GEOREFERENCING MULTI-TEMPORAL AND MULTI-SCALE IMAGERY IN PHOTOGRAMMETRY

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ABSTRACT:

In recent decades, photogrammetrists have been exploring the georeferencing approaches that can improve consistency, completeness, and reliability of referenced spatial information. In this paper, an economic feasible georeferencing method is presented. The research data is from Finnish Jabal Haroun Project (FJHP). The primary objectives of the photogrammetric documentation in FJHP have been to provide the archaeological survey group with local topographic maps and the excavation group with 3-D models and drawings. The data are often given in various different coordinate systems because there is no network of control points which existed originally. The differences in coordinate systems have been problematic for archaeological analysis and yielded inaccurate results. It would be important for the archaeologists that all the multi-temporal and multi-scale imagery (multi-image) as well as other data could be integrated into one coordinate system. This paper presents recursive georeferencing method which is performed by using bundle block adjustment in multi-temporal and multi-scale imagery blocks. New points can be obtained from block adjustment of images and can be used as control points in the block adjustment of the next scale. After the implementation of this approach, ten points are derived from different scale imagery– 1:30000 aerial images, 1:15000 aerial images and terrestrial images, respectively. Consequently, coordinate difference is within 2m tolerance. It turns out that the blocks are stable and reliable. As a result, all images are referenced to consistent coordinate system with desired accuracy. Consistency, completeness, and reliability of referenced spatial information are simultaneously improved.

1. INTRODUCTION

Georeferencing is to establish a relationship between images and object coordinate systems. It is crucial to make satellite and aerial as well as terrestrial imagery useful for mapping. The research of georeferencing methods has been developing for a long time. In photogrammetry, the georeferencing methods have direct georeferencing and indirect georeferencing according to different ways in deriving exterior orientation parameters (EO) of images. For direct georeferencing, EO of images can be determined directly by the integrated inertial and satellite technology comprised of an INS, the receiver of GPS, and a computer. Recent research results and the technological developments in the navigation, positioning and orientation systems, result that the direct georeferencing is widely used. However, there are few potential drawbacks of GPS that cannot be ignored. The main drawback is its high sensibility to multi-path and interference, which are the two main sources of errors in range and position estimations (Moeness, A., 2004). In addition, most GPS receivers cannot provide the desired accuracy because the uncertainty of the positional deviation from its antenna(Cramer, M., 2002). For indirect georeferencing method, EO of image is determined by performing block adjustment, stereo-model set-up or mono-image resection. The number of needed control points depends on the methods of indirect georeferencing. A large amount of control points are required to orient images by the methods of stereo-model set-up or mono-image resection. The determination of control points is expensive and time consuming. Block adjustment can greatly reduce the number of control points. Nowadays bundle block adjustment is popularly used in photogrammetry field. It has more advantages (Kraus, K., 1997) than previous block adjustment methods (e.g. polynomial strip adjustment, independent models).

i) It introduces the direct relation between image and ground coordinates; therefore, it is the most accurate method of aerial triangulation.
ii) It greatly reduces the number of GCPs.
iii) It achieves consistent mapping accuracy over the entire block.
iv) It provides the possibility of incorporating additional parameters in the process of the adjustment, such as interior orientation parameters, field-surveyed observations and so on.

Based on above advantages, the method of bundle block adjustment is widely used.

Our research work on georeferencing method is based on bundle block adjustment. The data is original from FJHP. The FJHP focuses on archaeological documentation of a Byzantine monastic complex and its environments on the Mountain of Prophet Aaron in Jordan. The data are often given in various different coordinate systems because there is no network of control points which existed originally. The available cartographic data consisted of 1:50,000 topographic maps, DEM with 5 m grid, satellite orthophoto with resolution 1.532 m/ pixel, two sets of aerial photographs in 1:30000 scale and 1:15000 scale, and also terrestrial images with different camera parameters. The 1:50000 topographic map was based on 1961 aerial photography. Satellite orthophoto was from 1999. For two sets of aerial photographs, scale in 1:15000 was from 1981 and scale in 1:30000 was from 1987. Terrestrial images were acquired during several years between 1997 and 2007. They were taken by amateur digital cameras with different focal lengths and different viewing angles (Figure 1.1).

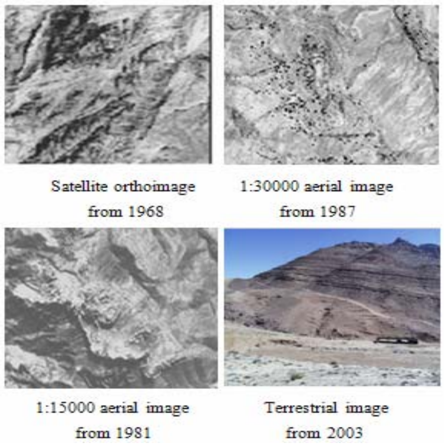

Figure 1.1 All types of georeferencing images

The problems derived from the source data were: 1) Information inconsistency of the imagery because of difference in imaging time; 2) weak block geometry because the initial control points were derived from satellite orthoimage. 3) data accuracy inconsistency in the block adjustment caused by different scales of imagery. Figure 1.2 shows the distribution of control points from satellite orthophoto.

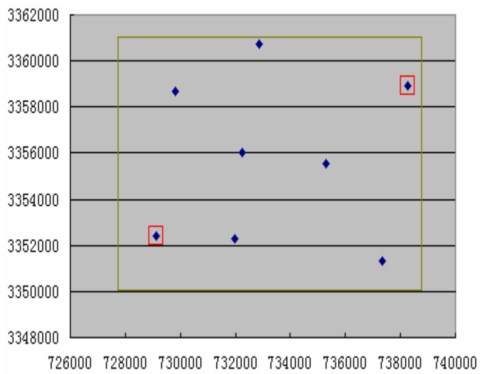

Figure 1.2 Control point distribution. Points in red frame are full control points while others are height control points. The outline indicates the entire area of KVR orthophoto.

This paper presents georeferencing method by using bundle block adjustment recursively in different scale image-block in order to strengthen internal block geometry and reference multi-imagery to consistent coordinate system. Different scale image blocks are referenced to each other by measuring some common points. That is to say, new points can be obtained from block adjustment of images and can be used as control points in the block adjustment of the next larger scale images.

The structure of paper is stated as follows. In section 2, georeferencing of two sets of aerial imagery as well as georeferencing of terrestrial imagery by satellite orthophoto will be covered. Then result and analysis will be described in section 3. The last section gives conclusion and discussion.

2. RECURSIVE GEOREFERENCING METHODS

Recursion is the process of connecting the global coordinate system to the local one, in order to connect the satellite and aerial imagery to the field surveys. The global coordinate system is defined by the satellite orthophoto. This is considered to be a preliminary control system, and the aerial image blocks are referenced to this. When adding the terrestrial images to the block, the local control points in the field become visible. In this case, multi-image is georeferenced to one common coordinate system by bundle block adjustment. Figure 2.1 shows the elementary principle of georeferencing multi-scale imagery. These georeferenced images include satellite orthophoto, 1:30000 aerial images, 1:15000 aerial images and terrestrial images. The georeferencing procedure in different scale imagery will be described in the following sections.

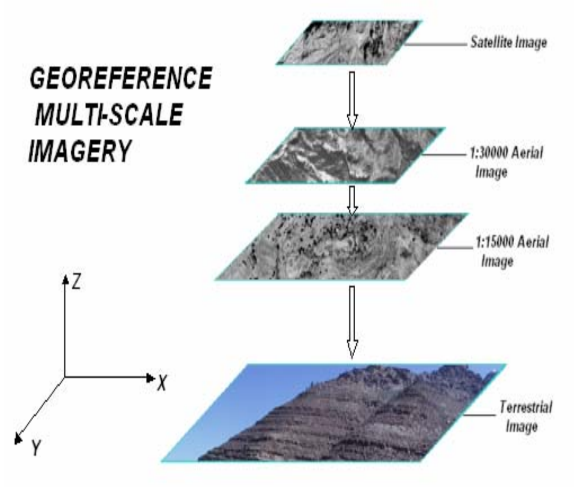

Figure 2.1 Georeferencing multi-scale imagery

2.1 Georeferencing by Satellite Orthoimage

As there were no field control points in Jabal Harun area, the source data provided the best georeference for the survey work. The control points were initially derived from satellite orthoimage, DEM and topographic map (Figure 2.2). The satellite orthoimage is produced from KVR-1000 satellite images based on the DEM from TK-350 (topographic camera) satellite image stereo pairs. In FJHP, the satellite orthoimage covered 11 km x 11km area with 1.5m ground resolution.

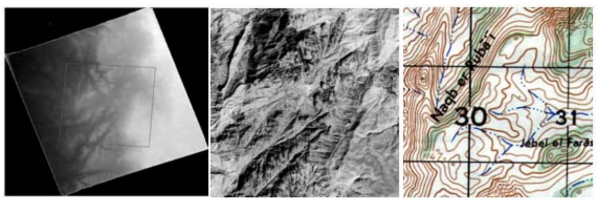

Figure 2.2 Provided cartographic data (Left: DEM, Middle: satellite orthoimage, Right: topographic map). The outline in left figure is referenced to the area of satellite orthoimage, and it is also the range of FJHP.

Generally speaking, control points should be chosen in distinct feature positions such as the top of mountain, the crossing of roads or rivers and so on. These positions are easy to be recognized from satellite orthophoto. Since coordinates of upper left corner in orthoimage are known, the locations of needed control points can be found on orthoimage and referenced to its upper left corner. Coordinates are in the right coordinate system.

The eastward is in positive x axis and the southward is in positive y axis.

$$X = xo + x * p$$
$$Y = yo - y * p$$

Where xo, yo --- coordinates of the upper left of orthoimage, x, y --- the amount of pixels in x and y direction from the upper left corner of orthoimage to the control point,
p --- pixel size.

After planar coordinates of the control points are obtained, corresponding elevations should be evaluated from DEM. According to the number of row and column of the point in image of DEM, with the command 'imagename (row, column)', the elevation of the point can be obtained with Matlab. Figure1.2 shows the distribution of derived control points. The accuracy of these extracted coordinates of control points can be controlled by comparing them with the position in 1:50000 topographic map. As a result, the derived control points are distributed as it is shown in figure 1.2. Two full control points and six height control points are achieved. The reason for control points chosen in figure 1.2 is that for weak internal geometry, sparse control points can reduce the effect of block deformation. On the contrary, more control points will introduce extra deformation.

2.2 Georeferencing Aerial Imagery

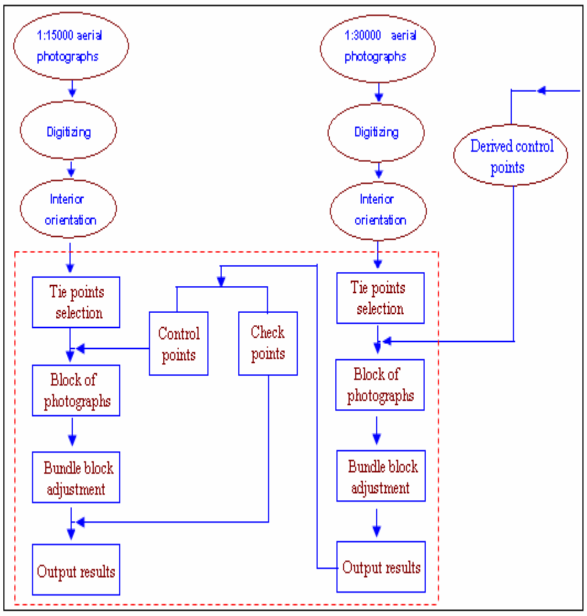

Figure 2.3 The work flow of multi-scale bundle block adjustment

In section 2.1, we introduced the method that control points are derived from satellite orthophoto. This part will describe how to georeference two sets of aerial images to consistent coordinate system by using these control points. Figure 2.3 shows the procedure that bundle block adjustment is performed in two sets of aerial images. The source materials and facilities include:

i) The two sets of paper prints aerial photographs, respectively, in scales of 1:15000 and 1:30000, with standard format 23cm*23cm,
ii) The data from camera calibrations,
iii) EPSON photo Scanner,
iv) Z/I digital photogrammetric imageStation

Digitizing paper-print aerial photographs is the first step of the workflow. It is important to choose appropriate resolution for scanned images. In this case, these digitized images are used for orientations in digital photogrammetric system. Therefore we choose 600 pixels / inch as the scanner resolution.

2.2.1 Interior orientation (IO)

The procedure of IO is to establish a relationship between pixel coordinate system and image coordinate system. For digital cameras, the relationship between pixel and image coordinates is almost constant and can be determined during calibration procedure. However, when film-based camera is employed, this relationship must be determined by measuring the fiducial marks. Figure 2.4 shows different types of fiducial marks in two sets of aerial imagery and also the relationship between pixel coordinate system and image coordinate system.

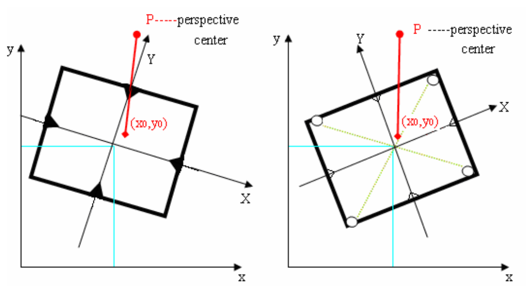

Figure 2.4 The relationship between pixel coordinate system and image coordinate system

X, Y-----image coordinate system x, y------ pixel coordinate system (Left : 1:15000 image , Right: 1:30000 image)

In FJHP, the process of measuring the fiducial marks from both 1:30000 and 1:15000 aerial images is carried out in the digital photogrammetric system (Z/I ImageStation). The residuals are estimated by comparing the measured and calibrated positions of the fiducial marks. The accuracy of IO is controlled within 0.022mm.

2.2.2 Implementation of multi-image bundle adjustment

Control points have been derived from satellite orthophoto and DEM. These control points can be applied to 1:30000 aerial image block. Figure 2.5 shows control points distribution over 1:30000 photographs block. The purple area in figure 2.5 is referenced to the position of 1:15000 photographs block, where dense pass points are chosen. The coordinates of these pass points can be derived from the 1:30000 block and can be used as control points or checkpoints in 1:15000 image block.

Figure 2.6 shows the distribution of points in 1:15000 block. In this block, it can be seen that control points are better distributed than in 1:30000 block because the points which are needed in 1:15000 block can be obtained from 1:30000 block. However, in order to distribute tie points well in 1:15000 block, except those points from 1:30000 block, some new tie points are also needed. In 1:15000 block adjustment, some control points can remain as check points which can be used to evaluate the block accuracy after block adjustment.

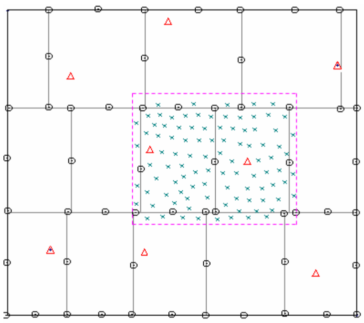

Figure 2.5 1: 30000 photographs block
The purple dash lines show the position of 1:15000 image block

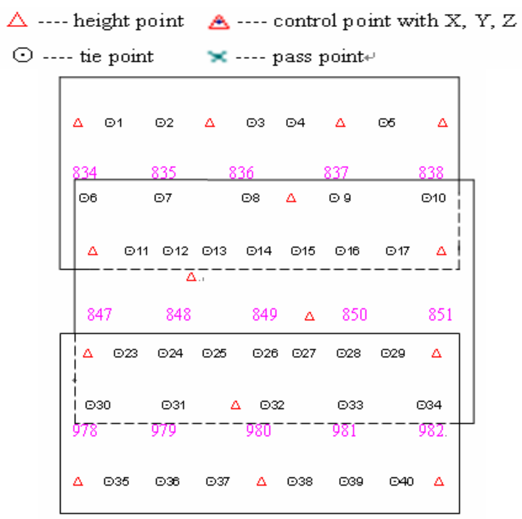

Figure 2.6 1.15000 image block
834, 835---- aerial photograph number △ ----control point
⊙ ---- tie point 19, 20---- tie point number

Weak internal geometry can be improved while the two sets of aerial images are referenced to each other by some corresponding points in common coordinate system. The number of observations and redundancies will greatly increase. The number of redundancy can be calculated from observed image coordinates and unknown coordinates. Take figure 2.6 as example, there are 15 control points and 35 tie points involved. Each measured image point yields two observation equations.

Observed image coordinates:
(18*2*2+30*2*4+2*2*2) = 320;
Unknowns:
3*15 = 45 projective centre coordinates;
3*15 = 45 rotations;
3*40 = 120 tie point object coordinates;
Total 210 unknowns.
Redundancy: 320 – 210 = 110;

The above shows the number of redundancy in 1:15000 block. For 1:15000 block, most of the points are from 1:30000 block. Therefore, these points are adjusted in both blocks. Thus the reliability of measurements is considerable improved.

In FJHP, bundle block adjustment of two sets of aerial images is performed with Z/I imageStation, respectively. As a result, in 1:30000 image block, the accuracy is RMS x: 1.821 m, y: 1.653 m, z: 2.115 m. In 1:15000 image block, it is RMS x: 1.673 m, y: 1.784 m, z: 2.096m.

2.3 Georeferencing terrestrial imagery

2.3.1 The principle of multiple images triangulation

For multiple images network orientations, several steps should be taken: Feature points measurements; automatic relative orientation, resection and spatial intersection as well as bundle block adjustment. It is an iterative process to determine the internal geometry of the block. With given control points, collinearity equations are employed to perform resection. Thus exterior orientation (EO) of images can be computed. Then according to these EO parameters, spatial intersection is followed to extract the object space coordinates of measured feature points. The iteration is processed until all parameters are obtained and unified solutions are achieved by using least squares method.

2.3.2 Image block implementation in iWitness software

Terrestrial images with different camera parameters can be referenced to common coordinate system by using control points acquired from the 1:15000 image block. This process is conducted with iWitness™ software, which is based on multi-image network orientation. Before performing multi-image block in iWitness, camera parameters should be determined by camera calibration. The camera parameters mainly include principal point of image, focal length and lens distortion.

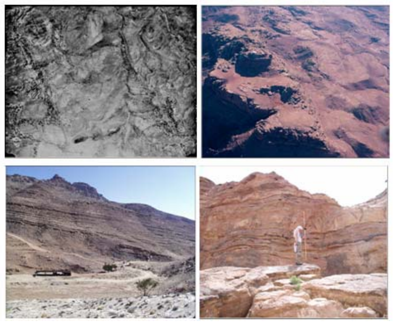

Figure 2.8 Image types in iWitness images block
a) vertical aerial image; b) oblique aerial image (Robert Bewley), c) and d) terrestrial images taken by different cameras
a,b,c,d are from left to right and from up to down

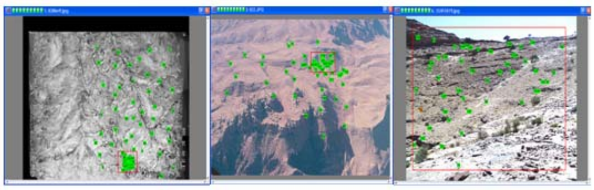

Figure 2.9 Images are referenced each other in iWitness

Figure 2.8 shows the types of images which are involved in iWitness. There are aerial images in vertical and oblique projection as well as terrestrial images with different camera parameters. They are referenced by measuring enough corresponding points (Figure 2.9). At least five corresponding points with well-distribution are needed to orient one image. After all images are oriented, the internal coordinates of feature points within this images block are computed. The internal coordinate system in iWitness keeps the first camera position as the origin of coordinate system. In order to reference this image block to the desired coordinate system, generally speaking, minimal four control points are needed for the transformation of the coordinate systems. In FJHP, GCPs can be derived from 1:15000 aerial image block adjustments. The location of GCPs chosen must be visible both in aerial images and terrestrial images. After the measurement of GCPs, multi-image network is georeferenced to consistent coordinate system. EO parameters of each image in this network are achieved. The accuracy of this image block is RMS 0.29 pixels. Pixel size is 0.042 mm. Because there are different pixel sizes in the block, this pixel size refers to the pixel size of the first referenced image (1:15000 aerial image). At the time, all images that include satellite orthophoto, 1:30000 aerial images, 1:15000 aerial images and terrestrial images are georeferenced to consistent coordinate system with desirable accuracy.

3. TEST AND ANALYSIS

After the implementation of georeferencing multi-imagery, coordinates are compared by selecting 10 points from 1:30000 aerial imagery, 1:15000 aerial imagery and terrestrial imagery, respectively. The results show that the differences between these compared coordinates are within desired tolerances (Table 1), but the differences cannot be ignored.

Point Number	Image Types	1:30000 Aerial Imagery (m)	The coordinate difference between 1:30000 and 1:15000 aerial Imagery blocks (m)	The coordinate difference between 1:30000 aerial Imagery and terrestrial imagery blocks (m)
1	X	29749.413	-0.339	0.700
	Y	55693.662	-1.357	-1.704
	Z	936.960	-1.785	-0.756
2	X	29759.262	0.272	1.598
	Y	55677.903	-0.859	-1.349
	Z	942.420	-1.617	0.232
3	X	29746.594	-0.373	0.788
	Y	55651.881	-0.231	-1.334
	Z	940.184	1.317	1.641
4	X	29735.342	-0.380	0.124
	Y	55631.312	-0.491	1.616
	Z	939.507	-1.050	-1.461
5	X	30094.045	-0.961	0.956
	Y	56258.671	-1.957	-1.285
	Z	900.901	0.384	1.119
6	X	30474.650	0.129	0.342
	Y	56277.644	1.288	1.783
	Z	905.265	1.511	1.076
7	X	30074.684	1.732	0.461
	Y	56173.337	-1.514	0.349
	Z	873.498	-0.763	-0.554
8	X	30173.850	0.900	0.637
	Y	56131.415	-1.757	-0.854
	Z	872.229	0.849	-0.801
9	X	30186.772	0.395	-0.909
	Y	56168.334	-1.540	-0.774
	Z	875.222	0.331	-0.071
10	X	29948.459	0.038	-1.737
	Y	56154.687	-1.776	-0.023
	Z	875.997	1.579	1.863

Table 1 Point coordinates comparison

Some factors can cause the differences:

a) Difference in relief displacement of corresponding points and difference in image scales

Figure 3.1 shows that tree as feature point is measured in both terrestrial image and aerial image. In the case, aerial image is vertical projection while terrestrial image is oblique projection. It causes relief displacement of corresponding points. On the other hand, when tree is measured as point in aerial image, clearer or bigger image is present in close range photo. Therefore it is difficult to position exactly it. In iWitness software, a predicted point in terrestrial image can be obtained when same points are measured in multiple aerial images.

Figure 3.1 Point in different scale imagery
Left: Terrestrial image Right: 1:15000 aerial image

b) Difference in imaging time

As it has been mentioned, source images were taken in different years. The time difference between 1:15000 aerial image and terrestrial image is around twenty years. Although interest area is high mountain, some changes have taken place during these years.

c) Difference in software algorithms;

For different software, algorithms could be different. Although the basic projective geometry is the same for close-range and aerial photogrammetry, the location and orientations of images are much less regular in close-range setups than in aerial applications, where relatively regular flight lines and standard image spacing are used (Mikhail, 2001). Therefore it is possible to achieve different solutions from aerial imagery and terrestrial imagery by employing different algorithms. For example, during relative orientation, photogrammetry conditional equations could be from collinearity equations, from line-based collinearity condition, or from coplanarity equations. For bundle block adjustment, solutions can be achieved from collinearity equations and also from direct linear transformation which are commonly used with close range images.

d) Difference in manual observations.

When different people interpret features from images, the results could be different. Furthermore, even if the same person measures same points for several times, it is possible to get different solutions.

Although above factors lead to the coordinates difference, from the table 1, it can be seen that the difference between these points is within 2m. It indicates that internal block geometry is stable and reliable, and consistent mapping of multi-scale images is achieved.

4. CONCLUSIONS AND FURTHER WORK

In FJHP, multi-image is successfully referenced to common coordinate system with desired accuracy. Bundle block adjustment is performed recursively in 1:30000 aerial imagery, 1:15000 aerial imagery and terrestrial images, respectively. These blocks are referenced to each other by measuring corresponding points. Points are derived from one block and are used as control points in next scale block. This method can be recursively performed until stable solutions are achieved. As a result, the following goals are achieved:

i) Complete information can be extracted;

As aerial images were produced in 1987(1:30000) and 1981(1:15000), respectively, features extracted from it are incomplete. New features can be acquired from recent terrestrial images since they have been referenced to common coordinate system.

ii) Weak ray geometry is greatly improved;
Two full control points and six height points are initially derived from orthoimage. After performing block adjustment in 1:30000 block, control points are well-distributed in 1:15000 block. Redundant observations greatly increase. It not only improves weak internal geometry but also increases block reliability.

iii) Consistent accuracy is obtained.
By point extraction from multi-image, coordinates are compared and the results show that these coordinates are stable in different blocks. Consistent accuracy are achieved. After multi-image is georeferenced, EO of each image is achieved and can be applied to the follow-up feature extraction. The coordinates of points are obtained and can be used in coordinate transformation of vector data. However, in this method, it is a challenge to find the corresponding points between different scale imagery, especially when small scale imagery is provided with less resolution or in great difference of image resolution.

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