
A SYSTEM TO CONTROL THE SPATIAL QUALITY OF ANALOGUE AND DIGITAL AERIAL IMAGES

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ABSTRACT

The spatial quality of an image consists of the geometric accuracy and the spatial resolution. The Finnish Geodetic Institute (FGI) has a permanent test field to control the spatial quality of airborne images. The permanent test bar targets of the test field are constructed from different types of gravel with contrast ratios 1:2 and 1:10. The transportable test bar targets (contrast ratios 1:2 and 1:10) are useful in two scales: 1:3000 and 1:60000. The ground control points are signalised with round shaped white signals and they are located in an area of about 1 km². The geometric accuracy of an imaging system can be analysed by imaging a 1:3000 scale block over the permanent test field. Block adjustment with and without additional parameters can be carried out for determining internal and external accuracies. Film exposure can be checked using a known grey scale on the ground. The spatial resolution of the aerial images can be determined visually or numerically.

We are developing a quality control system that takes into account different parts of the photogrammetric process. The spatial quality of the imaging and photogrammetric system must be controlled in the beginning of the season. More research and data are needed to get useful tolerances for the quality criteria and these have to be tested for several photogrammetric tasks at different scales before an operative system can be installed.

1 INTRODUCTION

1.1 General

The recent development of digital photogrammetry and the present and future development of GIS cause an increased interest in the spatial accuracy of the images and maps. Without a good accuracy a flexible use of digital images and digital maps is not possible. The spatial quality of an image consists of two elements: the geometric accuracy and the spatial resolution. Both are important when evaluating the usefulness of an image in photogrammetric and mapping tasks. It is impossible to predict accurately the spatial quality of images beforehand. This is caused by the effects of atmosphere on the images as well as the functioning of the equipment during flights. In-flight calibration is the only way to obtain facts about the spatial quality of images taken. In modern photogrammetric mapping digital images are used which usually means that images have to be digitised. Thus it is necessary to include the spatial quality of digitised images in the control procedure because the spatial quality of images lowers in scanning. The objective of this paper is to present the basic components of the test system which has been developed at FGI. It can be used to control the spatial quality of analogue and digital airborne images for each photogrammetric task and for all steps of the process.

1.2 Test fields for spatial quality control

In the 1960's the results from the photogrammetric test fields were presented. The main goal of using these test fields was to determine the geometric quality of aerial photographs in actual operational conditions. The main interest was to determine the accuracy of the interior orientation of the photographs, which mostly was connected with the radial distortions, caused by the lens of the camera. The test fields were permanent, ground control points were built in bedrock and their co-ordinates were measured with high accuracy geodetic methods. The results were useful giving possibilities to improve the accuracy of interior orientation and thus the whole photogrammetric process.

In the 1970's and 1980's increased the interest to determine the spatial resolution of aerial photographs by using test figures, because this way it is possible to obtain practical values for resolving power of photogrammetric systems in everyday photogrammetric tasks. These test figures were mainly painted on plywood plates that were installed on

ground for the periods of test photography. The plates were heavy and were difficult to transport from a place to another. The results were good giving a clear understanding how the spatial resolution of aerial photographs in practise is dependent on different factors, (Hakkarainen et al., 1992). In 1993 the Finnish Geodetic Institute (FGI) started to construct in the municipality of Kirkkonummi (situated about 30 km to the west of Helsinki) a permanent test field that could be used to control the spatial quality of airborne images. This quality control system has been developed by making several experiments in 1995 - 1997 in Finland. A part of this system has been earlier described by (Kuittinen et al., 1996).

2 METHODS

2.1 General

The method is based on two types of test fields; a permanent test field where the spatial quality of the photogrammetric system can be tested whenever during the snowless time of the year, and light transportable test figures that can be placed on the area which will be imaged. In addition to these, some laboratory devices are needed to control the quality in the photogrammetric process. The components and the use of the system are presented below in Table 1.

Type of field	Devices	Analysed characteristics of images
Permanent field	Test-bar figures	Spatial resolution of images
	Ground control points	Geometric accuracy of images and GPS coordinates of projection centres of images
	Grey scale	Exposure of film
Transportable targets	Test-bar figures	Spatial resolution of images
	Grey scale	Exposure of film
Laboratory	Precise grid	Geometric accuracy of scanning
	Grey scale (wedge)	Radiometry of scanning

Table 1. Material and analysed characteristics of images.

2.2 Mathematical methods

2.2.1 Determination of geometric accuracy of imaging system and aerial triangulation methods. The geometric accuracy can be analysed by imaging a 1:3000-scale block over the FGI test field. The block consists of three strips and three images per strip; 80% side and forward overlaps are used. A cross strip makes the block even more robust. Image measurements and aerial triangulation (AT) can be performed using analogue or digital images by suitable equipment and software. In the FGI test field there exists altogether 44 targeted ground control points, from which 34 points are used as GCPs in AT and the remaining 10 points are used as checkpoints. A dense tie point pattern, 25 tie points per image, is used. At FGI the Kern DSR-1 stereoplotter, Zeiss Phodis ST10 and Intergraph TDZ 2000 GL2/SSK workstations are used in the measurements. The mean coordinate error of image measurement is 3-5 μm , depending on the measurement method. Block adjustment is performed both with and without additional parameters using the ESPA AT software. Internal accuracy is analysed using standard error of unit weight σ_0 and standard deviations of solved parameters as quality measures. Quality of camera calibration is analysed based on the behaviour of additional parameters. External accuracy is determined using the independent checkpoints.

2.2.2 Determination of spatial resolution of images. The spatial resolution can be determined by visual or numerical methods. The fastest one is to determine the spatial resolution of the film by using visual inspection of the film. The results from this interpretation are not objective and thus a method to make this determination from digitised images has been developed. The numerical method can be used to determine the spatial resolution of scanned images that may differ a lot from the spatial resolution of film because of the pixel size of the digital image. The results of these methods are not the same, but because most of the photogrammetric work is still done visually the numerical method can be calibrated so that these results are comparable with those of visual ones.

To determine the spatial resolution of digital images (digital microdensitometer data) the method described in (Kuittinen et al., 1996) can be used. For each image several profiles over the test-bars are measured. Each measured profile and bar group is analysed separately. For the decision making of the acceptance of the bar group we have to calculate the common standard deviation of the bars and the background bars, for each bar group means and standard deviations, mean of bar maxima, mean of background bar minima, standard deviation of bar maxima and standard deviation of background bar

minima. The majority of the determined spatial resolutions (separately for each profile) give the final resolution of the image.

To calculate the MTF a special programme has been developed. It can be used in a normal PC. The input data for this software are microdensitometer profiles or a digital image of the test-bar target from which about five profiles are automatically selected. Calculations are based on the maximum and minimum of the single bars and backgrounds in each profile of the test target.

When taking aerial photographs with an overlap of 80 % it is possible to determine the AWAR-values for each imaging (Kuittinen et al., 1996). Ten measurements allow the determination of AWAR-values for the photographs. The following equation is used.

$$AWAR = \sum \frac{A_i}{A} \sqrt{R_i T_i} \quad (1)$$

where A_i is the area of the circular zone between radius r_i and r_{i+1} ,

R_i is the radial spatial resolution in the area A_i ,

T_i is the tangential spatial resolution in the area A_i ,

A is the area of the whole image.

2.2.3 Determining the geometric quality of digitised images. The geometric quality of the scanned images can be controlled using two methods. First the quality of scanner can be analysed by digitising a precision grid and analyse the residuals of the grid co-ordinates. By repeating this regularly the quality of scanning can be monitored. Secondly it is possible to control the geometric quality of scanned images by measuring the co-ordinates of the ground control points of the test field and analysing the residuals of co-ordinates. This method is possible only in cases when the scanning is made using the best possible spatial resolution (small pixel size).

2.3 Characteristics of the test material

2.3.1 Ground control points. The ground control points of the permanent test field are located in an area about 1 km². The points are marked by round-shaped white signals having the diameter of 30 cm. The background of the signal is black. 18 points are fixed in the bedrock and 26 points are fixed in constructions and soil. The co-ordinates of the points fixed in the soil and constructions are measured annually after the frost has melted by using GPS to control the possible movements of the points. The standard deviations of the co-ordinates of the all 44 ground control points measured in 1994-1997 in the test field of the FGI are 5 mm in x and y and 10 mm in z. The points are located evenly on the test area so that it is possible to take a small block of images to test the geometric accuracy of images and navigation.

2.3.2 Permanent test bar targets. These targets are constructed from different types of gravel, (Kuittinen et al., 1994) and (Kuittinen et al., 1996). Gravel is practical because it is weather resistant, rain does not damage it, it dries quickly after rain and its reflectance is closer to a Lambertian reflectance than the reflectance of the more smoother materials. Table 2 presents the characteristics of the test-bar targets.

Recommended scale/ gravel diameter [mm]	Contrast ratio	Width of bars [m]	Length of bars [m]	Ratio of the bar widths	Range of spatial resolution [l/mm]
1:3000/3 - 6	1:2	0.03 - 0.12	1.0	$\sqrt[6]{2}$	25 - 100
1:3000/3 - 6	1:10	0.03 - 0.12	1.0	$\sqrt[6]{2}$	25 - 100
1:60000/8 - 16	1:2	0.75 - 1.50	3.0 - 6.0	irregular	40 - 80
1:60000/8 - 16	1:10	0.75 - 1.50	3.0 - 6.0	irregular	40 - 80

Table 2. The characteristics of the test-bar targets.

In each of the group there are two targets that are perpendicular to each other. The reflectance curves of the gravels are presented by (Kuittinen et al., 1994). The bidirectional reflectance distribution functions have also been measured in the JRC (Joint Research Centre) in Ispra, Italy by using the EGO-goniometer. The grey scale of the test field is constructed by mixing dark and light gravel and it is used to control the exposure of the film.

2.3.3 Transportable test-bar targets. These targets are designed for different photographic scales to obtain them as small as possible. To reduce the size of the target only one bar of same width is used. To make easier the scanning by using microdensitometer, the length of the bars are equal. The characteristics of the transportable targets are presented in Table 3.

Recommended scale	Contrast ratio	Weight [kg]	Width of bars [m]	Length of bars [m]	Ratio of the bar widths	Range of spatial resolution [l/mm]
1:3000	1:2	4	0.03 - 0.12	2.5	$\sqrt[6]{2}$	25 - 100
1:3000	1:10	4	0.03 - 0.12	2.5	$\sqrt[6]{2}$	25 - 100
1:60000	1:2	50	0.53 - 2.12	5.0	$\sqrt[4]{2}$	28 - 113
1:60000	1:10	50	0.53 - 2.12	5.0	$\sqrt[4]{2}$	28 - 113

Table 3. The characteristics of transportable test-bar targets.

The test targets can be placed on ground and fixed with rods and reps. Two targets are needed, one for testing the radial and one for testing the tangential resolution. The targets can be placed in terrain so that it is possible to obtain enough material for estimation of AWAR-values, (Kuittinen et al., 1996). A grey scale of 8 steps (pieces / $5 \times 5 \text{ m}^2$) is under construction. The reflectances of the steps are 5, 10, 20, 25, 30, 45, 50 and 70 %. All pieces of the grey scale can be used separately depending on the physical area available or the amount of steps needed.

2.3.4 Material for testing the scanner. To control the scanner a precision glass grid and a grey scale can be used. The FGI used the following materials. We have a calibrated photogrammetric glass grid of 25 cm x 25 cm x 0.7 cm, manufactured by Zeiss. The spaces between the lines are 10 mm and the number of lines is 23 in both directions. The RMSE value of the grid is $\pm 1 \mu\text{m}$ and tolerance (maximum error) $\pm 2 \mu\text{m}$. A Kodak Photographic Step Tablet No. 3 (grey scale) of 35 mm x 250 mm has been used. This plastic tablet has the density range from 0.05 to 3.05 units. The density difference between each step is 0.15 units.

3 PRELIMINARY RESULTS

3.1 Geometric accuracy of analogue images

In order to achieve some idea about the quality of the determination of the geometric accuracy using the test field a strip of 3 images was calculated. It acts more as a demonstration than as an accuracy analysis of the system. The colour photography was made using a wide-angle camera in scale 1:3300. The scale of photography was selected so that the test field was covered by the middle image. In all 38 targeted ground control points (GCP) were measured using the Kern DSR1 analytical stereo plotter of the FGI. The strip was adjusted using the ESPA bundle block adjustment program both without additional parameters for interior orientation and with the 12 parameter model of Ebner. The estimated accuracy for ground control co-ordinates was 5 mm in plane co-ordinates and 10 mm in elevation. These values are higher than the corresponding estimates from GPS measurements because they include also the anticipated deformations of the targets. The results are presented in Table 4.

Adjustment	σ_0	m_x	m_y	m_z	m_{x0}	m_{y0}	m_{z0}
No add. param.	6.6	6	6	12	51	52	27
With add. param.	6.4	6	6	12	67	67	33

Table 4. Mean errors of block adjustments. m_x , m_y and m_z are the a posteriori values for control points and m_{x0} , m_{y0} and m_{z0} for the projection centres. Values are in mm except for σ_0 that is in μm .

Due to the small number of images, it is difficult to draw any justifiable conclusions from these calculations. The results are of medium accuracy. The estimates of ground co-ordinates reflect mainly a priori estimates. The comparison of σ_0 values shows that there are no larger systematic deformations on images. On the other hand the parameter model corrects the image co-ordinates on some border zones with values greater than 10 μm . This can result from insufficient amount of observations in this case.

As another example test flights and measurements of the GCPs by a private company are presented here. The 1998 aerial block contains only five images and the 1999 blocks contain six images, which is less than suggested previously. Different aerial triangulations were made at the FGI both with and without 12 Ebner additional parameters. The standard errors of unit weight σ_0 are in Table 5. A priori standard error of unit weight is 5 μm . A priori standard errors for the coordinates of control points are 0.005 m in x and 0.01 m in z .

Year	Lens	GCPs	σ_0 (μm)	σ_0 (μm), AT with additional parameters	Images in the block
1998	13158	30	4.3	3.8	5
1999	13215	35	4.8	4.2	6
	13158	32	5.4	4.5	6
	13335	33	4.2	3.7	6

Table 5. The results of aerial triangulations (AT) without and with additional parameters.

In these cases the results are of medium accuracy. The standard error of unit weight σ_0 is bigger at aerial triangulation without additional parameters. The difference is 0.5-0.9 μm compared to AT with additional parameters. The test field has demonstrated its usefulness for general camera control but if one would like to test the quality of the camera calibration then more images from cross flights and more measurements are needed.

3.2 Simulated aerial triangulations (AT)

Real image blocks contained only three to six images and we wanted to use more observations and images to find out the optimum flight geometry. All ground control points were used in the adjustments. Scale 1:4000 was too small to fulfil the image area with ground control points so the scale 1:3000 was studied further. Over and side laps were 80 %. Flight geometries were: One strip of three images from west to east (case A), two crossing strips from west to east and north to south of 3 + 3 images (case B) and 3 strips from west to east and 3 crossing strips from north to south containing 18 images (case C). Ground control points in the image area in different cases are in Figure 1. Points are accepted to the aerial triangulation if their image coordinates are between -105 and 105 mm.

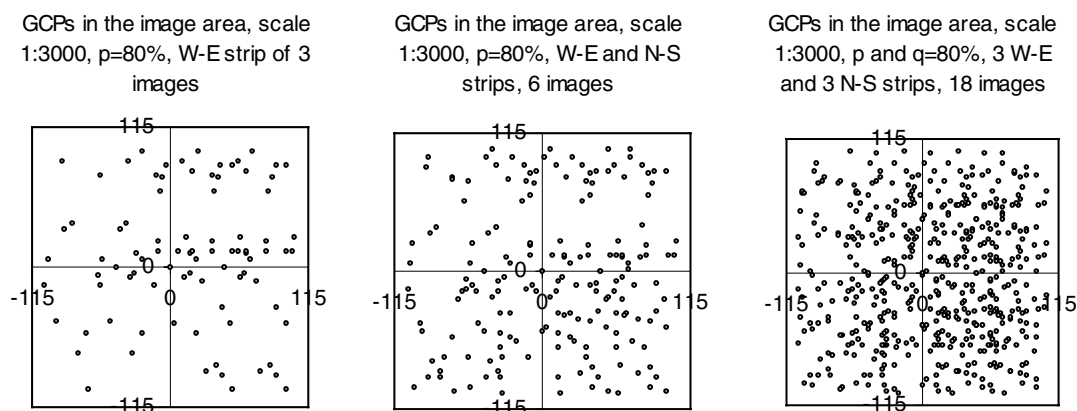


Figure 1. Ground control points in the image area in different flight geometries.

Normally distributed random errors were generated to the image coordinates. The standard deviation of random errors and a priori standard error of unit weight were 3 μm . Nine random error cases for each flight geometry were generated. ATs with 12 Ebner additional parameters and corrections at different parts of the image area were calculated. Maximum corrections in the image corners ($x,y=\pm 100$ mm) were 13 μm in case A, 6.5 μm in case B and 4 μm in case C. Systematic errors were introduced to the image coordinates already containing random errors. Changes in xy-coordinates were calculated by formulas

$$\Delta x = b_4 xy \quad (2)$$

$$\Delta y = -b_4 (2y^2 - 4b^2/3) \quad (3)$$

When $x,y=100$ mm and base $b=46$ mm the systematic errors were $\Delta x=2.5$ μm and $\Delta y=-4.3$ μm . Figure 2 shows the corrections of random error and systematic error cases. Also normally distributed random errors with a standard deviation of ± 5 μm were generated to the image coordinates. ATs with 12 Ebner additional parameters were calculated

and maximum corrections in the image corner were 8 μm in case C. A priori standard error of unit weight was 5 μm in these adjustments. Small systematic errors cannot be detected.

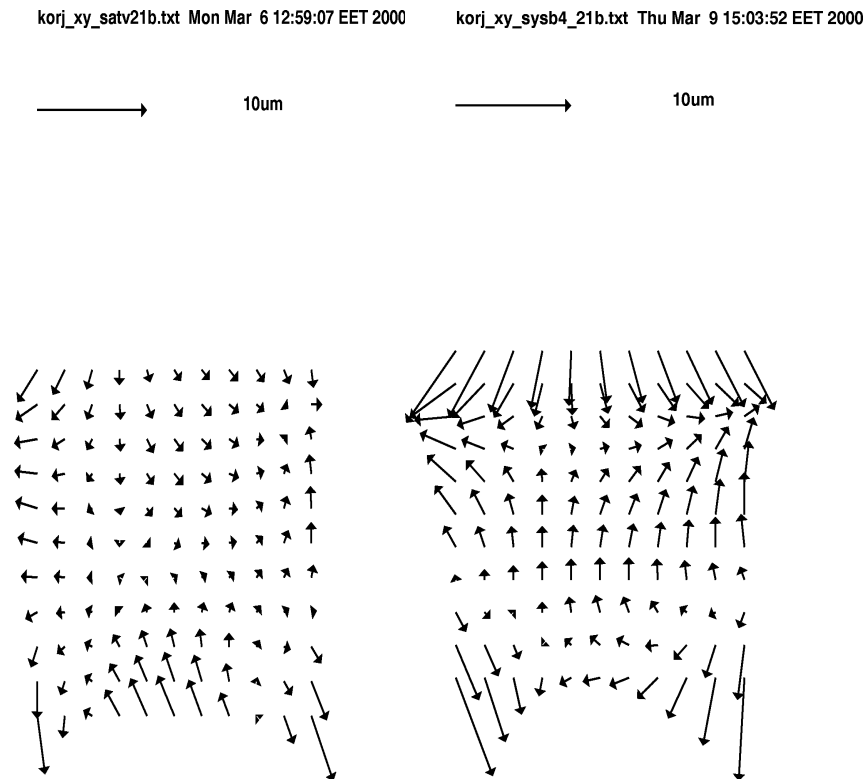


Figure 2. An example of corrections of random and systematic errors. Case B.

Unfortunately the ESPA software does not test the significance of each additional parameter.

One strip of 3 images is not a good choice to detect systematic errors, because the point distribution at the image edges and corners is weak. As a conclusion for good flight geometry an image block of two crossing strips (W-E and N-S) and 3 + 3 images is sufficient and the amount of ground control points to be measured is still moderate. Flying more than two strips will give a possibility to get more observations to the analysis (see 2.2.1).

3.3 Spatial resolution of analogue images

The spatial resolution of analogue images can be determined either visually with a microscope or they can be measured using a microdensitometer (in this case J-L Automation Ltd Microdensitometer 3CS) and analysing the results numerically. Let the dimensions of the measurement slit be Δx (width) and Δy (length) when the slit is moved in the direction x . ΔX is the width of one test bar. The narrowest bar of the target ΔX_{\min} defines the width of the measuring slit so that $\Delta x < 0.5 \cdot \Delta X_{\min}$.

The profiles of the 1:3 000 scale photographs were digitised with a slit size of $\Delta x = 5 \mu\text{m}$ and $\Delta y = 100 \mu\text{m}$. Altogether seven profiles were scanned over each test target. The profiles of the 1:60 000 scale photographs were digitised with a slit size of $\Delta x = 5 \mu\text{m}$ and $\Delta y = 20 \mu\text{m}$. The number of scanned profiles over the test targets varied.

Table 6 shows the differences between the spatial resolution of permanent and transportable targets. Visual interpretation and a numerical analysis of microdensitometer measurements were used. Images 72 and 78 have moved in the flight direction during exposure resulting in poor tangential resolution. This is the reason why AWAR-values were not calculated for images 70-78. To calculate the AWAR-values the image was divided into circular zones. The mean values for tangential and radial spatial resolution were calculated in each zone. Spatial resolution values were determined graphically from 4 radius values. Extrapolation was used when needed. Detailed description of the calculation method is given by (Hakkarainen et al., 1992). AWAR-values were calculated using equation (1) and they are presented in Table 7. In the scale 1:3000 AWAR-values are nearly the same but there is a difference between

permanent and transportable targets in the scale 1:60 000. Transportable targets give higher values. This is possibly due to the range of spatial resolution and also to the ratio of widths of bars of the permanent targets designed for high altitude images. The high altitude transportable targets contain two more test-bars compared to the permanent targets in the range 0.75-1.5 m.

Target type	image number	Aperture=4, time=1/410s						Aperture=5.6, time=1/410s					
		50	51	52	62	63	64	70	71	72	76	77	78
Permanent	Tangential	56	71	71	45	39	71	79	88	<25	62	79	<25
		56	62	71	45	39	62	62	71		62	62	
	Radial	71	71	56	62	56	62	88	88	71	50	88	62
		62	62	56	62	50	50	71	56	62	45	62	62
Transportable	Tangential	56	79	79	50	35	71	100	100	<25	71	100	<25
		62	79	71	56	39	79	71	71		62	62	
	Radial	71	71	62	71	62	71	100	100	100	56	100	71
		62	79	62	62	79	56	79	71	79	45	79	62

Table 6. Spatial resolution [l/mm] of film using permanent and transportable targets, and determined visually and *using numerical analysis of microdensitometer measurements*. Image scale 1:3 000.

Image scale	1:3000	1:60 000	1:60 000
Target type	Aperture=4, time=1/410s	Aperture=4, time=1/410s	Aperture=5.6, time=1/410s
Permanent	59 56	39 48	48 58
Transportable	63 63	46 63	59 70

Table 7. AWAR-values [l/mm] of film for permanent and transportable targets. Determined from visual observations and *numerical analysis of microdensitometer measurements*.

3.4 Geometric accuracy of digitised images

Scanning a calibrated grid using a pixel size of 10 μm controlled the geometric quality of scanner. The grid was scanned 30 times between 24th of July 1996 and 17th of November 1997. From the digital grid image 5x5 grid points were measured manually by using the ERDAS-software and a digital workstation and 5x5, 12x12 and 23x23 grid points were measured automatically. As a result of affine transformation between reference co-ordinates and measured co-ordinates RMSE values and residuals for points' row and column co-ordinates were achieved. Table 8 presents the RMSE values for all the scanings.

Grid points	Average RMSE [μm]		Average min and max residuals [μm]			
	Row	Column	Row min	Row max	Column min	Column max
5x5 manual	± 1.4	± 2.3	-2.7	2.6	-4.0	4.9
5x5 autom.	± 1.2	± 2.1	-2.1	2.4	-3.6	4.5
12x12 autom.	± 1.2	± 2.5	-3.2	3.4	-4.9	7.6
23x23 autom.	± 1.3	± 2.2	-4.0	4.1	-5.3	7.6

Table 8. Averages of RMSE and residual values (12x12 grid points: 30 scanings, others: 29 scanings).

An Ortho Vision scanner of the National Land Survey of Finland or a Leica-Helava scanner of the Fotonor AS, have been used in digitising images.

3.5 Spatial resolution of digitised images

The spatial resolution of the digitised images was determined visually on an image workstation display and also numerically. The results are presented in Tables 9 and 10.

Target type	Image number	50	51	52	62	63	64	Mean
Permanent	Tangential	35 32	45 39	45 39	35 28	32 25	45 35	39.5 33.0
	Radial	39 32	50 39	45 32	35 32	39 35	45 32	42.2 33.7
Transportable	Tangential	39	50	50	39	32	50	43.3
	Radial	50	50	45	39	39	45	44.7

Table 9. Spatial resolution [l/mm] of digital images (12.5 μm pixel size) determined visually and *numerically*.

Target type	Image number	50	51	52	62	63	64	Mean
Permanent	Tangential	32 25	32 25	32 25	32	32 25	35 28	32.5 25.6
	Radial	32 25	32 25	32	32 25	32	32 25	32.0 25.0
Transportable	Tangential	35	35	39	35	32	35	35.2
	Radial	35	35	35	32	28	35	33.3

Table 10. Spatial resolution [l/mm] of digital images (25 µm pixel size) determined visually and *numerically*.

The results show that due to the digitisation the spatial resolution has been decreased by 40 % or 54 % when compared with the analogue images. The continuous test bar target cannot be used in numerical analysis of the spatial resolution because the shapes of the bars in the image are not good enough to make any mathematical analysis.

4 DISCUSSION AND CONCLUSIONS

The geometric quality of the imaging and processing system (camera and block adjustment) must be controlled in the beginning of the season. However the geometric quality of scanning has to be carried out regularly during the digitisation process.

The spatial resolution of the image decreases as the pixel size increases which puts the limit to the pixel size used in digitisation. If a certain type of object has to be interpreted it has to contain at least four pixels before we can be sure that it can be interpreted. Transportable test figures give slightly higher values of spatial resolution than the permanent ones. This may be caused by the smoother surface of the target. Numerical method gives lower values of spatial resolution than the visual method in scale 1:3000. This is caused by the criteria used in the numerical method for determining the last detectable bar. Local variations of the pixel values have too much weight. The criteria have to be improved. More research is needed to get useful tolerances for quality criteria. This means that methods have to be tested for several photogrammetric tasks at different scales before an operative system can be installed in any mapping agency.

The fastest and cheapest way to do the control of the spatial resolution is to use the visual method. However this means that the results are not very objective. Even if the films will be digitised for further processing this visual method may be needed as the first control of the spatial quality of the image. After that the numerical method can be used for controlling the quality of the produced digital images.

The present transportable targets do not have a uniform reflectance in different zenith angles. A new type of paint is being developed and when this is ready better AWAR-values can be obtained.

The prototype method presented here is developed in co-operation with some Finnish mapping agencies and the Finnish Air Force. The aim is to develop this method operational during the coming years, which means that mathematical method, tolerances and test material will be finalised. The control of the GPS-based navigation and image projection centre determination will be included in the test procedure. Also the control of correct exposure will be included by developing a method to use grey scales in connection with the test-bar targets.

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