# Optimizing Orientation by GCP Refinement of Very High Resolution IKONOS Satellite Images

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***Abstract***

*The Rational Polynomial Coefficients (RPC) provided with the IKONOS images contains a large error and they need Ground Control Point (GCP) refinement. To present the technique of refinement of RPCs by the application of some appropriate transformation algorithm with some suitable number of GCPs in proper constellation in an optimal way to achieve high geometric accuracy during spatial data acquisition from IKONOS stereo image is the objective of this paper. From this study it was found that GCP refinement of RPCs by affine transformation with four GCPs in proper constellation is optimal for the orientation of the image pair under study, it was also found that at least two redundant GCPs are necessary for proper refinement by a particular transformation algorithm.*

## 1. Introduction

Since its launch in September of 1999, the IKONOS satellite has been consistently providing high quality 1-meter panchromatic and 4-meter multi-spectral images. The initial post-launch IKONOS geometric accuracy was verified during the On-Orbit Acceptance Test (OOAT), using the San Diego test range consisting of 140 GCP over a 22 by 22 km area [Grodecki and Dial, 2002]. The OOAT results indicated that the absolute horizontal and vertical accuracy of uncontrolled IKONOS stereo images, block adjusted without GCPs, was better than 6 m. The IKONOS satellite simultaneously collects imagery in four multi-spectral bands and a single panchromatic band with 11-bit resolution. For panchromatic images the ground sampling distance (GSD) of the IKONOS sensor is 0.82 m at nadir. GSD of multi-spectral images is four times that of panchromatic images, i.e., 3.28 m at nadir. At 26 degrees off nadir the GSD is 1 m for panchromatic and 4 m for multi-spectral images.

These high spatial resolution satellite images can be used as a potential alternative of the aerial photographs for producing and updating the large scale geo-information products. Not only the high spatial resolution but also their multi-spectral data and capability for stereo mapping with short revisit time giving highly frequent updatability have made a great benefit in this regard. To reach to the end geo-spatial data product these images are to be processed through different production steps applying various methods and algorithms, so, proper choice of processing methods considering the available software and other required information like ground control points (GCPs), independent check points (ICPs) is also equally important for optimal exploitation.

In this paper, how the orientation among the different steps of geometric processing of high spatial resolution satellite images can be optimised to get targeted production accuracy has been presented.

## 2. Orientation

Orientation determines the geometry of the imaging rays including the actual location of the sensor, its pointing angle with respect to the ground. Orientation results in formula to calculate image coordinates (x, y or row, column) from terrain coordinate (X, Y, Z) [N. Kerle et al, 2004].

Because of the geometrical properties of the sensors of High Spatial Resolution Image (HSRI), central perspective geometry, as used in airborne photogrammetry, cannot be directly applied onto high resolution satellite image, moreover, providers might not release information about the interior orientation parameters. So, to solve the orientation problem, some alternative approaches are applied. The orientation methods based on rational polynomial functions, affine projection and Direct Linear Transformation (DLT) are mostly used for HRSI. They can be a possible alternative to rigorous models when the calibration data are not released by the image provider or when the sensor position and attitude are not available with sufficient precision [Daniela Poli, 2005]. The rational function model (RFM) is becoming well known to the mapping community, largely due to its wide adoption as a new standard. Open GIS Consertium (OGC) has already decided to adopt it as a part of the standard image transfer format [OGC 1999a]. Space Imaging has adopted the RFM scheme in order to deliver the imaging geometry, so, instead of delivering the interior and exterior orientation geometry of the IKONOS sensor and other physical parameters associated with the imaging process, the RFM is used as a sensor model for photogrammetric exploitation [Yong Hu et al, 2004]. RFM uses a ratio of two polynomial functions of ground coordinates to compute the row image coordinate, and a similar ratio to compute the column image coordinate. The two image-coordinates (row and column) and three ground-coordinates (e.g., latitude, longitude and elevation) are each offset and scaled to fit the range from –1.0 to 1.0 over an image or image section.

$$r_n = \frac{\sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} a_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} b_{ijk} X_n^i Y_n^j Z_n^k}$$

$$c_n = \frac{\sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} c_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} d_{ijk} X_n^i Y_n^j Z_n^k}$$

where $r_n$ and $c_n$ are the normalized row and column index of pixels in image respectively, $X_n$ ,$Y_n$ and $Z_n$ are normalized coordinate values of object points in ground space, and $a_{ijk}$, $b_{ijk}$, $c_{ijk}$, $d_{ijk}$ are polynomial coefficients called rational function coefficients (RFCs) or rational polynomial coefficients (RPCs).

RPCs provided by image vendors may not always approximate the real imaging process well; RPCs can be refined in the domain of the image space or of the ground space, when additional control information is available. IKONOS Geo products and Standard stereo products can be improved to sub-meter absolute positioning accuracy using one or more high quality GCPs or be close to the accuracy of the GCPs whose quality is low [Yong Hu et al, 2004]. The RFM may be refined directly or indirectly. The direct refining methods update the original RPCs themselves while the indirect refining introduces complementary or concatenated transformations in image or object space, and they do not change the original RPCs directly. The affine transformation or a translation (shift) for the simplest case is often used [Yong Hu et al, 2004]. Leica Geosystem's LPS offers 0th 1st and 2nd order polynomial refinement which means translation, affine and 2nd order polynomial transformations respectively [LPS online help], in this study all the refinement orders with different number of GCPs has been tested.

## 3. Study Area

The study area is the southern part of China which is an area of varying terrain and land cover. It has flat, hilly and mountainous terrain; and open, water covered, forest and built-up land covers. It covers approximately 96.28 square kilometres area

Distribution of GCPs and ICPs have been given in the figure 1.2 below, the accuracy information of these GCPs and ICPs is not known but referring to the Wang Tiejun, 2005 these are highly accurate points observed with GPS. The elevation of these points ranges from minimum 62.432 to maximum 227.538 meters.

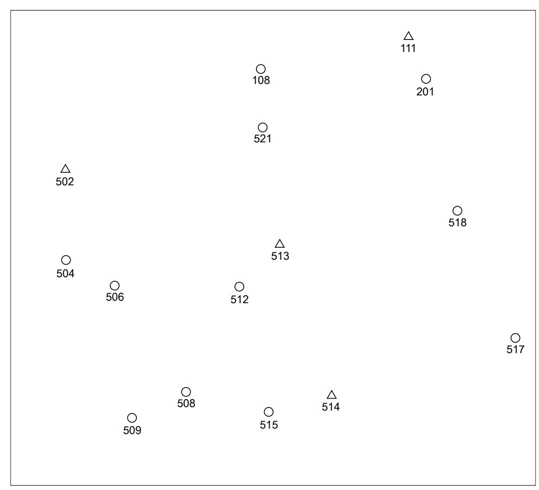
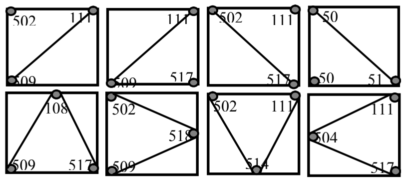



Fig1.2. Distribution of GCPs and ICPs

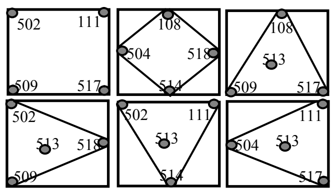
## 4. Methods

After the orientation of the pan images in LPS block with RPCs the 25 GCPs were measured carefully in the classic point measurement tool according to their description, then refinement of the orientation was proceded with following schemes.

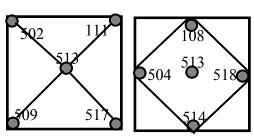
1. Simple shift transformation (0th order refinement) was applied with one control and 24 check points at five different locations at centre and at four corners.
2. Simple shift transformation was applied with two control and 23 check points at four different locations at two diagonals left right and top bottom directions
3. Simple shift transformation and affine transformation ($0^{th}$ order and $1^{st}$ order refinement) was applied with three control and 22 check points at eight different constellations as shown in the diagram below.



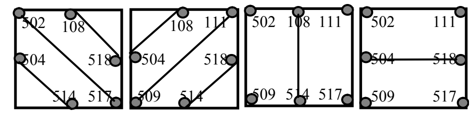
4. Simple shift transformation and affine transformation (0th order and 1st order) was applied with four control and 21 check points at six different constellations as shown in the diagram below.



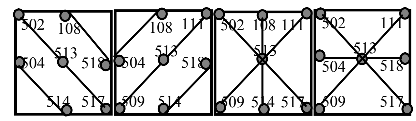
5. Simple shift transformation and affine transformation (0th order and 1st order refinement) was applied with five control and 20 check points at two different constellations as shown in the diagram below.



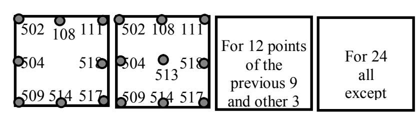
6. Simple shift transformation, affine transformation and polynomial transformation (0th order, 1st and 2nd order refinement) was applied with six control and 19 check points at four different constellations as shown in the diagram below.



7. Simple shift transformation, affine transformation and polynomial transformation (0th order, 1st and 2nd order refinement) was applied with seven control and 18 check points at four different constellations as shown in the diagram below.



8. Simple shift transformation, affine transformation and polynomial transformation (0th order, 1st and 2nd order refinement) was applied with 8, 9, 12 and 24 control and 17, 16, 13 , 1 check points respectively as shown in the diagram below.




NB: simple shift refinement is applicable if one or more GCPs are available, affine transformation refinement is applicable if at least three GCPs are available and polynomial refinement is applicable if at least 6 GCPs are available.

## 5. Results

From the aerial triangulation error report for the control points the RMSE_X, RMSE_Y, RMSE_Z and the computed value of $\text{RMSE\_XY} = \sqrt{RMSE\_X^2 + RMSE\_Y^2}$ of the refinement with the simple translation, affine and polynomial transformation for all the schemes mentioned above are plotted in the figure below,

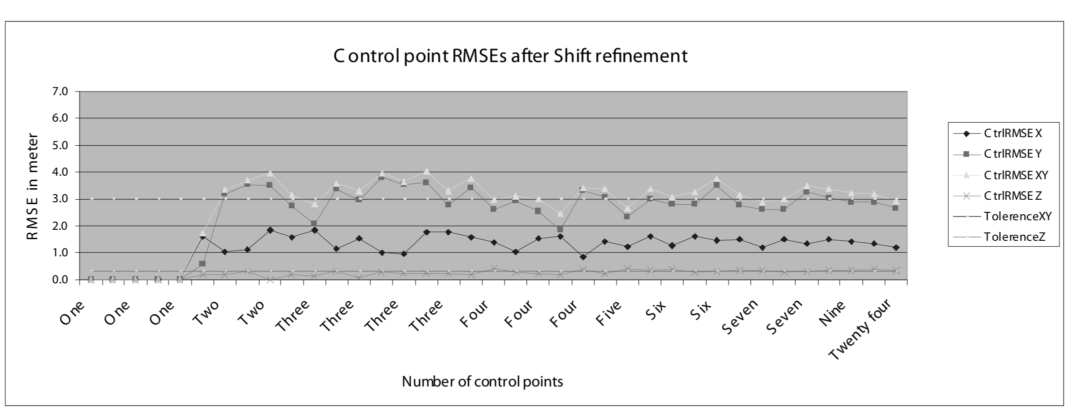



Fig 1.3 Plot of control point RMSE after 0th order refinement

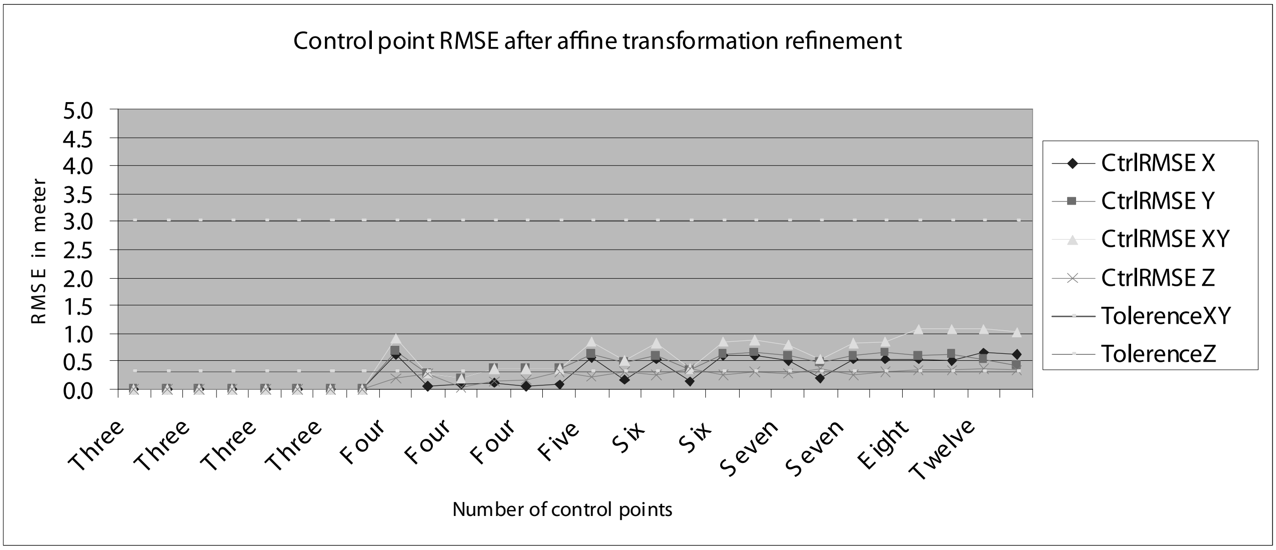



Fig 1.4 Plot of control point RMSE after 1st order refinement

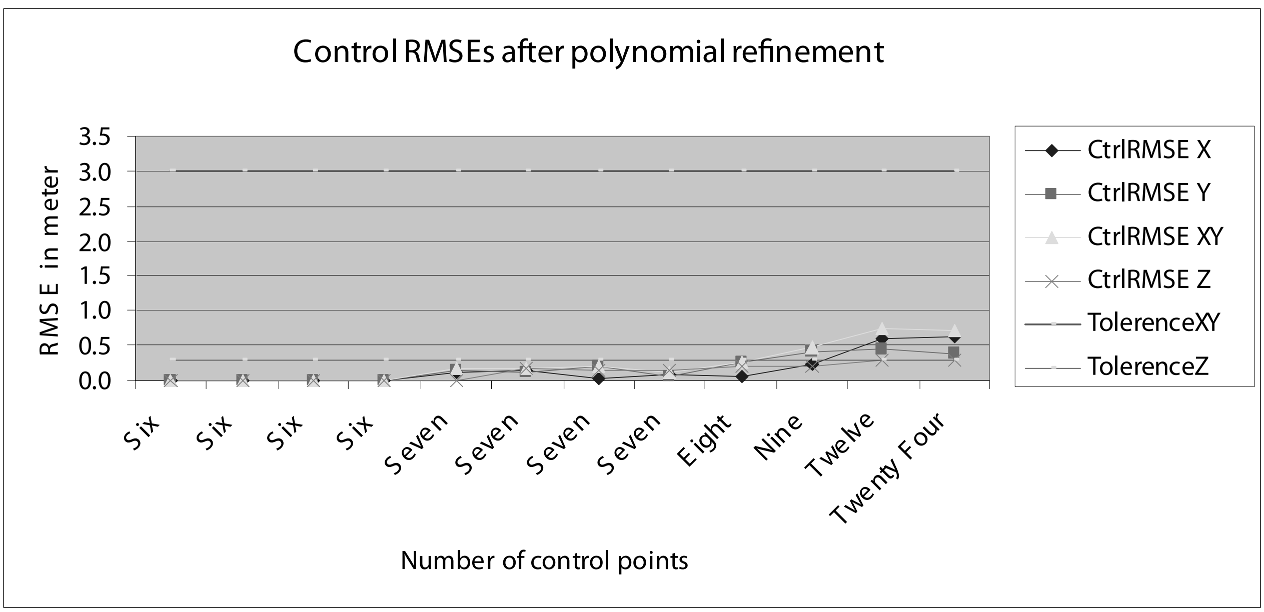



Fig 1.5 Plot of control point RMSE after 2nd order refinement

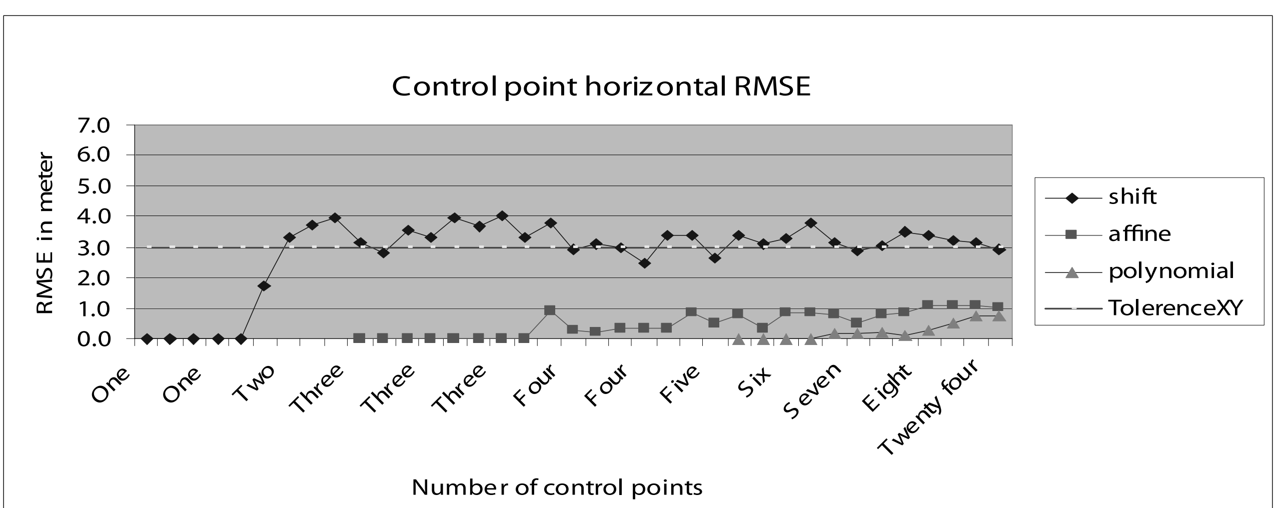



Fig1.6. Plot of control point horizontal RMSE after 0th, 1st and 2nd order refinement

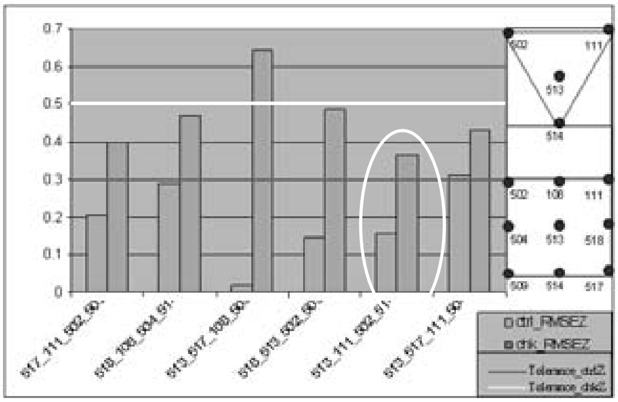



Fig 1.6 Plot of control and check point vertical RMSE after 1st order refinement with 4 GCPs

## 6. Conclusion and Recommendations

The accuracy of the required additional information like RPCs and GCPs influence the accuracy of the final product. To get the data within the required accuracy, in a time and cost effective way, the choice of proper processing method and algorithm is also equally important which is a matter of optimization of the geometric processing. In this study the IKONOS Geo product stereo images of a part of China were used for experimentation with their RPCs and 25 accurately measured and well distributed GCPs. The results were analysed and concluded on the basis of Chinese specifications for the base data of 1:10000 scale. From this study it can be concluded that the ttranslation transformation refinement does not meet the accuracy of specifications.

The minimum number of GCPs required to apply a particular transformation algorithm, is not practically sufficient for proper refinement and it needs two more redundant control points.

If the number of redundant control points increased the accuracy goes on improving up to two redundant GCPs, the further redundancy has no significant improvement.

The accuracy not only depends on the number of GCPs used but also on their constellation and spatial distribution within the study area.

The affine transformation with four GCPs in the constellation as shown in the Figure 1.6 was found to be optimal for the orientation of the experimented dataset for which the horizontal and vertical RMSEs for control points are 0.37, 0.16 meters and that for check points are 1.22, 0.37 meters respectively.

During orientation the same number of GCPs applied in similar constellations (e.g. just change of the orientation of the constellation upside-down or left side right) have different results so it is recommended to look also into the other factors influencing on the accuracy like distribution of GCPs in along- and cross- track directions, elevation differences of the used controlpoints, type of GCPs (e.g. at intersection of linear features in different angles, corner of the rectangular features in different background, centre of the circular features, edges of the linear features etc), accuracy of GCPs etc. On the basis of the findings of this study it is suggested for the further researchers that there is no point in experimenting with orientation using more than 5 control points for refinement and use of other than affine transformation algorithm

## References

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