ACCURACY ANALYSIS OF POLYNOMIAL RECTIFICATION FOR QUICKBIRD IMAGERY

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Abstract

Geometric rectification is a process to relate space coordinate systems of satellite imagery with the ground coordinate systems. Rectification involves georeferencing in which ground coordinates are assign to image data. Photogrammetric data extraction from satellite imagery can be done after the image being geometrically corrected. There are several rectification methods proposed by photogrammetric remote sensing experts. Each method is having its own characteristics in term of mathematical model used, geometrical accuracy and computation constrains. Conventional polynomial rectification was reported as not suitable for geometric rectification of high resolution satellite imagery. The study is conducted to access and evaluate the accuracy of polynomial rectification for QuickBird imagery. Analysis will be focused to the effect of 1st, 2nd and 3rd polynomial order on rectified imagery. This paper briefly reviews polynomial rectification model and presented the result of the study. Sub-pixel accuracy can be achieved for fairly flat area.

1.0 INTRODUCTION

Geometric rectification is a process to relate space coordinate systems of satellite imagery with the ground coordinate systems. Rectification involves georeferencing in which ground coordinates are assigning to image. Data extraction from satellite imagery can only be performed after the image being rectified and geometrically corrected. The availability of high resolution satellite imagery with better geometric accuracy has marks a new era in mapping industry (Dial & Grodecki, 2003).

Most of high resolution satellite sensor are using Couple Charged Device (CCD) array sensor to collect image of the earth surface. The image consists of lines scanned independently at different instants of time and stored next to another. Each scan line on the image is acquired at different set of parameters (position and attitude). Classic rectification algorithms using camera parameters could not be used to georeference this kind of image as the physical camera models are not available. Furthermore, the number of unknowns i.e 6 external orientation parameters for each image line, would be huge. Therefore, an external orientation modeling is required (Poli, 2002). Experiment conducted on several SPOT images using conventional algorithm had shown that some image could not be processed and generate correct result (Zhang and Zhang, 2002). Rational Polynomial Camera Coefficients model (RPC) has been introduced by image provider which allowing user to perform image rectification without accessing to physical camera parameters.

This study is aimed to analyze the capability of polynomial rectification model offered by off-the-shelf image processing software to be used with mono-view imagery. In this study, 1st, 2nd and 3rd orders polynomial rectification of ERDAS Imagine v8.5 will be evaluated. High resolution satellite imagery from QuickBird of Digital Globe Inc. over Kuala Lumpur city centre at about 25 square kilometer will be used in this study. This paper briefly reviews polynomial rectification model and presented the result of the study. Planimetric accuracy which is better than 1 pixel can be achieved for fairly flat area.

2.0 OBJECTIVE

The objective of this study is to analyze the capability of polynomial rectification model to be used with mono-view of high resolution satellite imagery such as IKONOS and QuickBird. The evaluation will be based on the planimetric accuracy of rectified imagery utilizing 1st, 2nd and 3rd orders of polynomial rectification. The evaluation on spatial accuracy will be based on coordinate displacement compared to GPS measured ground control points.

3.0 POLYNOMIAL RECTIFICATION

Polynomial rectification is developed based on polynomial functions which also known as traditional method for rectification. Polynomial rectification is often applied to orthographic rectification of optical image (Huang, et.al 2004). (Zhang and Zhang, 2002) had stated that for better rectification result, the polynomial with higher order should be applied, therefore, more control points are needed. 1st , 2nd and 3rd order polynomial equations are given by the Equation (1), Equation (2) and Equation (3) respectively.

$$u = a_0 + a_1x + a_2y + a_3xy$$
$$v = b_0 + b_1x + b_2y + b_3xy \tag{1}$$

$$u = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2$$
$$v = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 \tag{2}$$

$$u = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2 + a_6x^3 + a_7x^2y + a_8xy^2 + a_9y^3$$
$$v = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3 \tag{3}$$

where;

$u, v =$ point coordinates in the image system (line and sample);
$a, b =$: coefficients;
$x, y =$: point coordinates in the ground system;

In the polynomial rectification, the solution is based on the ground control points and does not require parameters of the interior orientation and ephemeris information. The approach is based on 2D empirical model, and the advantageous of polynomial rectification are that it is mathematically simple and fast computation time. However, polynomial rectification is not suitable if there is great terrain variation.

This approach has been suggested for the geometric modeling of high resolution satellite imagery over generally flat surface

4.0 METHODOLOGY

4.1 Test Site

The test site for this study is Kuala Lumpur City Centre area covering about 25 square kilometer. QuickBird Image which was taken on 08 March, 2002 was obtained from and with the courtesy of The Department of Survey and Mapping Malaysia (JUPEM). The Kuala Lumpur area has been selected due to several factors including the availability of QuickBird image of the area and its topographical conditions. Built-up area is suitable for the selection of control point. Impervious surface such as road junctions, building corners and pavements are clearly visible on the image, and can be used as ground control point.

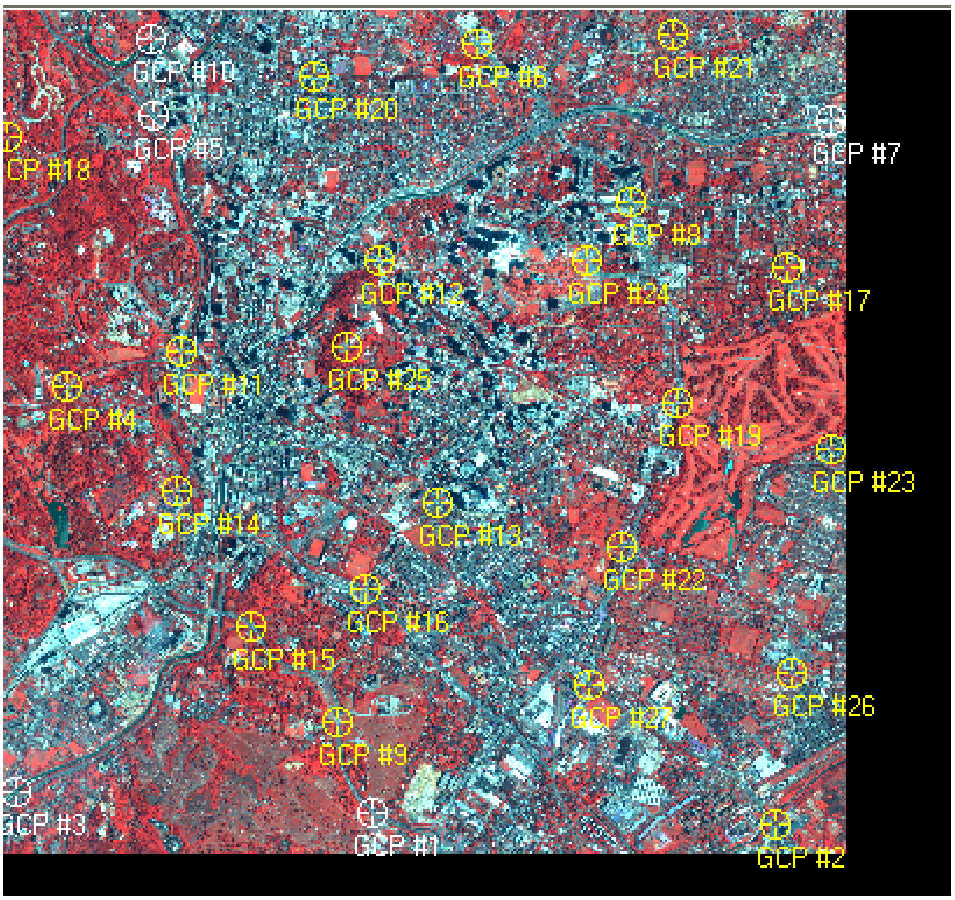

Figure 1: QuickBird Image of Kuala Lumpur

4.2 Method

4.2.1 Ground Control Points (GCPs)

The selection of GCPs is a critical part in the accuracy analysis study. Among the factors which could affect the rectification result are the distribution of GCPs, coordinate accuracy and the number of GCP used in the processing. GCPs are distributed over the study area which performed large triangles. The minimum number of GCPs required in the polynomial rectification are as follows;

$$\frac{(r+1)(r+2)}{2}$$

where r is the order of rectification. Therefore, the minimum GCPs required for 1^{st}, 2^{nd} and 3^{rd} order polynomial transformation are 3, 6 and 10 respectively. GCPs have been carefully selected which could represent the whole study area. The object selected as ground control points are clearly visible and identifiable on the ground and on the image. Objects such as road junction, round-about and pavement can be easily identified on one meter resolution imagery. GCPs coordinated are measured using quick-static GPS observation. As GPS receiver needs sufficient overhead clearance to receive signal, it is quiet difficult to locate GCPs in built-up areas. A total of 12 control points have been selected in this study. The location and distribution of ground control points are shown on the Figure 1.

4.2.2 Independent Check Points (ICPs)

Independent Check Points (ICPs) are required to assess and verify the accuracy of rectified imagery. It is important for independent error checking. The purpose is to check whether there are any constraints for the polynomial model to be used with high resolution satellite imagery. The coordinates of ICPs are also measured using quick-static GPS observation. In this study, 16 ICPs have been selected and measured.

4.2.3 GPS Observation

In the accuracy assessment of the rectification procedure, it is important to ensure that the accuracy of GCPs and ICPs coordinates are accurate and uniform. For this reason, quick-static observations have been carried out. Every control point has been observed for at least 30 minutes using dual-frequency GPS receiver. Three geodetic type GPS receiver have been used, including Trimble 4800 and Leica System 500. To improve surveying accuracy and support network adjustment in GPS system, all control points were observed in a closed loop, where at least two control points were observed simultaneously. To reduce cost and time for fieldwork operations, GPS data from nearest MASS station were downloaded and used in the computation and adjustment. Coordinates of all ground control points were derived from KTPK MASS station located on top of the Kementerian Tanah dan Pembangunan Koperasi building. GPS data processing and adjustment were carried out using Trimble Geomatic Office (TGO) software of Trimble Navigation Inc. The coordinates of ground control points derived from GPS survey were transformed to Malaysian Rectified Skew Orthomorphic Projection (RSO). The root mean square error (RMSE) of all GCPs and ICPs coordinates is 0.0198m which is acceptable for mapping requirement. Table 1 shows the coordinates of ground control points and independent check points together with their errors.

Table 1: Coordinates of GCPs and ICPs

GCP/ICP Number	Location	Easting	Northing	Height (Ellipsoidal)	N error	E error	h error
1	TUDM	412198.365m	345621.089m	33.680m	0.013m	0.014m	0.032m
2	PGRM	414919.881m	345546.051m	37.808m	0.035m	0.048m	0.106m
3	BFLD	409771.551m	345765.429m	29.267m	0.023m	0.027m	0.054m
4	TUGU	410124.939m	348504.033m	48.636m	0.023m	0.025m	0.053m
5	PWTC	410712.900m	350339.079m	31.610m	0.022m	0.025m	0.053m
6	LIBR	412952.316m	350789.469m	32.640m	0.023m	0.023m	0.048m
7	KRMT	415321.570m	350285.435m	34.028m	0.044m	0.040m	0.128m
8	AMPG	413948.761m	349737.766m	38.972m	0.060m	0.063m	0.172m
9	DBP	411950.564m	346242.739m	42.892m	0.020m	0.024m	0.045m
10	BNM	410903.646m	348747.944m	29.984m	0.024m	0.023m	0.056m
11	RENN	412250.208m	349345.717m	29.666m	0.033m	0.029m	0.061m
12	PENJ	412624.854m	347720.931m	45.374m	0.043m	0.044m	0.143m
13	MSJD	410866.981m	347806.407m	32.620m	0.003m	0.003m	0.007m
14	ISTA	411367.299m	346883.748m	31.104m	0.004m	0.004m	0.009m
15	SANP	412143.717m	347123.225m	43.322m	0.003m	0.003m	0.006m
16	UTAN	415011.168m	349299.345m	36.686m	0.003m	0.004m	0.008m
17	BKTE	409715.601m	350183.705m	70.051m	0.003m	0.003m	0.005m
18	KGDS	414272.683m	348387.937m	37.960m	0.003m	0.003m	0.006m
19	UKM	411802.866m	350592.717m	32.513m	0.004m	0.003m	0.006m
20	KENT	414239.619m	350876.574m	35.773m	0.003m	0.003m	0.007m
21	BPAN	413864.761m	347433.659m	37.557m	0.003m	0.003m	0.007m
22	DESA	415309.818m	348077.542m	40.712m	0.010m	0.014m	0.043m
23	KLCC	413661.458m	349359.235m	37.488m	0.004m	0.004m	0.009m
24	KLTO	412018.055m	348773.958m	89.325m	0.003m	0.003m	0.007m
25	MALU	415044.357m	346563.559m	41.489m	0.003m	0.003m	0.006m
26	JCSL	413683.307m	346472.710m	40.776m	0.003m	0.004m	0.008m

4.2.4 Image rectification

ERDAS Imagine Ver.8.5 provides five types of geometric models to be used with satellite imagery. The geometric models available are Landsat, SPOT, Affine, Polynomial and Rubber Sheeting. For Polynomial model, user is having options to select polynomial orders to suit image requirement. Landsat and SPOT geometric model are specifically designed for Landsat and SPOT imagery. Affine model is to be used for model orientation. Rubber sheeting model is designed for 3D surface interpolation and DTM generation. Linear rubber sheeting is based on 1^{st} order polynomial while non-linear rubber sheeting is based on 5^{th} order polynomial. For the purpose of this study, we would like to investigate and analyze the capability of polynomial model to be used with high resolution satellite imagery including IKONOS and QuickBird.

In order to analyse the effect of control points to rectification accuracy, we had perform several rectifications for different configuration of control points. 1^{st} order polynomial rectifications were carried out with 3, 6 and 10 GCPs, while 2^{nd} order polynomial with 6, 9 and 12 GCPs. For 3^{rd} order polynomial, the image was rectified with 10, 13 and 16 GCPs.

4.2.5 Accuracy assessment

Planimetric accuracy of rectified image was analyzed using independent check points which have been selected over the image. The easting and northing residual of ICPs were measured and recorded. The root mean square errors (RMSE) of ICPs were used to describe the accuracy of the image geometry. Figure 2 shows overall performance of 1^{st}, 2^{nd} and 3^{rd} order polynomial models with respect to the number of control points used in the rectification process. Figure 3, 4 and 5 show individual error pattern of 1^{st}, 2^{nd} and 3^{rd} polynomial respectively. The error pattern of the 1^{st} order polynomial model is shown in Figure 3. The 1^{st} order polynomial was tested with four combinations of ground control points i.e 4, 6, 10 and 12. From the figure, the error pattern observed from independent check points shows that the use of 4 and 6 GCPs produce RMSE less than 0.8 meter. Rectification with 10 and 12 GCPs had produce RMSE from 0.4m to 1.8m. Figure 4 shows the error pattern of the 2^{nd} order polynomial model. The 2^{nd} order polynomial was tested with three combinations of ground control points i.e 6, 10 and 12. From the figure, the error pattern observed from independent check points shows that the use of 6 GCPs (minimum) produce largest RMSE compared to 10 and 12 GCPs. The used of 12 GCPs had result to the lowest error pattern which is below 1 meter. The error pattern of the 3^{rd} order polynomial model is shown in Figure 5. The 3^{rd} order polynomial was tested with two combinations of ground control points i.e 10 and 12. From the figure, the error pattern observed from independent check points shows that the use 3^{rd} order polynomial had increase the overall error.

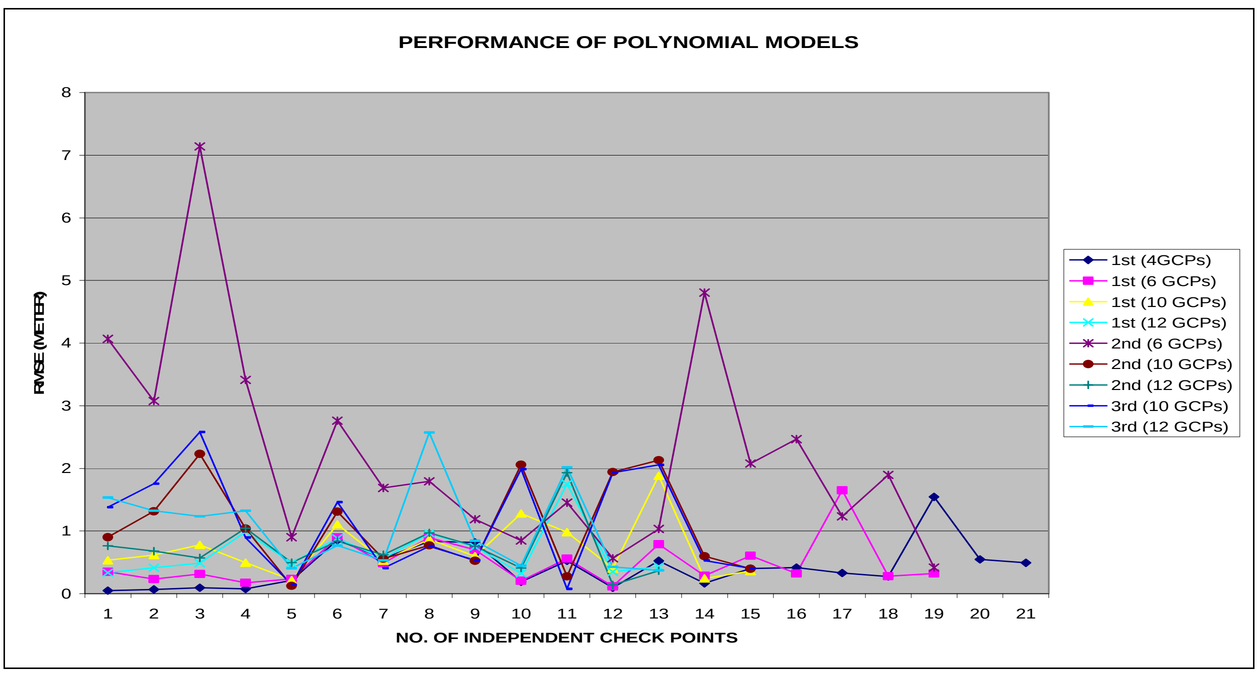

Figure 2: Error Pattern of Polynomial Models

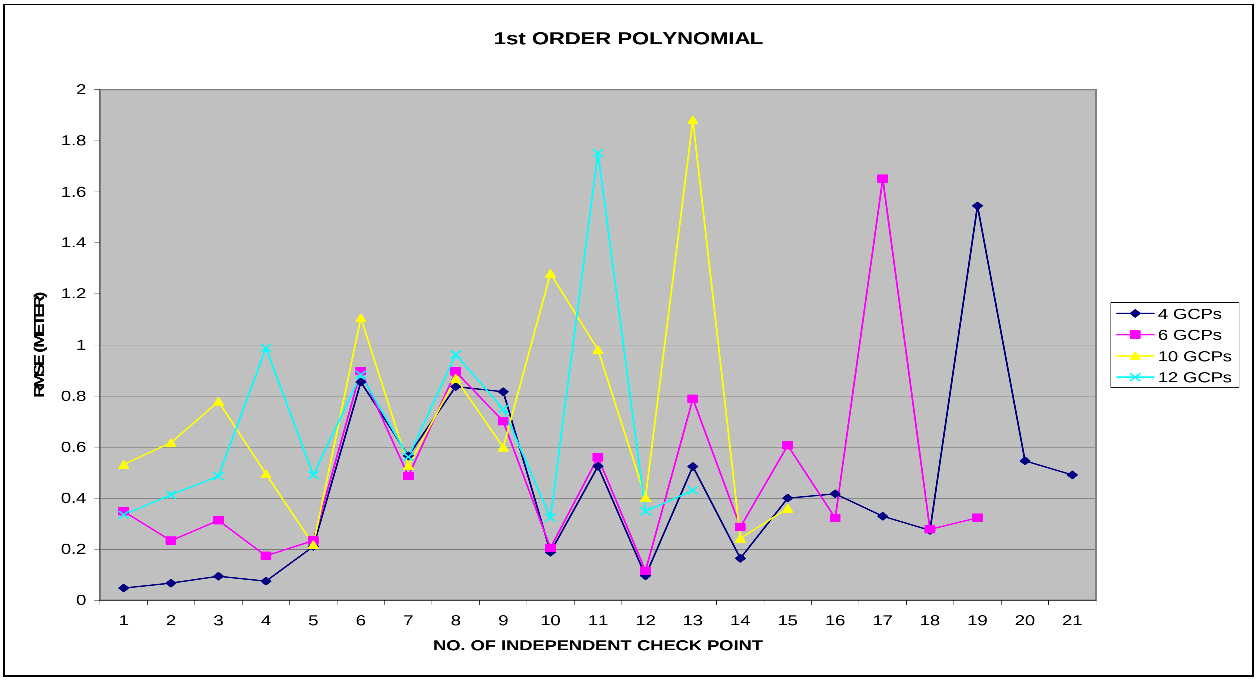

Figure 3: Error Pattern of 1st Order Polynomial Model

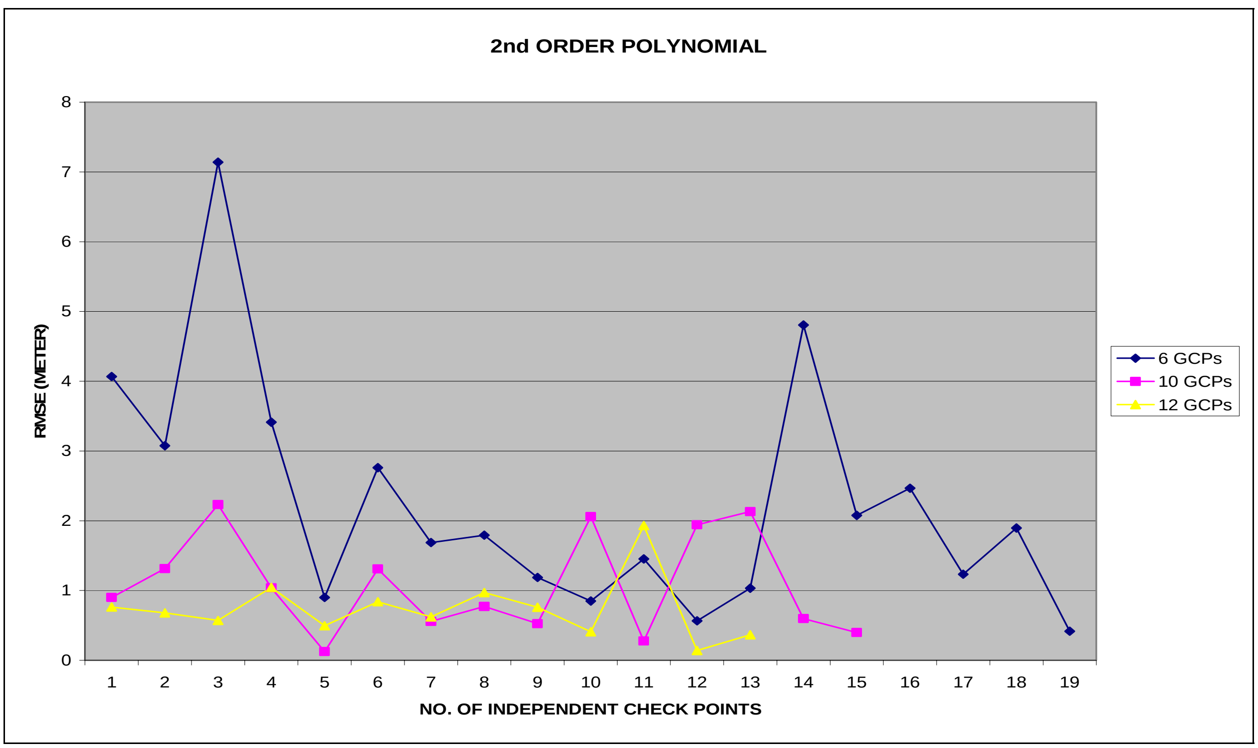

Figure 4: Error Pattern of 2nd Order Polynomial Model

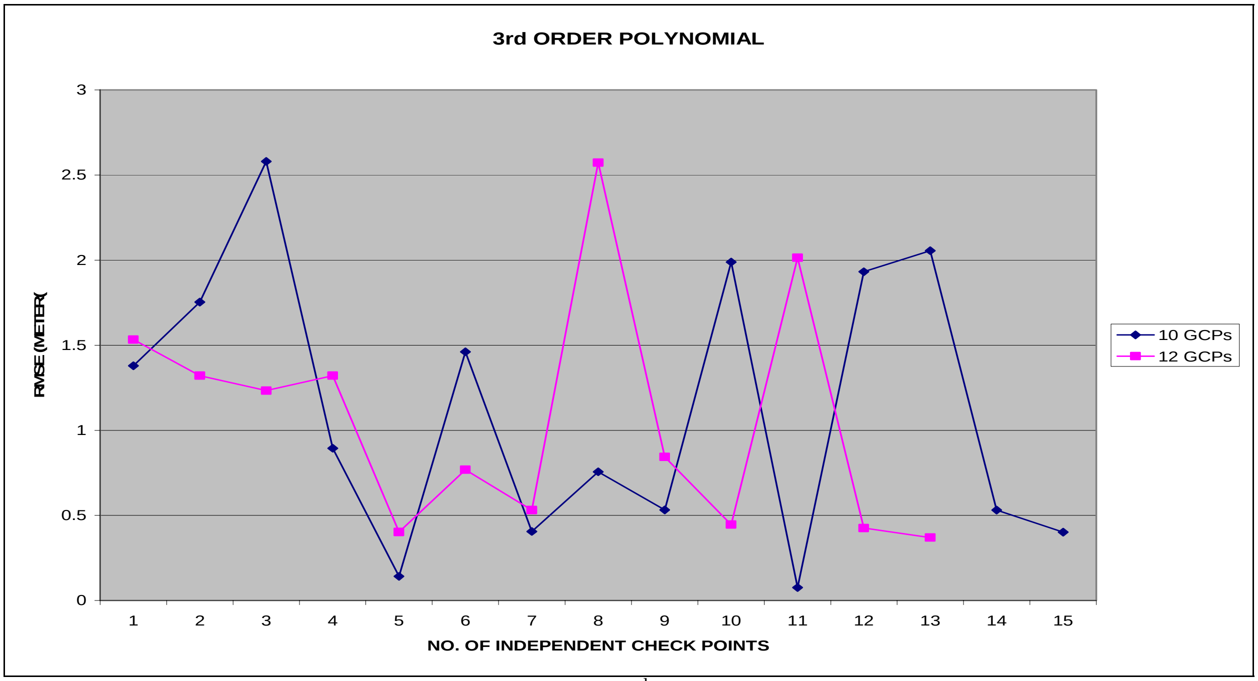

Figure 5: Error Pattern of 3rd Order Polynomial Model

We suggest that the RMSE which were below 1 meter is acceptable for most medium scale mapping application. It is important to note that the number of GCPs used in rectification had significant impact to error patterns in every polynomial order. Therefore, care must be taken to apply the correct polynomial order with correct GCP combination. Finally, from the study, we can conclude that for fairly flat area, 1st order polynomial can be applied to high resolution satellite imagery.

5.0 CONCLUSION

The advantageous of polynomial rectification are that it is mathematically simple and fast in computation time. However, polynomial rectification is only suitable for relatively flat surface. From the study, we examined the possibility of using polynomial rectification model for mono-view of high resolution satellite imagery. The approach is based on 2D empirical model. Although the number of test sites was limited, it seems reasonable to conclude that the polynomial model can be used with high resolution satellite imagery.

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