Geometric Correction of High Resolution Satellite Data - Effect of the Distribution, Accuracy and Number of GCP

Thilantha Lakmal Dammalage
Asian Institute of Technology
PO Box 4, Klong Luang, Pathumthani, Thailand.
Thilantha.dammalage@ait.ac.th

Lal Samarakoon
Earth Observation Research Center, Japan Aerospace Exploration Agency,
Triton Square Office Tower-X 23F, 1-8-10 Harumi, Chuo-ku, Tokyo, Japan.
lal@ait.ac.th

Susaki Janichi
Asian Institute of Technology
PO Box 4, Klong Luang, Pathumthani, Thailand.
susaki@ait.ac.th

ABSTRACT: High resolution satellite data is becoming as an indispensable data source in large scale mapping due to affordable cost and possibility of supplying data on-demand. Among currently available and most successful sources are IKONOS and QuickBird that belong to commercial agencies. Panchromatic band of QuickBird is providing 0.61 meters ground resolution that can easily be used to derive high accuracy large-scale maps from space data.

Spatial accuracy of the information extracted from these high-resolution images highly depends on the accuracy of the geometric properties of images provided by vendors. Further, in most of cases users heed to carryout their own geometric correction to adjust satellite data for their respective projection and coordinate system primarily with Ground Control Point (GCP).

This study evaluates the effect of GCP accuracy, distribution and the number of GCP's in the processes of geometric correction of QuickBird data over Bangkape area of Bangkok. More than 50 GCP's over different locations were collected using GPS instruments that provide different accuracies based on receiving frequencies. Also, points were collected considering shape, location, distribution and observation time. Analysis was carried out to find the optimal number of GCP for a scene, accuracy changes due to single frequency and dual frequency observations, best suitable shapes of GCP's etc. Also, this paper discusses data collection as a practical point of view.

Keywords: QuickBird Satellite Image, Geometric Correction, Accuracy, GCP, GPS

1. Introduction

Satellite images are vital tool in various applications such as land use and land cover mapping and have been providing information for the various Geographic Information System (GIS) data analysis. With the technology development the pixel resolution (Spatial Resolution) of remotely sensed data becoming finer. Because of this improvement of the spatial resolution, application of satellite images in the field of large-scale mapping and high accuracy DEM generation is becoming popular and demanding. At present there are number of sensors that produces high resolution data with spatial resolution 2m or smaller. Some of them are SPOT-5, CARTOSAT-1, IKONOS and QuickBird.

Since the successful launch of DigitalGlob's® QuickBird satellite in to the orbit on October 18th, 2001 with 61-72cm (2-2.4ft) panchromatic and 2.44-2.88m (8-9.4ft) multispectral sensors (depending upon the off-nadir viewing angle (0°-25°)), (www.pcigeomatics.com/company/papers/eom_quickbird_2003.pdf) and these satellite imagery has narrow down the gap between the use of aerial photographs and satellite images for the information extraction for large scale mapping from the space data. Further more, it also has along-track and/or across-track stereo capability, large area coverage, and the ability to take images over any area, especially hostile areas where airplanes cannot fly, are certainly the major advantages over the use of aerial photos.

However for the precise and reliable information extraction from the remotely sensed data a process referred to as geometric correction has to be carried out in order to remove the geometric distortions cause during the process of image acquisition. The objective of this pre-processing of remotely sensed data is to make the image objects geometrically correct, introducing relative or absolute location of each pixel with respect to there position on the Earth in order to use images as same as maps. Therefore the precession of the geometric correction is directly affecting the accuracy of the information extracted and also the required accuracy of the geometric correction depend on the application of the remotely sensed data using and the spectral resolution. For an example, large scale mapping of an urban area using high-resolution satellite data like IKONOS or QuickBird, a precise geometric correction is very much necessary to perceive the geometric accuracy requirement for the large-scale mapping.

Geometric correction can be carried out in two ways. One is mathematically model all physical components of viewing geometry to carry out the geometric correction. In commercial satellites, these information's are not provided and in most cases it is difficult to obtain all information with sufficient accuracy. The most adopted method is correcting the image geometry using polynomial transformation with a set of ground control points (GCP). These are the points that can be clearly identify over the image with the ground coordinate.

Traditionally in photogrammetry, targets are often placed in fields at known (surveyed) locations to supply ground control points. When selecting ground control points for the remote sensor data, generally the main concern is to select an area that has large spectral difference or that supply a target with high contrast. There are several methods of collecting the GCP's. Some of the methods are collecting GCP's using topographic maps, Large-scale maps and Global positioning system (GPS). But the methods of collecting GCP's are mainly depending on the accuracy requirement of the GCP's for the particular geometric correction and the spatial resolution of remotely sensed data. As the spatial resolution of the satellite images getting finer with the technology progress the use of GPS instruments for the GCP collection also getting more common due to the high accuracy and the reliability of the GPS positioning after the termination of the Selective Availability (SA) of the GPS signal degradation on 1st May, 2000 by the US department of defense (DOD).

The purpose of geometric correction is to compensate the geometric distortions due to the systematic errors and random errors. Systematic errors are those that can be modeled, because the errors are well understood and behave in a predictable manner. Random errors are not predictable in magnitude or in sign. Almost all the commercial remote sensing software's, these errors corrected base on polynomial transformation functions and the coefficients of the polynomials solve with the use of selected ground control points. Resampling methods including nearest neighbor, bilinear and cubic convolution used. Depending on the geometric distortions, the order of the polynomials will be determined and the number of GCP should be more than the number of unknown parameters. For this study we have been used the ENVI 4.0 commercial remote sensing software.

In this paper, we investigate the geometric correction of high-resolution satellite data (spatial resolution of less than sub-meter, QuickBird, 0.61m) with the GCP's collected using GPS instruments that have different accuracy, based on different GPS observation methods. The two main GPS instruments used are hand held GARMIN III^{+} receiver (single frequency L1) and TRIMBLE ProXR duel frequency (L1, L2) receiver with the real-time BECON signal receiving capability. The Department of Town and Country Planning (DTCP), Thailand provided Bangkok Base station observation in order to archives the differentially corrected (DGPS) ground control points (GCP's). The post-processing of the Base data and the rower data were carried out with using Trimble Pathfinder office software, version 3.0.

2. Objectives of the study

The GCP's can be collected over different geometrical places with different accuracy GCP's observed using different GPS instruments and different observation methods. The main objective of this study is to analysis the effect of these factors in the process of geometric correction of QuickBird, 0.61m spatial resolution satellite images with different number of GCP's and different degree of polynomial transformation functions.

3. Study Area and Data set

3.1 Study Area

Study area is located in Bangkape (13°44'N, 100°37'E) southern part of the downtown Bangkok city, Thailand. This area is a build up area with dense commercial and residential buildings located over flat terrain of 5Km by 4.5Km.

3.2 Data Set

3.2.1 Satellite Image

For this study, panchromatic with 0.61m spatial resolution and multi-spectral with 2.44m spatial resolution were used. Image was acquired 2^{nd} November 2002. This QuickBird image was provided as *Standed Imagery Products*, which designed for users acquainted with remote sensing applications and image-processing tools that require data of modest absolute geometric accuracy. These standard imagers are radiometrically calibrated, corrected for sensor and platform-induced distortions, and map to a projection system. This image mapped base on Universal Transverse Mercator (UTM), zone of 47 North on the WGS84 ellipsoid.

3.2.2 Ground Control Points

In this study about 50 GCP's were collected over different locations using four different GPS data collection methods base on the WGS 84 ellipsoid and the Universal Transverse Mercator (UTM) projection system. These four methods provide four different coordinates for each GCP location with four different accuracies. Hence, the effect of GCP accuracy on the process of geometric correction can be analysis. The GCP's were collected with using GARMIN III^+ hand held L1 GPS receiver and TRIMBLE ProXR dual frequency (L1 and L2) GPS receiver.

The methods used for the GCP collection were,

1. Hand held GPS observations with GARMIN III^+ receiver.
2. Uncorrected short time static GPS observations with using Trimble ProXR GPS receiver. For this method the observations were carried out for about 15 minute to 20 minute with 5 second logging interval.
3. Real Time Corrected short time static GPS observations with the DGPS correction broadcasts by Bangkok harbor conforming to the IALA (International Association of Lighthouse Authorities) standards. Observations were carried out with the same Trimble ProXR GPS receiver for about 10 minute to 15 minute with 5 second logging interval.
4. Differential GPS (DGPS) post-processing correction method. In order to get the DGPS corrected GCP's used the above discuss method number three (3) row data as the rower data and the Department of Town and Country Planning Bangkok Base station observations as the base data. Trimble pathfinder office software, Version 3.0 used for the post-processing.

In order to evaluate the effect of distribution of GCP's over image, and the number of GCP's in geometric correction process, GCP's were collected over different geometrical locations such as road junctions, ground level sharp corners, ect. Figure 2 shows some examples of collected road junctions. And the figure 3 shows some examples for ground level sharp corners.

- The figure 3.2.1 and figure 3.2.2 shows a road junction in the field and in the QuickBird satellite image respectively. The point that selected as a GCP has good contrast to make it sharp in the image and easy to identify in the field also. So a point like this in a road junction provides a better ground control point.
- The figure 3.2.4 also shows a road junction but in this case the bending point is not sharp like the first case. The figure 3.2.3 shows the corresponding bending point of the road junction. So the GPS observation was carried out in the center of the bend and in the image also the point observation can be easily identify.
- We collected 26 GCP's in the bending corners of the road junctions. These are the maximum number of GCP's collected over a same geometrical location (Road Junctions) due to easy accessibility, availability of allover the image and clear identification on the image.

Figure 3.2.1 Road junction corner, GPS observation.

Figure 3.2.2 Road junction, QuickBird image. (QuickBird and courtesy DigitalGlob's®)

Figure 3.2.3 Road junction corner, GPS observation.

Figure 3.2.4 Road junction, QuickBird image. (QuickBird and courtesy DigitalGlob's®)

Due to the high spatial resolution (0.61m) of the QuickBird satellite image the bend of a road junction is clearly visible and it's providing an accurate GCP for the geometric correction.

- 16 GCP's were collected over the sharp geometrical locations that identified over the image. For example a corner of a tennis court in the image and the field it can be identify very easily (figure 3.2.5 and Figure 3.2.6). And also the corner of a water body is very sharply appearing over the image, like an edge swimming pool. (Figure 3.2.7 and Figure 3.2.8)
- The figure 3.2.9 and Figure 3.2.10 shows a center of a basketball field, the GPS observation was carried out in the center of the circle and it can be easily identify over the image. So this provides a better ground control point.
- Altogether for the geometric correction 47 GCP's were collected with respect to different types of geographical locations. Figure 4.2 shows distribution map of GCP's.

Figure 3.2.5 Tennis court corner, GPS observation.

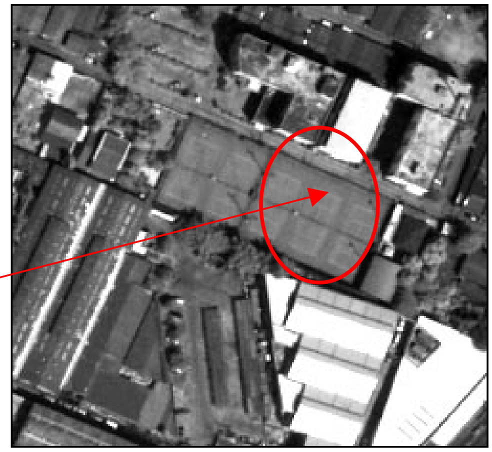

Figure 3.2.6 Tennis court, QuickBird Image. (QuickBird and courtesy DigitalGlob's®)

Figure 3.2.7 Swimming pool corner, GPS observation.

Figure 3.2.8 Swimming pool, QuickBird Image. (QuickBird and courtesy DigitalGlob's®)

Figure 3.2.9 Basketball court center, GPS observation.

Figure 3.2.10 Basketball court, QuickBird Image. (QuickBird and courtesy DigitalGlob's®)

Due to the high spatial resolution (0.61m) of the QuickBird satellite image the sharp object corners are clearly visible and it's providing an accurate GCP for the geometric correction.

4. Methodology

4.1 GCP Collection

This research work carried out according to the flow that shown in the flow chart. Figure 4.1. The GCP's were collected using GPS instruments described in the last chapter (3.2.2 Ground Control Points). And also the GPS observation methods used for GCP collection and the different geographical locations also described in the same chapter (3.2.2 Ground Control Points). Figure 4.2 shows the map of all collected GCP with there spatial distribution.

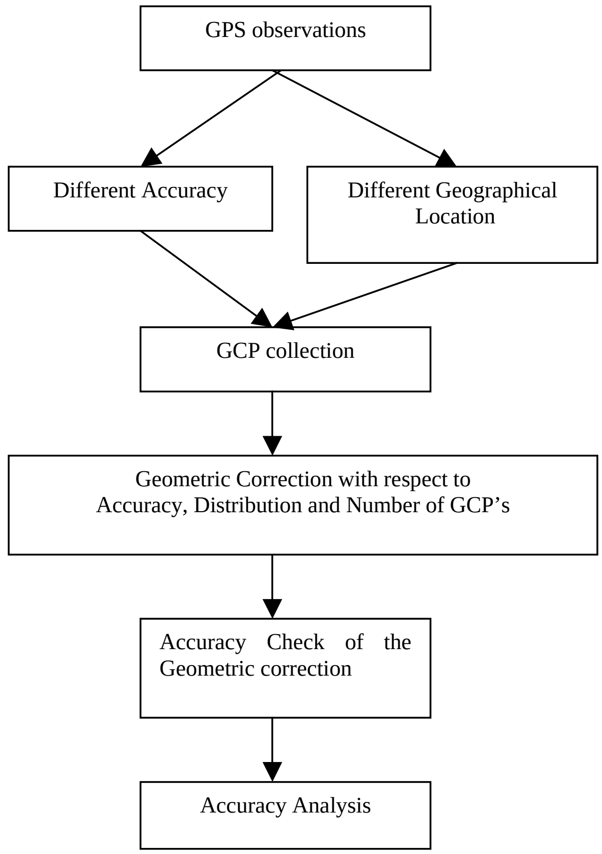

Figure 4.1 The flow chart of the study.

4.2 Geometric Correction

Based on these collected ground control points, geometric correction was carried out with respect to accuracy, distribution and number of GPS's with using ENVI 4.0 commercial remote sensing software. Geometric correction perform according to 2 combinations of GCP's. Each of these GCP combinations were satisfying the well distribution condition of GCP's over the image. Those combinations are,

The first combination was with GCP's with different geographic locations and have a 1st degree polynomial transformation. According to the change of the number of points and the different accuracy of the GCP's it is possible to have many different combinations to have a better analysis. The resulted RMS errors of these combinations are shown in the Table 5.1.The second combination is to change the number of GCP's and have a 1st degree polynomial transformation. Similar to first case here also it's possible to have many different combinations with different accuracy GCP's. Using this same combination it is possible to check the effect of GCP accuracy for geometric correction process. The resulted RMS errors of these combinations are shown in the Table 5.2.

And also it's possible to have different geometric corrections according to the different degree of the polynomial transformation. For this study, 1st, 2nd and 3rd order polynomial transformations were used to see the variation in errors. The resulted RMS errors of different polynomial transformations with respect to the different accuracy of the GCP's are shown in the Table 5.3.

4.3 Accuracy Measurement

After the geometric correction the checking the accuracy is very important. So in order to check the accuracy of the geometric correction three types of GPS observations were carried out. 1) Point features, static GPS observation 2) Linear features, Kinamatic GPS observation 3) Circular features, Kinamatic GPS observation. These GPS observations used to measure the qualitative and quantitative accuracy of the geometric correction.

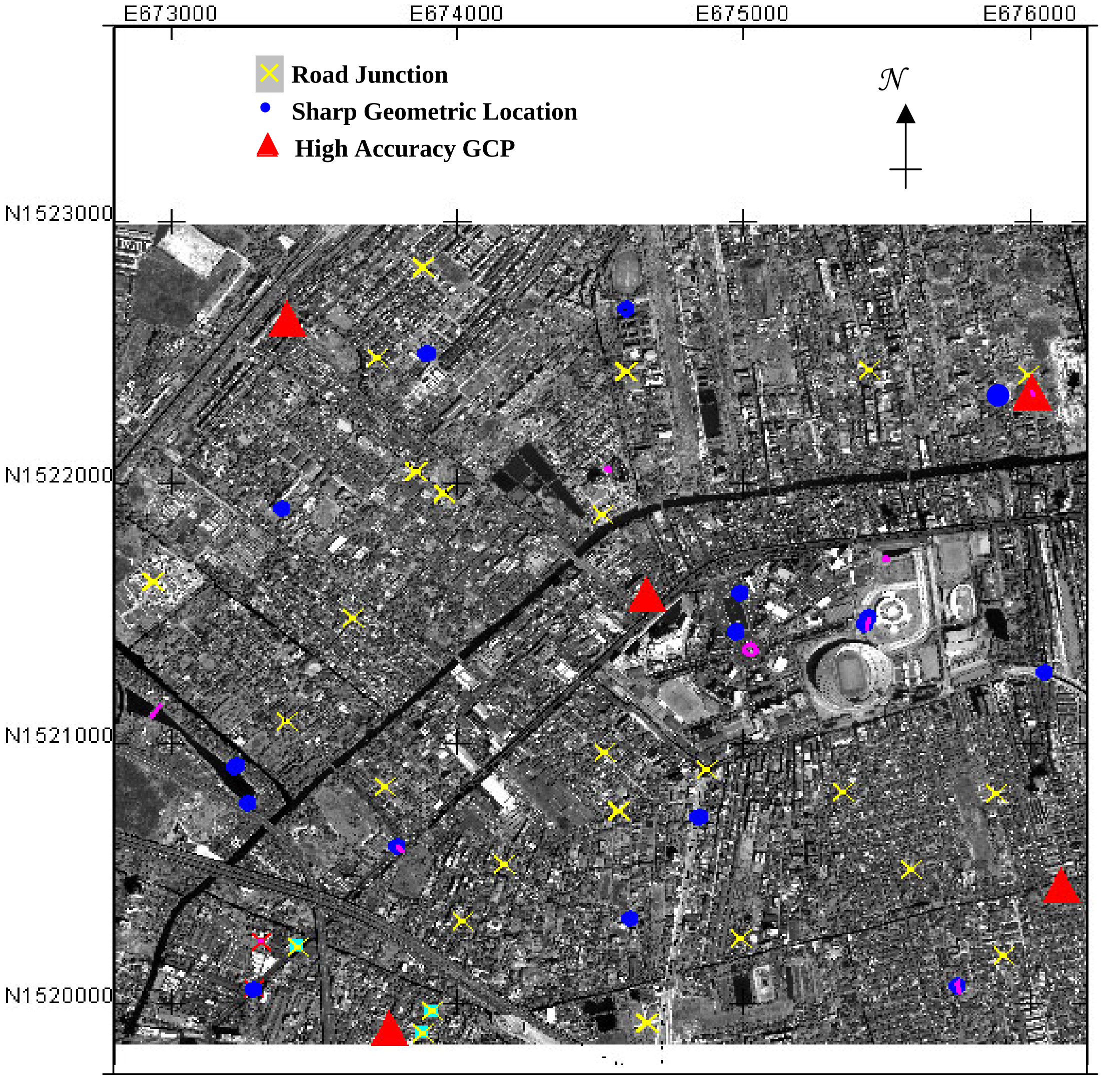

Figure 4.2 Observed Ground Control Points Distribution.

5. Result and Discussion

The results of the present work is summarized as below,

- Figure 5.1 shows the spatial distribution of the GCP's (20) selected for the geometric correction.
- For the GCP based geometric transformation the comparisons of Root Mean Square (RMS) errors, according to the different combinations as follows showing in the following tables.

  1. Table 5.1 compare the RMS error according to the geometric location and GPS.
  2. Table 5.2 compare the RMS error according to the number of GCP's and GPS observation method.
  3. Table 5.3 compare the RMS error according to the Degree Polynomials Transformation and GPS observation method.

1st Degree Polynomials Transformation RMS Errors According to Geometric Locations					
Geometric Location	**Number of GCP's**	**Uncorrected**	**Hand Held GPS**	**RT_Corrected**	**DGPS**
Sharp Object	5	1.693	1.389	0.496	0.103
Road Junction	5	1.015	3.135	0.734	0.317
Sharp Object	9	1.754	2.452	0.935	0.607
Road Junction	9	1.434	4.909	1.462	1.263

Table 5.1 RMS errors according to the geometric location and GPS observation method

1st Degree Polynomials Transformation RMS Errors					
Number of GCP's	**Uncorrected**	**Hand Held GPS**	**RT_Corrected**	**DGPS**	**HA_GPS(DGPS)**
5	1.693	1.389	0.496	0.103	0.039
9	1.754	2.452	0.935	0.607	-
20	2.170	5.172	1.488	1.393	-

Table 5.2 RMS errors according to the number of GCP’s and GPS observation method

RMS Errors According to the Degree Polynomials Transformation (20 GCP’s)					
PT_Degree	**Uncorrected**	**Hand Held GPS**	**RT_Corrected**	**DGPS**	**HA_GPS(DGPS)**
1st	2.170	5.172	1.488	1.393	0.039
2nd	1.844	4.564	1.152	0.986	-
3rd	1.200	1.642	0.955	0.551	-

Table 5.3 RMS errors according to the Degree Polynomials Transformation and GPS observation method.

RT_Corrected : Real time corrected GCP, **HA_GPS(DGPS) :** High accuracy GCP, DGPS corrected,
PT_Degree : The degree of the Polynomial Transformation

For each and every combination of GCP’s in a polynomial, a better distribution (Figure 5.1) over the image was considered. For comparison of RMS error (Table 5.1) with the geometric location, GCP’s were selected to have the same distribution with sharp geometric objects and road junctions. And also for eliminate effect of pointing error (error due to the different of pointing the same point in the image) same image coordinate were used when assigning the GCP coordinate in different Accuracies (due to different GCP observation methods).

- According to the resulted RMS error describes in Table 5.1, the geometric location of the GCP is affecting the value of the RMS error. Sharp object corners resulting better value than the road junctions for all the GPS observation methods. And also with the increase of accuracy GPS instrument the RMS value getting better.
- Hand held single frequency GPS also providing a better RMS when it is observed over a sharp object corner, but for the road junctions its shows a relatively poor RMS value.
- According to the resulted RMS error describes in the Table 5.2, the high accuracy GCP’s shows the best RMS error. Also it can be clearly see that the accuracy of the GPS observation method is affecting the RMS value and getting better with the high accuracy GPS observation methods.
- With reference to the Table 5.2, when the number of GCP’s increasing the RMS error getting increases. This tendency is following for all the GPS observation methods. Further studies have been carrying out to identify the pattern and the reason for this behavior.
- According to the resulted RMS error describes in the Table 5.3, when the degree of the Polynomial Transformation getting higher as 1st, 2nd and 3rd , the value of RMS error also improve for all the GPS observation methods.

- If high accuracy GPS observation methods like DGPS corrected GCP's or real time corrected GCP's are used better RMS error in the geometric correction is achieved and it does not depend on the geometrical location. But for these observations need expensive GPS receivers and have to spend more time for observations.

Figure 5.2 shows the very long (each one more than 1200m) linear features observed using kinamatic GPS observation method to check the qualitative accuracy of the geometric correction. These observed lines are providing a good accuracy (DGPS corrected) and the well distribution over the image. Also these lines are spreading to almost all directions of the image so they provide a good check for the geometric correction. For the collection of these lines the GPS instrument fixed over a vehicle and drive along one edge of the road maintaining approximately a constant velocity and a fixed offset to the edge of the road. To make the observed lines smoother maintain a relatively low speed (around 40 Km/H) and recorded the observations with an interval of one second. This minimizes the gap between two loggings (recording coordinates) and makes the line smooth.

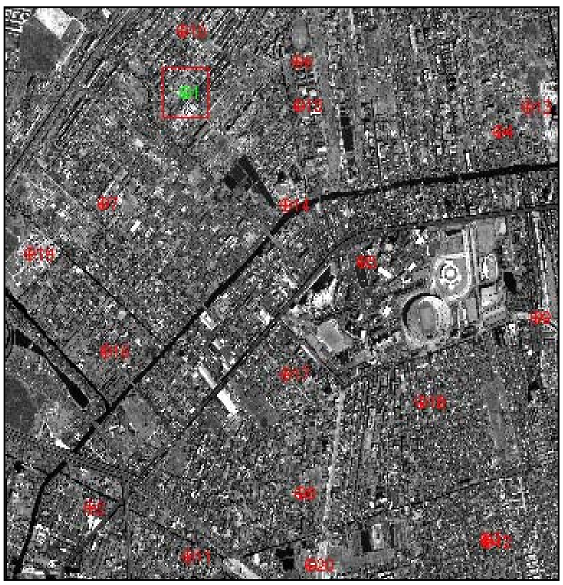

Figure 5.1 The selected GCP's Distribution for the geometric correction with 20 GCP's.

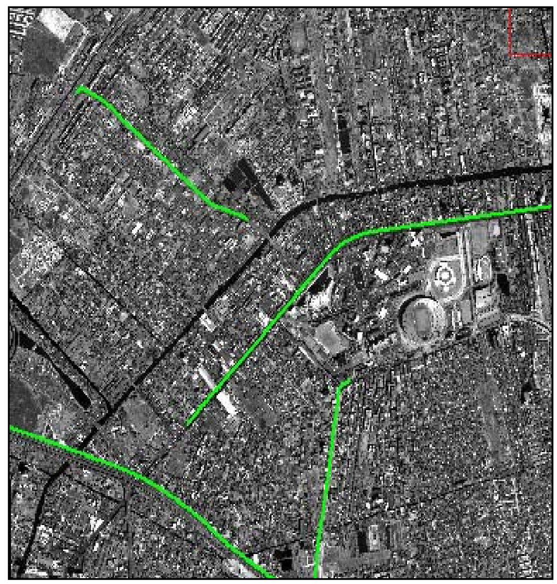

Figure 5.2 The four long linear feature collected using Kinamatic GPS observation method.

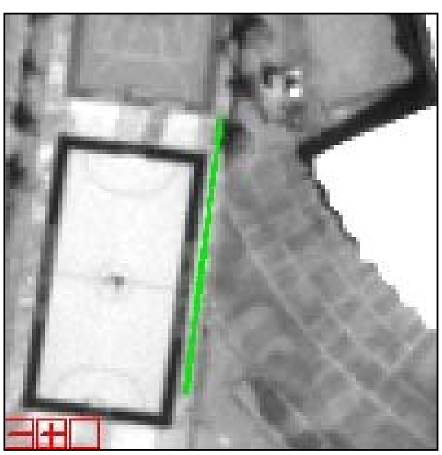

Figure 5.3 A linear feature collected using Kinamatic GPS observation method (DGPS corrected), overlay before geometric correction of the image.

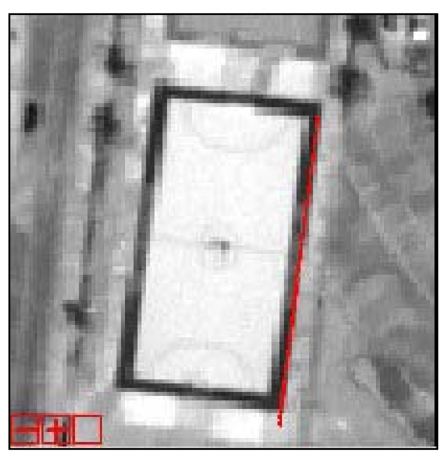

Figure 5.4 A linear feature collected using Kinamatic GPS observation method (DGPS corrected), overlay after geometric correction of the image.

The figure 5.3 and figure 5.4 shows a linear feature overlay over the image before geometric correction and after geometric correction of the image. This line is a kinamaticaly observed GPS line and post-processed with the base station data to achieve the DGPS accuracy. Figure 5.5 and Figure 5.6 shows a kinamaticaly observed GPS line, post-processed with the base station data to achieve the DGPS accuracy. The overlay of this accuracy circular feature over the image before and after geometric correction is shown in the Figure 5.5 and Figure 5.6 respectively.

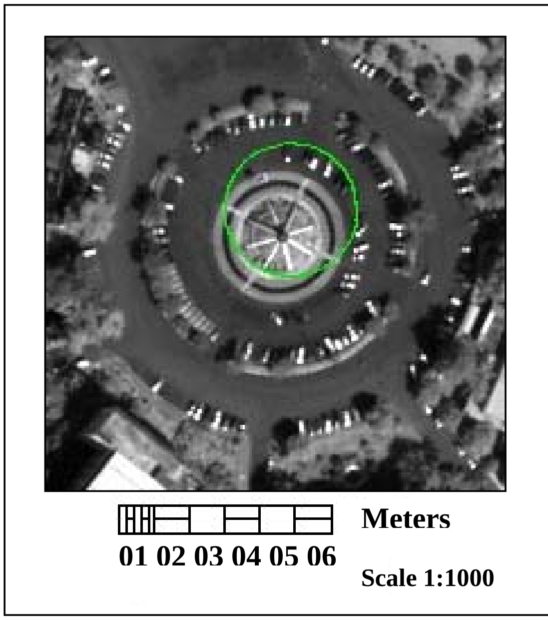

Figure 5.5 A circular feature collected using Kinamatic GPS observation method (DGPS corrected), overlay before geometric correction of the image. (Scale 1:1000)

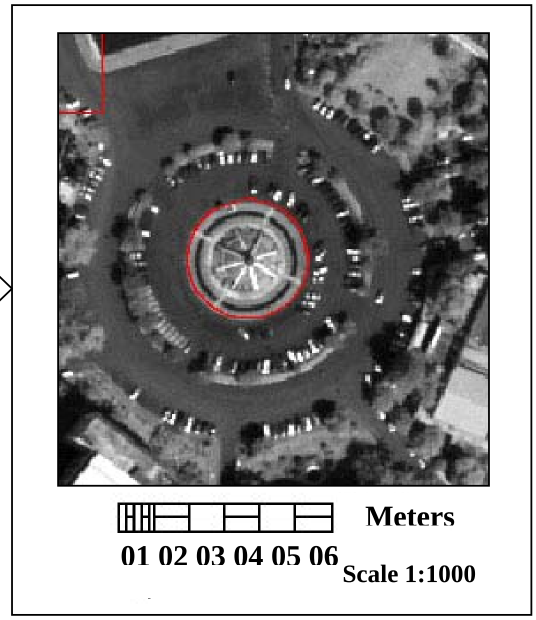

Figure 5.6 A circular feature collected using Kinamatic GPS observation method (DGPS corrected), overlay after geometric correction of the image. (Scale 1:1000)

6. Conclusions

The conclusions of the present work are summarized below,

- Minimum of 5 high accuracy well distributed GCP's and 1st degree polynomial transformation is sufficient to perform the geometric correction of a high resolution image over a flat area.
- Due to the better availability and the geometry (PDOP<3.0 for most of the observations) of the GPS satellite over this area the effect of the GCP's that observed by hand held GPS and the Uncorrected GCP's observed using duel frequency GPS receiver not show significant difference in geometric correction.
- Sharp object corners on the ground (not elevated) are the best choice as the GCP observation locations for the hand held (one frequency L1) GPS observations. High accuracy GCP collection methods such as DGPS corrected and real time corrected even using road junctions it is possible to achieve relatively a better RMS value for the geometric correction.
- Hand held GPS observations are relatively faster to observe and cheaper to carried out than high accuracy GPS observation methods. Accuracy is diminishing but usage can be decided with applications.
- Road junctions are the easiest accessible locations to collect GCP's and the most available over the images than the sharp object corners. But geometric accuracy is lower than sharp object corners.
- Liner and circular GPS observations are providing both qualitative and quantitative check for geometric correction.

7. Further studies

Study is continuing to examine the reason for diminishing accuracy with the increase of number of points. Methods will be developed to use linear features to use in geometric correction.

Acknowledgement

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