

# PERFORMANCE EVALUATION OF MULTIPLE SCALE AUTOMATIC AERIAL TRIANGULATION

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Commission III, WG III/8

**KEY WORDS:** Automation, Correlation, Matching, Aerial Triangulation, Orientation

## ABSTRACT:

Automatic Aerial Triangulation (AAT) is an increasingly interesting research topic. Most experiments have been carried out with a view to testing accuracy and reliability of matching methods and it is thought that efficiency is directly related to successful automation and increased accuracy. In the project presented here, we experimented with different scales and their combinations. The project, the results and experiences of Automatic Digital Aerial Triangulation using images of different scales of the National Technical University of Athens (N.T.U.A) campus are described. The entire area of the campus is covered by 1:3500, 1:6000 and 1:8000 image scales taken on the same day. The detailed aims of the project were to investigate, the geometric stability of the blocks, the accuracy of the tie points and the derived orientation parameters. The program ISAT (ImageStation Auto Triangulation) of Z/I Imaging was employed in this project, in order to adjust various block combinations. Firstly, both a manual and an AAT solution for the 1:3500 block were performed. The computational time was about 3 minutes per image and the  $\sigma_0$  value was 0.30-0.35 pixel. Secondly, AAT was applied to scales 1:6000 and 1:8000 and it was observed that for the 1:8000 images a less accurate solution was obtained. Moreover, the combination of 1:3500 and 1:8000 image scales failed to provide a solution probably because the software splits the block in two parts due to different resolutions. The combination of 1:6000 and 1:8000 image scales gave a solution with impressive results. However, user intervention was necessary. Finally, a comparison of the above results with those derived from an analytical solution of the same area and using the same images has been carried out.

## 1. INTRODUCTION

### 1.1 Automatic Aerial Triangulation

Automatic Aerial Triangulation (AAT) has been an increasingly interesting topic of research and development in digital photogrammetry. For a number of years, Aerial triangulation has been a complex operation which includes planning the photo flight, establishing ground control points, taking and developing aerial photographs based on preset specifications, performing interior orientation, measuring and transferring all tie, check, and control points appearing on all photographs, and performing a least squares block adjustment. This process ultimately provides the exterior orientation parameters for all photographs and the three-dimensional coordinates for all measured object points.

Recent progress in digital photogrammetry has brought to light new possibilities. The impetus for this evolution has been the advancement of computer technologies and image processing techniques. While the photogrammetric principles have not changed, the implementation tools have. An important advancement in digital photogrammetry involves automatic aerial triangulation using image matching techniques to automate point transfer and point mensuration phases, which were not available within the analytical stereoplotter environment. Several correlation techniques and computer programs for digital aerial triangulation have been developed, based on the automatic selection and transfer of tie points using multiple image feature based and/or least squares matching.

Several researchers have reported attempts to automate Aerial Triangulation, e.g., Tsingas (1991), Agouris (1992), Ackermann & Tsingas (1994), Schenk (1995) and Toth & Krupnik (1996). Several Automatic Aerial Triangulation packages have been developed over the recent years with different capabilities (Büyüksalih & Zhang 2003). EuroSDR – formerly OEEPE – devoted recently a common test to assess their performance.

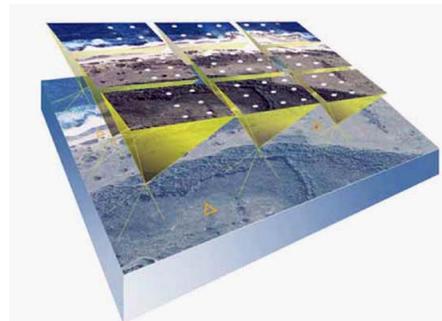


Figure 1: Automatic Aerial Triangulation

### 1.2 Motivation

The aim of this project was to investigate the geometrical stability of the block, the accuracy of the tie points and the derived orientation parameters using Automatic Aerial Triangulation algorithms. It was decided to use a variety of image scales of the same area in multiple combinations, in order to derive substantial conclusions, spot eventually essential matching problems and present the results of these adjustments.

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### 1.3 Available Data

The wider area of the National Technical University of Athens (NTUA) campus was covered by 1:3500, 1:6000 and 1:8000 image scales taken on the same day (08/08/1999). The B&W images present forward and side overlaps of 60% and 25% respectively. It is a slightly hilly area with a big mountain as its east boundary. The camera used was a Z/I RMK TOP 15 with 152.611mm principal distance. The analogue negatives were scanned at a 1800dpi resolution, i.e. pixel size of 14µm using a photogrammetric scanner. This high resolution would ensure good and straightforward recognition of the control points (Ackermann & Krzystek 1997). The Z/I ImageStation digital photogrammetric workstation was employed for this project. The mensuration software offered are the ISDM (Image Station Digital Mensuration) and the ISAT (ImageStation Auto Triangulation) for the interactive and automatic triangulation respectively. The number of images per strip and scale are shown on Table 1 and Figure 2 presents an aerial image of the area, in which the campus of the National Technical University of Athens appears.

Image scale	Images/strip	Strips	Total of Images
1:3500	7	2	14
1:6000	5	2	10
1:8000	4	1	4

Table 1: Image data



Figure 2: Image scale 1:3500, with N.T.U.A. depicted on it

A number of control points were measured using a pair of GPS receivers to an accuracy of a few centimetres, in the Greek Geodetic Datum (EGSA87) a Transverse Mercator projection with GRS80 as reference ellipsoid.

### 1.4 Image Station Automatic Triangulation (ISAT)

Image Station Automatic Triangulation (ISAT) is an automatic aerial triangulation software package equipped with powerful editing facilities. The objective of ISAT is to automate point transfer and tie-point measurement operations, thereby, minimizing manual work and operator intervention and maximizing objectivity and speed. In addition, ISAT supplies

editing facilities with Z/I Imaging's Image Station photogrammetric products.

### 1.5 General Workflow of ISAT

The approach is intended as a fully automatic process. The entire procedure is characterized by two main steps:

1. Initialization, which determines enough, fairly accurate tie point areas at the von Gruber point positions.
2. Application of the matching strategy in the homologous image patches through the image pyramid by the kernel system.

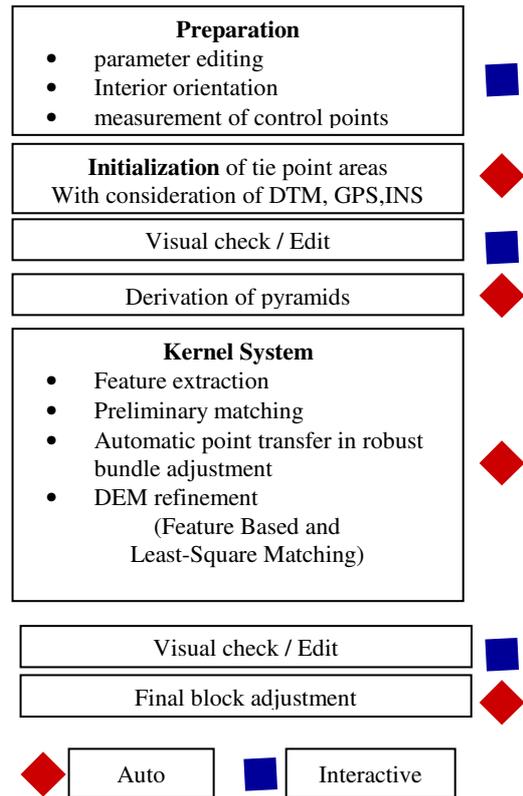


Figure 3: General workflow of ISAT

The ISAT process (Figure 3) applies image pyramids for a coarse-to-fine strategy. In each pyramid level the following steps are performed:

- Automatic initialization of the tie point areas. Tie points are preferably selected at the vonGruber positions, where the best multi-image tie points are located.
- Feature extraction using Förstner operator (Förstner 1986)
- Preliminary image matching using a combination of feature based and least squares matching and a sophisticated strategy for obtaining evenly distributed tie points over the whole block.
- Robust bundle block adjustment for automatic tie point selection and for the initialization of the next pyramid level.
- In the last pyramid level the internal block adjustment supplies the final adjustment result.

In weak block areas tie points may be added by interactive point measurement. After manually adding points, the internal block adjustment can be started again, without repeating the automatic process (Sigle & Heuchel 2001).

Having approximate exterior orientation parameters and image overlaps available, the AAT approach starts with a block formation based on feature based matching (FBM) and runs through overview levels to generate a primary point list. The match with the largest correlation coefficient yields the most likely homologue point. Feature based matching determines the correspondence between image features. Least squares matching requires accurate approximate values (Figure 4). It refers to the determination of the correspondence between image area based matching on the similarity of their gray values. The cross correlation and the least square matching are the appropriate methods. So that, after the FBM, the collinearity equations can be used as a convergence based on least square matching (LSM) and can work more accurately and improve the success rate of the matching. (Dörstel et al. 2001).

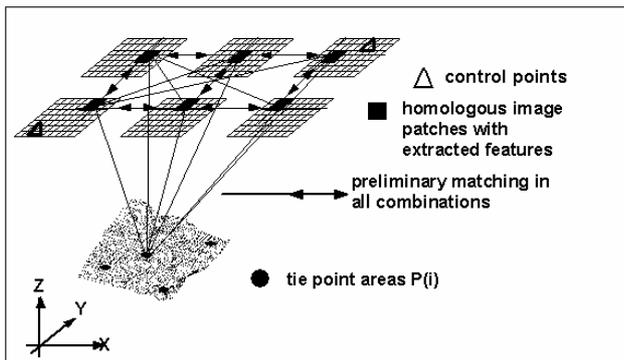


Figure 4: Matching Scheme in the Kernel System

The work by Tsingas represents the first research on fully automatic digital aerial triangulation (Ackermann & Tsingas 1994). Instead of gray levels interest points are used as matching entities and the matching method is based on graphs (Jaakola & Sarjakoski 1996).

In addition, ISAT generates considerably more conjugate points and point clusters in the areas of multiple overlap areas. Finally, the produced data are the orientation parameters for the images and the analysis of results.

## 2. PERFORMED TESTS

### 2.1 Preparation of projects

For testing the AAT algorithm, several tests were performed with the data available. Firstly, a manual solution and an AAT solution were performed for the same block of the 1:3500 images. Secondly, the comparison of two solutions for the 1:3500 images, using different number of patches in each one, was carried out. Thirdly, AAT was applied separately to scales 1:6000 and 1:8000. Moreover, the combinations of 1:3500 with 1:8000 image scales and 1:6000 with 1:8000 were also tested.

The most important project parameters were defined as follows: as coordinate system the Greek System EGSA87 was used, the average ground elevation was set at 300m, the standard deviation for the photo measurements  $7\mu\text{m}$ , the  $\sigma_{\text{max}}$  for interior orientation  $10\mu\text{m}$ , the  $\sigma_{\text{max}}$  for the relative orientation  $10\mu\text{m}$  and the  $\sigma_{\text{max}}$  for the absolute orientation  $10\mu\text{m}$ .

The main tests performed include the following projects:

1. Manual aerial triangulation with measurement of tie and control points in images of 1:3500 scale using ISDM.
2. Autotriangulation adjustment of the 1:3500 scale images, using a 3x3 pattern of vonGruber point positions with ISAT
3. Autotriangulation adjustment of the 1:3500 scale images, using a 5x5 pattern of vonGruber point positions with ISAT
4. Autotriangulation adjustment of the 1:6000 scale images with ISAT
5. Autotriangulation adjustment of the 1:8000 scale images with ISAT
6. Autotriangulation adjustment of the combination of 1:6000 and 1:8000 scales with ISAT
7. Autotriangulation adjustment of the combination of 1:3500 and 1:8000 scales with ISAT

For every project the appropriate data files were created and the various parameters were defined. They include, among others, camera, photo, model, control points, altitude information, such as flying height and average ground elevation, the desired linear and angular units, the type of imagery and camera parameters (such as name, lens distortion values, focal length, and principle point coordinates), the order of images and strips and the coordinate system for the control points. The essential number of overviews for every image is created with the Gaussian method of resampling - full set is recommended - so that the images may be better manipulated by the software (Z/I Imaging, 1999).

### 2.2 Images of 1:3500 scale

The 1:3500 scale images were ordered in two strips, with a mean absolute flying height of about 1000m. Initially, the interior orientation process for every individual photo, with the help of the corresponding module of Automatic Orientation, was performed.

**2.2.1 Triangulations with manual measurements of tie and control points:** As already mentioned, an adjustment of manual measurements of the 1:3500 images was initially performed. Tie and control points were measured in every photo in which they were well defined.

**2.2.2. Autotriangulation (using a 3x3 pattern of vonGruber point positions):** For this project approximate values of the exterior orientation parameters were provided, with an accuracy of 50m for the projection centers, while the  $\omega$ ,  $\phi$  angles were considered equal to zero and the  $k$  angle was calculated from the approximate values of the image centres. The initialization automatically creates nominal tie-points, in object coordinates, for later use in correlation. These nominal tie-points (in a 3x3 vonGruber point pattern) will be used later by ISAT to generate clusters of matched points. Default value for the size of every patch window is 100x100 pixels. As an example of the matching method, tie points in multi-photo view are presented below. The user is obliged to control the success of the algorithm visually.

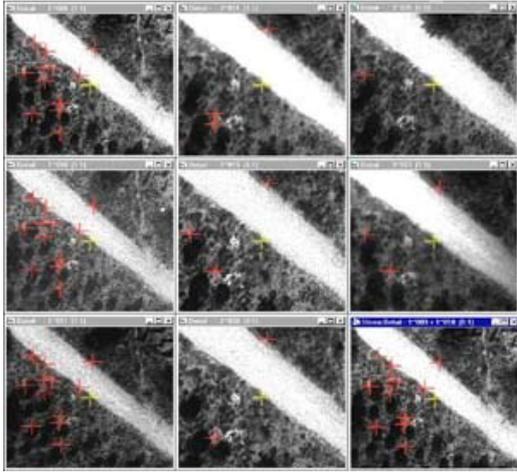


Figure 5: Tie points in multi-photo view

**2.2.3. Autotriangulation (using a 5x5 pattern of vonGruber point positions):** In this project the same images and the same parameters were used. The only difference was in the initialization. Using a 5x5 pattern of vonGruber point positions the tie points areas increase in number and density.

The comparison between the manual solution and the AAT solution for the 1:3500 images showed that (a) the RMS value of control points and the standard deviation are of the same order and (b) a lower a-posteriori value for  $\sigma_0$  is observed in AAT (Table 3). The feature based matching approach provides very accurate and reliable exterior orientation parameters due to its capability of generating many redundant tie points due to the strong geometry configuration. The computational time was about 3 minutes per image and the  $\sigma_0$  value was 0.30-0.35 pixel, given that the system used had four Pentium Pro 200MHz processors, with 128MB RAM and Ultra SCSI HDD. Today on a modern system built around two Pentium IV Zeon 3.2GHz processors, with 2GB RAM the time required would be less than 1.5 minutes per image.

### 2.3 Images of scale 1:6000

The 1:6000 scale images are deployed in two strips with absolute flying height of about 1300m. The approximate values of the exterior orientation parameters were given with an uncertainty of 100m.

### 2.4 Images of scale 1:8000

The 1:8000 scale images formed just one strip with absolute flying height of about 1500m. The approximate values of the exterior orientation parameters were given with an uncertainty of 100m. In this set of images a second analysis step was carried out in order to assess the accuracy of the obtained orientation parameters independently. Using interactively additive measured coordinates of GCPs as observations and the obtained tie points coordinates as GCPs in the robust bundle adjustment of the first analysis step as constant values, over-determined least-square forward intersections were computed. Obviously the solution gave better accuracy.

### 2.5 Analytical Aerial Triangulation

Finally, a comparison of the above results (AAT) with those derived from an analytical solution of the same area and using the same images has also been carried out. In the analytical

project several of attempts were made with the intention to conclude on essential and thought provoking results. The point measurements on the diapositives were carried out on an analogue Zeiss Jena Technocart D, converted to analytical with the ADAM conversion system. The GCPs used were the same as those used in the Automatic Triangulation. The standard deviation for the photo measurements was set to 10  $\mu\text{m}$ , the  $\sigma_{\text{max}}$  of the interior orientation to 10 $\mu\text{m}$ , the  $\sigma_{\text{max}}$  of the relative orientation to 10  $\mu\text{m}$  and the  $\sigma_{\text{max}}$  of the absolute orientation to 10 $\mu\text{m}$ . The bundle adjustment for the aerial triangulation was performed with the BINGO-F software (Zervas & Papaharisi, 2000).

## 3. RESULTS AND ANALYSIS

### 3.1 Multi-ray tie points

In contrast to conventional aerial triangulation, ISAT's matching strategy determines tie point clusters instead of single points. The measuring precision is directly influenced by the preferred matching technique and can be maximized by the LSM technique up to 0.1 or 0.2 pixels. The matching strategy also leads to measuring fully transferred tie points. If this goal cannot be reached, ISAT accepts only the best matches, avoiding 2-fold points. Tie point clusters are well distributed over the entire image with preference to the von Gruber positions as the most effective positions for tie points.

Project	Scales		# of tie points				
1	Manual 1:3500		-				
2	ISAT 1:3500 (5x5 von Gruber pattern)		1911				
3	ISAT 1:3500 (3x3 von Gruber pattern)		891				
4	ISAT 1:6000		869				
5	ISAT 1:8000		818				
6	ISAT combination 1:6000 – 1:8000		2199				
7	ISAT combination 1:3500 – 1:8000 (it stops at the sixth pyramid level)						
Project	# of multi-ray tie points observations						
	2x	3x	4x	5x	6x	7x	8x
1	-	-	-	-	-	-	-
2	247	349	39	26	14	-	-
3	50	128	26	33	23	-	-
4	109	134	41	17	-	-	-
5	148	174	-	-	-	-	-
6	207	200	125	70	51	3	1
7	-						

Table 2: Projects and multi-ray tie points after AAT

### 3.2 Analysis of results

The comparison between ISAT solution with 3x3 and 5x5 von Gruber points respectively, using different number of patches, shows similar accuracy. However, in the case of 5x5 pattern an improvement in the residuals was observed. That was due to the avoidance of gross errors. Consequently, in the 5x5 pattern the blunder errors were avoided.

Project	$\sigma_0$		RMS (m) at the GCPs		
	pixels	$\mu\text{m}$	X	Y	Z
1		5.2			
2	0.35	4.9	0.043	0.078	0.047
3	0.35	4.9	0.044	0.073	0.055
4	0.44	6.1	0.049	0.077	0.079
5	0.31	4.3	0.009	0.011	0.018
6	0.54	7.6	0.064	0.136	0.148
7	4.23	59.2	0.017	0.029	0.017

Table 3: Results of bundle adjustment for GCPs

In Table 3, the values  $\sigma_o$  from the robust bundle adjustment (both in pixels and in  $\mu\text{m}$ ) and the RMS values in object space are presented. It may easily be concluded that:

- The standard deviation  $\sigma_o$  of the tie point coordinates generally lies between 0.3 and 0.5 pixels or 4 to 8  $\mu\text{m}$ . This result has been obtained although the expectation for the accuracy of the image coordinates, as expressed in a priori  $\sigma_o$ , was set to 10 $\mu\text{m}$ .
- The  $\sigma_o$  value from the robust adjustment alone cannot be considered as an indicator for the quality of the aerial triangulation results. The reason is that in contrast to analytical photogrammetry in AAT an appropriate point distribution in each image and proper connections between the images and strips are not necessarily ensured. (Heipke & Eder, 1996).

Project	RMS on image		Mean Stand. Deviation (m)		
	x ( $\mu\text{m}$ )	y ( $\mu\text{m}$ )	X	Y	Z
1					
2	2.9	3.5	0.028	0.029	0.045
3	3.5	3.3	0.020	0.021	0.035
4	4.1	4.1	0.050	0.050	0.084
5	3.6	4.5	0.021	0.021	0.040
6	5.6	5.6	0.076	0.076	0.131
7*	156.4	52.5	12.249	11.224	40.728

Table 4: Results of bundle adjustment for all points

\* procedure stopped at 6<sup>th</sup> pyramid level

For scales 1:6000 and 1:8000 a small reduction of the accuracy is noticed compared to the 1:3500 block. Obviously, the smaller the image scale, the smaller the accuracy of the solution obtained. For scale 1:8000 extra control points were added in order to strengthen the solution, i.e. provide better geometrical stability.

Project	Iterations	GCPs	Max Residuals (m)		
			X	Y	Z
1		11			
2	10	11	0.062	0.157	0.101
3	7	11	0.081	0.163	0.097
4	7	8	0.085	0.125	0.120
5	8	18	0.120	0.104	0.144
6	12	11	0.149	0.315	0.292
7	17	10	0.043	0.060	0.030

Table 5: Residuals

The combination of scales 1:6000 and 1:8000 led to predictable results, but important for the discussion. This procedure was successful but it should be noted that a lot of attempts were made to this direction. One of them was to increase the patch window size to 120 pixels so that more pixels could take part in the matching procedure. Moreover, control points were added interactively. Therefore, this combination gave a solution with impressive results (Table 5).

The combination of the scales 1:3500 and 1:8000 failed to provide a solution. One possible reason was the drastic difference between the two flying heights consequently the big difference between the resolutions of the images (Figure 6). Thus, the software split the block into two sub-blocks in order to solve them separately. Without having additional known DEM information, the block adjustment failed.



Figure 6: The difference in resolution between scales 1:3500 and 1:8000 in the same level of zoom

### 3.3 Results of analytical solution

The results of the various analytical adjustments of the various blocks or combinations thereof are summarized in Table 6.

Block	Tie points (cm)			GCPs (cm)		
	$\sigma_x$	$\sigma_y$	$\sigma_z$	$\sigma_x$	$\sigma_y$	$\sigma_z$
1:3500	6.3	6.3	10.2	4.0	3.7	4.5
1:6000	5.1	5.8	10.9	4.7	5.1	6.3
1:8000	7.4	7.5	17.4	4.2	4.1	4.6
1:3500-1:6000	6.2	6.2	10.9	4.7	4.6	5.5
All scales	6.3	6.3	12.1	4.6	4.5	5.8

Table 6: Results of the analytical adjustments

It is obvious that for the smaller scales the solution gives relatively better results, mainly because the images include more GCPs. On the other hand, larger scales contribute to the solution with more accurate determination of elevations. With the exception of the elevation accuracy of the 1:8000 images, the other solutions are assessed as satisfactory. The better accuracy in 1:6000 than in 1:3500 is probably due to the appearance of more GCPs in a more favourable distribution.

The combined solution of the three scales proved to be a very useful tool for the detection of systematic errors. Every single solution usually presents small deviations, but the whole block may depart from the correct absolute position within the reference system. The combined adjustment with all images of all scales, detects this as residuals in the measurements. The large number of observations gives the capability for checking. In addition, the unified solution seems to have values closer to the average value of all and it presents uniform distribution of errors. It presents no increase in accuracy but it is a more reliable solution (it has more GCPs and measurements than the others). The ellipses of errors have direction to the center of the area and they present a big deviation outside the University campus where there are few GCPs.

### 3.4 Conclusion

There is no doubt that the future belongs to the Automatic Aerial Triangulation. It is common knowledge that the initialization, point transfer and point measuring phases can be successfully and reliably automated. However, geometric stability may only be achieved through the increase of the number of tie points. At the same time the distribution and the number of GCPs is crucial, perhaps more than in the case of an analytical solution. Hence the “replacement of intelligence with redundancy” (Ackermann 1996) should be carried out with extreme caution.

Multi scale solutions contribute to this goal by undoubtedly increasing the overall efficiency and decreasing the necessary computational time per image. The large number of points, which may be observed and included in the adjustment contribute to (a) the reliable computation of additional parameters for the compensation of systematic errors, (b) the accuracy improvement for the determination of the exterior orientation parameters and finally (c) the increase of the error analysis reliability and, hence, of the overall block adjustment.

However, drastic scale differences pose severe problems to the automatic solution leading to non convergence. This may be overcome by suitably instructing the algorithm to compensate for this effect.

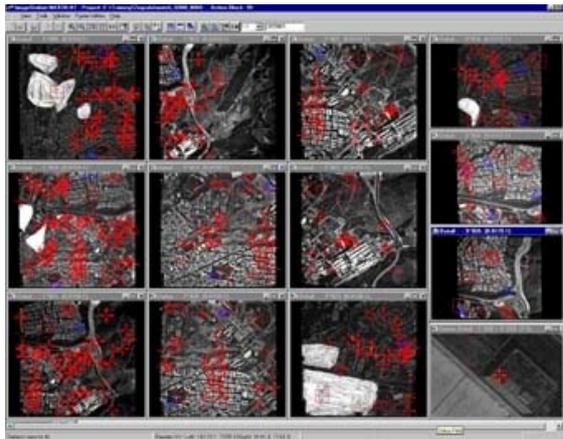


Figure 7: Distribution of tie points allocated on images

As seen in Table 7, the average computational time for the adjustment was below 3 minutes per image with a  $\sigma_0$  value of 0.30-0.50 pixel. Experience and literature (Ackermann & Krzystek, 1997) suggest that pixel sizes smaller than about 20 $\mu$ m do not increase the accuracy of the tie points. On the other hand, high resolutions are required for the clear identification of control points. Large area coverage involving 100 to 300 points per image is required to ensure high block stability (Heipke & Eder, 1996).

The automatically determined orientation parameters are more reliable than those from the analytical solution, since blunders can be easily detected due to the high redundancy. Another consequence is that critical cases of the relative orientation, such as the e.g. the dangerous cylinder, have no practical significance, since it is virtually improbable for all conjugate points to lie on such a surface (Heipke, 1997).

Project	Total time/Time per Image	Average of points per image
1	-	-
2	27min / 1.98 min	64
3	47min / 3.38 min	145
4	35min / 4.37 min	114
5	10min / 2.59 min	205
6	27min / 1.51 min	202
7	2h 13min / 11 min	67

Table 7: Time required for AAT and points per image

### 3.5 References

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### 3.6 Acknowledgements

We would like to express our acknowledgements to Dr. B. Tsingas for his help and advice about the Automatic Aerial Triangulation. We also wish to thank the Z/I Imaging Hellas Limited for the support of the appropriate software named Image Station Automatic Triangulation (ISAT).