

# TIN Based Geometric Correction with GCP

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**Abstract :** The mainly used technique to correct satellite images with geometric distortion is to develop a mathematical relationship between pixels on the image and corresponding points on the ground. Polynomial models with various transformations have been designed for defining the relationship between two coordinate systems. GCP based geometric correction has performed overall plane to plane mapping. In the overall plane mapping, overall structure of a scene is considered, but local variation is discarded. The Region with highly variant height is rectified with distortion on overall plane mapping. To consider locally variable region in satellite image, TIN-based rectification on a satellite image is proposed in this paper. This paper describes the relationship between GCP distribution and rectification model through experimental result and analysis about each rectification model. We can choose a geometric correction model as the structural characteristic of a satellite image and the acquired GCP distribution.

**Key Words :** Ground Control Point, Geometric Correction, TIN.

## 1. Introduction

There are two points of view to correct geometric distortion of satellite images. One is a system rectification which is a process to correct distortion by analyzing causes of geometric distortion systematically (Philpot, 2001; Lillesand and Kiefer, 1987). It easily corrects geometric error from all images in the same system if an inverse transformation of a system, a transformation from a scanned image with distortion to an original scene, is defined. But it is difficult to analyze causes of all distortions and to correct absolutely in the case of ground with high undulations. The other is a rectification with ground control points(GCPs) which corrects distortions by defining the mapping relation

mathematically between a scanned image and a base map without analyzing cause of distortion(Jensen, 1986; Vorrawat, Cheevasuvit, Dejihan, Mitatha, Somboonkaew, Richards, 1986). It corrects a geometrically distorted image more accurately than the systematical geometric correction if GCPs are accurately collected. But the rectification with GCPs is dependent on the accuracy of GCPs collection.

This paper focuses on the rectification method with GCPs and analyzes experimental results with various transformations. The Rectification with GCPs has been applied as a plane level correction, but it is hard to correct highly variable local regions and some distortions still remain in a rectified image. TIN based rectification proposed in this paper improves local errors

by transforming TIN by TIN. First, plane geometric correction method is described in the second section, and TIN based geometric correction method is introduced in the third section. The fourth section is about the result of each method numerically analyzed. Finally we conclude and introduce future work.

## 2. Plane Geometric Correction

Plane geometric correction is a method to rectify a satellite image by defining the mathematical relationship between GCPs and their corresponding image control points(ICPs). Suppose that a GCP is a point on X-Y plane and a ICP is a point on u-v plane. The mapping relation between GCP and ICP can be defined by some transformations such as affine, conformal, pseudo-affine, projective transformation and n-th order polynomial (Philpot.W 2001; Lillesand and Kiefer, 1987; Jensen, 1986). Affine transformation defines a mapping relation as follows.

$$\begin{aligned} u &= a_1x + b_1y + c_1 \\ v &= a_2x + b_2y + c_2 \end{aligned} \quad (1)$$

Eq.(1) needs three or more pairs of GCP and ICP for six affine parameters. Conformal transformation consists of four parameters in eq.(2) and needs two or more pairs of GCP and ICP.

$$\begin{aligned} u &= ax + by + c \\ v &= -bx + ay + d \end{aligned} \quad (2)$$

Pseudo-affine transformation is a bilinear form of affine transformation and represents mapping relation with eight parameters in eq.(3) and requires four or more pairs of GCP and ICP for pseudo-affine parameters.

$$\begin{aligned} u &= a_1x + b_1y + c_1xy + d_1 \\ v &= a_2x + b_2y + c_2xy + d_2 \end{aligned} \quad (3)$$

Projective transformation is more general than above transformations and defines mapping relation non-

linearly. It uses eight parameters and needs four or more pairs of GCP and ICP as shown by eq.(4).

$$\begin{aligned} u &= (a_1x + b_1y + c_1) / (a_3x + b_3y + 1) \\ v &= (a_2x + b_2y + c_2) / (a_3x + b_3y + 1) \end{aligned} \quad (4)$$

Eq.(5) is a linear form of projective transformation and also comprised eight parameters.

$$\begin{aligned} u &= a_1x + b_1y + c_1 - a_3xu - b_3yu \\ v &= a_2x + b_2y + c_2 - a_3xu - b_3yu \end{aligned} \quad (5)$$

Eq.(5) needs four or more pairs of GCP and ICP for computing the parameters. Finally, most widely used transformation for geometric correction is a method to get parameters by defining mapping relation with n-th order polynomial, a form of eq.(6), and requires n/2 or more pairs of GCP and ICP.

$$\begin{aligned} u &= c_1 + \sum_{j=0}^n \sum_{k=0}^{n-j} a_{jk} x^j y^k \\ v &= c_2 + \sum_{j=0}^n \sum_{k=0}^{n-j} b_{jk} x^j y^k \end{aligned} \quad (6)$$

These transformation parameters are applied to plane-level rectification and define mapping relation between spatial plane and image plane.

## 3. TIN based Geometric Correction

Transformation parameters under plane geometric correction are computed through least-square estimation process using pairs of control points more than the required. Some high variable region affects overall transformation and the distortion of the local region is not corrected well. Therefore, we construct TIN by a *Delauney triangulation method*(Guibas and Stolfi, 1985) and apply transformations described at second section to each TIN. Because every TIN consists of three GCPs, transformations with seven or more parameters- pseudo-affine, projective transformation and the second or higher order polynomial- cannot be used for TIN based

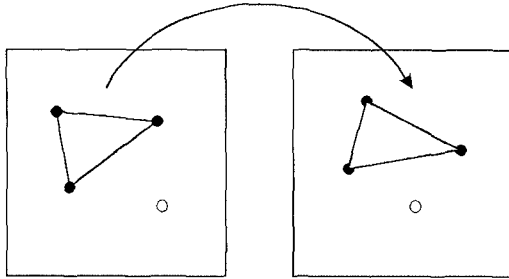


Fig. 1. TIN based geometric correction.

rectification. As shown in Fig. 1, transformation parameters are computed by TIN level.

A TIN consisting of three GCPs corresponds to a triangular patch comprised of three ICPs of an image. Each ICP of a triangular image patch corresponds to each GCP of a mapped TIN. Fig. 2, an IKONOS image of Daejeon, is resampled, which is shown in Fig. 3 by a TIN-level geometric correction with affine transformation. Fig. 4 shows a corrected image of Fig. 2 under plane geometric correction using affine transformation.

TIN-level geometric correction improves local errors but it can generate inconsistent boundaries of TIN, because a test image is corrected TIN by TIN. Image coordinates of patches' boundary of a corrected image make an error less than one pixel, but spatial coordinates are inconsistent at the boundary. There are three solutions for this problem as followings:

1. Use a linear displacement vector in a linear transformation
2. Use an average value
3. Compute the common parameters for TINs sharing boundaries

If we use a linear transform for the TIN-level correction, each coordinate of TIN boundary is expressed by a linear combination of coordinates of two peak points of a TIN and displaced by a linear transformation equation. After TIN-level correction is finished, we compute coordinates of each TIN boundary

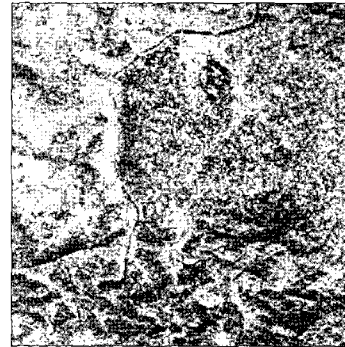


Fig. 2. IKONOS image.



Fig. 3. TIN based rectification.



Fig. 4. Plane rectification.

with linear combination. This method is limited to linear transformations. The simpler method is to allocate an average value of coordinates inside TIN to TIN boundary. This method is based on the hypothesis that variation of spatial coordinates inside each TIN is very low. The last method is to re-compute transformation

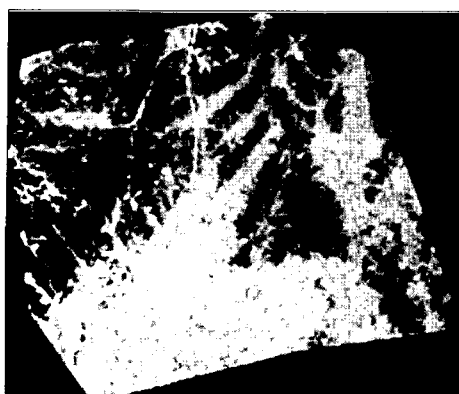


Fig. 5. TIN based rectification.

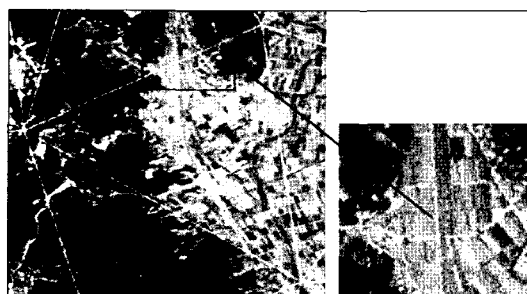


Fig. 6. Boundary of a TIN.

parameters for TINs with common boundary. Any method shows little difference and we used an average method to solve boundary inconsistency in this paper.

Fig. 5 is a result image of the TIN based rectification with an input image, KOMPSAT image of nonsan. A part of the image is cut in the left of Fig. 6, and it shows TIN boundary lines. The right part of the Fig. 6 shows that some area including TIN boundary is zoomed. This figure is resampling by an average method to solve boundary inconsistency. We can see that TIN boundary is smoothly resampled.

#### 4. Result Analysis

The mapping relation between GCP and ICP is changed according to each pair of GCP and ICP and the difference is big at the region with high variation of

ground. So, the plane level rectification applying least-square method to all pairs of GCP and ICP makes errors in the geometric correction of images with highly variable region. But we cannot guarantee with only a resampled image in Fig. 3 that TIN based geometric correction complements the defect of plane geometric correction if GCPs are not collected over various regions with various height. To verify that TIN-based geometric correction complements defects of plane geometric

Table 1. GCP list.

ID	Ground Control Point(GCP)		
	x	y	Z
1	3.528327e + 5	4.024984e + 6	6.882000e + 1
2	3.552423e + 5	4.024802e + 6	6.888000e + 1
3	3.569202e + 5	4.024683e + 6	6.712000e + 1
4	3.509735e + 5	4.023604e + 6	7.342000e + 1
5	3.591581e + 5	4.023168e + 6	8.596000e + 1
6	3.514869e + 5	4.020892e + 6	7.440000e + 1
7	3.503315e + 5	4.018708e + 6	8.877000e + 1
8	3.541701e + 5	4.018823e + 6	1.043800e + 2
9	3.563099e + 5	4.017989e + 6	1.510400e + 2
10	3.561400e + 5	4.015916e + 6	9.622000e + 1
11	3.503676e + 5	4.015972e + 6	8.512000e + 1
12	3.572693e + 5	4.021847e + 6	8.453000e + 1
13	3.508509e + 5	4.022260e + 6	7.671000e + 1
14	3.550191e + 5	4.020328e + 6	7.211000e + 1
15	3.583416e + 5	4.024119e + 6	8.100000e + 1
16	3.585379e + 5	4.016097e + 6	1.498900e + 2
17	3.568769e + 5	4.023851e + 6	6.334000e + 1
18	3.522042e + 5	4.019890e + 6	7.649000e + 1
19	3.568430e + 5	4.015051e + 6	1.058200e + 2
20	3.592710e + 5	4.021218e + 6	7.799000e + 1
21	3.597402e + 5	4.018934e + 6	1.310600e + 2
22	3.496534e + 5	4.021475e + 6	7.867000e + 1
23	3.598908e + 5	4.016884e + 6	1.353800e + 2
24	3.505233e + 5	4.020185e + 6	1.018100e + 2
25	3.508803e + 5	4.024827e + 6	7.196000e + 1
26	3.554730e + 5	4.021519e + 6	6.898000e + 1
27	3.543366e + 5	4.014584e + 6	1.184800e + 2
28	3.579156e + 5	4.022690e + 6	6.853000e + 1
29	3.516403e + 5	4.023012e + 6	7.038000e + 1

correction, we tried numerical approach. We used an affine transformation to compare TIN based rectification with plane rectification and computed variance of each pair of GCP and ICP and that of each affine parameter. Fig. 2 is a test image. Table 1 shows a GCP list used in this experiment.

Fig. 7 is a graph showing variance of pairs of GCP and ICP under affine transformation in plane rectification and shows difference of variances of pairs of GCP and ICP. Variance of each pair of control points is slightly different but control points of id 11, id 26 and id 27 in the list of Table 1 are widely different from variances of others in the figure 7. This implies that distribution of variance of ICPs mapped to GPCs by affine transformation affects accuracy and reliability of affine parameters and that errors increase under plane rectification.

Affine parameters in plane rectification are listed in the Table 2. Figure 8 shows difference value between GCPs and coordinates computed by an inverse

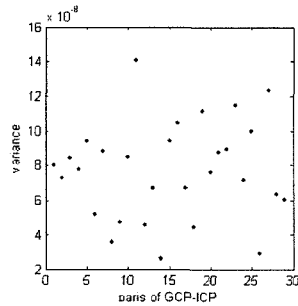


Fig. 7. Variance of ICPs mapped to GCPs by affine transformation under plane rectification.

Table 2. Affine parameters.

Parameter	Value
$a_1$	$9.937952e - 001$
$b_1$	$-1.393752e - 002$
$c_1$	$-3.121805e - 003$
$a_2$	$6.890367e - 002$
$b_2$	$-9.898057e - 001$
$c_2$	$1.564162e - 002$

transformation of corresponding ICPs with affine parameters of Table 2.

Fig. 8 shows that the difference of variance of control points affects reliability of plane rectification method. If the number of pairs of GCP and ICP is more than that of

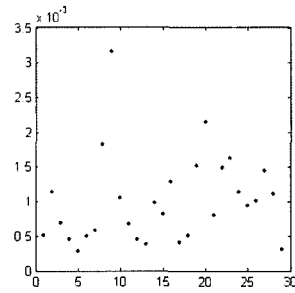


Fig.8. Difference between GCPs and coordinates computed by inverse transformation.

Table 3. TIN List.

TIN ID	GCP ID	TIN ID	GCP ID
1	1 2 3	23	7 8 18
2	1 2 26	24	7 11 22
3	1 4 25	25	7 18 24
4	1 4 29	26	7 22 24
5	1 26 29	27	8 9 10
6	2 3 17	28	8 9 14
7	2 17 26	29	8 10 27
8	3 15 17	30	8 14 18
9	4 13 22	31	8 27 11
10	4 13 29	32	9 10 16
11	4 22 25	33	9 12 14
12	5 15 28	34	9 12 21
13	5 20 21	35	9 16 21
14	5 20 28	36	10 16 19
15	6 13 22	37	10 19 27
16	6 13 29	38	12 14 26
17	6 14 18	39	12 17 26
18	6 14 26	40	12 17 28
19	6 18 24	41	12 20 21
20	6 22 24	42	12 20 28
21	6 26 29	43	15 17 28
22	7 8 11	44	16 19 23
		45	16 21 23

control points required for computing affine parameters, we generally get statistical values with least-square method. In the case that variance of control points is considerably different from each other, it causes parameters to be compute with error and satellite images are corrected with distortion. But without using all pairs of control points, we get a unique set of parameters TIN by TIN. Table 3 is a list of TINs created with GCPs by Delauney triangulation method(Guibas and Stolfi, 1985). From a mapping relation between TIN and triangular image patch, a unique set of affine parameters is computed and a coordinate system of transformed triangular patch keeps the same to the coordinate system

of TIN.

Figs. 9 to 14 are graphs of affine parameters in TIN based rectification. At each figure, blue points are values of affine parameters in TIN based rectification and red lines are values of affine parameters in plane rectification. Figs. 9, 10, 11, 12, 13 and 14 are graphs of parameter  $a_1$ ,  $b_1$ ,  $a_2$ ,  $b_2$ ,  $c_1$  and  $c_2$ , respectively.

In each graph of parameters, TIN 44 with big difference against other TINs consists of GCPs of id 16, id 19 and id 23 and has a large variance under plane rectification. TIN 14 and TIN 29 also have big difference against the other TINs consisting of GCPs with large variance, because a highly undulating region is constructed to form a TIN. This means higher undulate it is, more errors it has. It also means that TIN based rectification depends on the method of TIN construction.

## 5. Conclusions

We proposed TIN based rectification for decreasing accumulative errors over all pairs of GCP and ICP. The overall error of an image is decreased by constructing TIN with GCPs and transforming TIN by TIN. We also introduced three solutions for the boundary inconsistency in TIN based rectification. According to the experiments and analysis, TIN based rectification is dependent on the method of creating TIN and also controlled by accuracy of the mapping relation between GCP and ICP. We have further work with respect to this problem.

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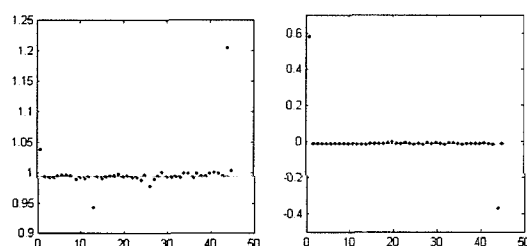


Fig. 9. Parameter  $a_1$ .

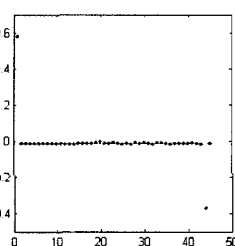


Fig. 10. Parameter  $b_1$ .

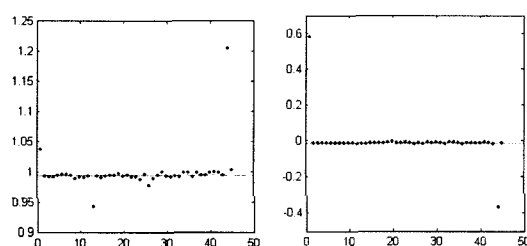


Fig. 11. Parameter  $a_2$ .

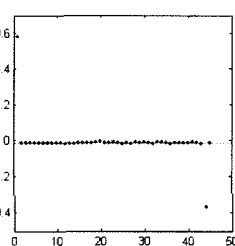


Fig. 12. Parameter  $b_2$ .

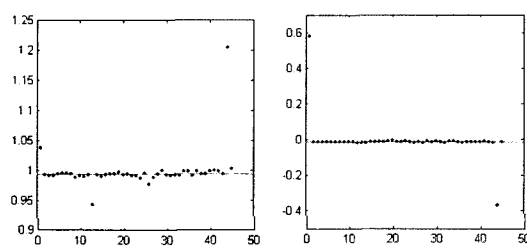


Fig. 13. Parameter  $c_1$ .

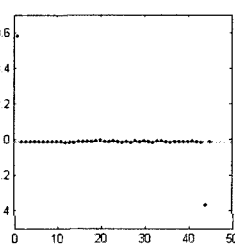


Fig. 14. Parameter  $c_2$ .

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