not give higher accuracy than GCPs but it produces images with spatial data suitable for many applications as reconnaissance and over all survey for city planning. So, it is important to get RPC file for satellite images for applications that do not need high accuracy to save cost and effort for establishing GCPs in the field of area of study.

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