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THE QUALITY CONTROL IN THE FINNISH LAND PARCEL IDENTIFICATION SYSTEM ORTHOPHOTO PRODUCTION

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ABSTRACT

Digital orthophotos covering whole Finland (land area ≈340000 km^2) were produced during 1996-1997. The duration of the project was 18 months, including planning, scanning and orthorectification. The Finnish Geodetic Institute functioned as an expert and quality control consultant in the project. The particular emphasis of this article is on the quality specifications and control procedures used in scanning and orthophoto production. The quality control was divided into process design, on-line quality control and acceptance sampling. Both the visual and geometric quality were considered. Quality of the orthophotos has been investigated in the field areas, and it seems to fulfill the expectations. According to preliminary results, the RMS point error is less than 1.6 m in the main part of the country and in most parts of the country the quality requirement 2.5 m is fulfilled. Interior accuracy is clearly better. Visual quality of the orthophotos, produced of 1:60 000 aerial photographs, is not high, but the future investigations will show the usability of the material. Furthermore, practical tools for orthophoto geometric accuracy estimation are published.

1 INTRODUCTION

In the spring of 1996 Ministry of Agriculture and Forestry of Finland (MAF) initiated a project to develop a nationwide digital orthophoto database. The orthophotos are one part of the Finnish Land Parcel Identification System (FLPIS) which is a geographic information system belonging to the Integrated Administration and Control System (IACS) realized by MAF to control the agricultural subsidizes. The IACS belongs to a more general system, The Agriculture Administrative Information System. The FLPIS contains spatial data about farms and base parcels which are connected via the attribute data to the central IACS. Description of the system is given in (Sonkkila 1996, Schulman 1997 and Söderholm 1997). This article concerns the orthophotos produced for the system. Especially the quality and quality control issues will be discussed.

The orthophotos are utilized in the FLPIS by two ways, in parcel boundary digitization and in printing of 1:5 000 hardcopy orthophoto maps with vector overlay for the farmers. Furthermore, the orthophotos form the first national digital orthophoto data set of Finland and are available for public use.

The orthophotos were produced using existing nationwide materials, 1:60 000 aerial panchromatic photographs, the national digital elevation model with 25 m grid spacing and the aerial triangulation points produced mainly by National Land Survey of Finland (NLS). New ground control points were measured only in a small part of the country. Adequacy of the materials to the quality requirements was verified theoretically.

The orthophoto generation process was divided into two phases, scanning of the photo negatives and orthorectification. All the production work was done by contracting companies. In both of the phases there were three participants 1) MAF (customer), 2) contractor(s) (producer(s)) and 3) The Finnish Geodetic Institute (FGI, expert and quality control consultant).

The orthophoto production begun in summer of 1996 with scanning. The orthorectification started in autumn of 1996. The main part of the country was orthorectified before summer of 1997 and the last orthophotos were rectified in November 1997.

Quality issues have a long tradition in mapping tasks. Tendency in the photogrammetric mapping is to go to total quality management by developing standards for every step in the photogrammetric production line, see (Newby 1992, ASPRS 1995, Ackermann et al. 1996). Quality management of photogrammetic processes faces new challenges because of the GIS and the rapid development of digital photogrammetic techniques. Especially, it has been realized that GIS requires reliable quality management. Issues concerning quality, quality control and standards of digital orthophoto production have been discussed in (Arbiol et al. 1987, Schiewe et al. 1994, Manzer 1995, Kirwan et al. 1996, Lee et al. 1997, FGDC 1997, Honkavaara et al. 1998).

There were several factors which resulted in difficulties in realizing the quality control for the project. First of all, the quality of the materials used was heterogeneous and partly unknown. Reason for this is that the data has been produced during a long time period by different organizations and quality of all the data has not been verified. Another point was that the orthophotos were not produced for mapping in any special scale, but the quality and costs were to be optimized in the given limits. Because of this, existing standards for photogrammetric mapping were not directly applicable. Completely new criteria were to be produced for the orthophoto visual quality. Finally, the project organization (contractors, MAF, FGI) was new and a reliable quality management system was to be built up in a short time.

In this article, only a short description of the subject is given. The detailed results are given in (Honkavaara et al.

1998). The organization of this article is as follows. In chapter 2, the factors affecting on the orthophoto quality are discussed. In chapter 3, the produced orthophotos are shortly described. In chapter 4, the quality control arrangements are outlined. In chapter 5, some central results of the quality control are given and finally the geometric quality of the map is discussed in chapter 6.

2 ON QUALITY OF DIGITAL ORTHOPHOTOS

2.1 Quality of digital orthophoto

In orthophoto production, there are basically two classes of quality properties to be considered, the technical properties (like meta data, existence, format and saving to CD) and the digital image quality. In the following the latter is discussed.

Quality measures of orthophotos are generally the same as of images, i. e. geometric quality, spatial resolution, radiometric resolution and spectral resolution. However, additional details to be concerned are completeness, age, mosaicking, handling of 3D objects (houses etc.) and defects (like double image, missing image, image smear), (Manzer 1995, FGDC 1997 and Honkavaara et al. 1998). In this article the quality components are divided to *geometric quality* and *visual quality*.

2.2 Orthophoto production process

Orthophoto is an end product of a long production line. Significant processes in this line are

1. Generation of digital images
2. Generation of DTM
3. Defining the orientations
4. Computation of orthophoto
5. Mosaicking
6. Radiometric corrections

Realization of the processes is based on the quality requirements of the orthophotos. Important parameters are:

1. Digital images. Selections concern geometric quality, spatial resolution, radiometric resolution and spectral properties. These are dependent on several factors, like flight, camera system, imaging geometry, scale, photographic processing, scanner and pixel size.
2. DTM. Basically, the only important factor is the achievable height accuracy. Affecting factors are, among the others, the terrain type, accuracy of the mapping method, DTM type and the interpolation method used during orthorectification.
3. Orientation. The accuracy of the relation between the ground and the image is of interest. Affecting factors are numerous, for instance, camera calibration, image quality, scale, mathematical model, computation method (aerial triangulation vs. spatial resection), control (GCP, GPS etc.) and image measurements.
4. Orthorectification. Main parameters to be selected are resampling method (sampling interval and interpolation method), rectification method (anchor point or pixel-by-pixel), handling of 3D objects and DTM height interpolation method.
5. Mosaicking. Selections concern, for instance, the mosaicking border and geometric and radiometric feathering.
6. Radiometric corrections.

Out of these, factors 1-5 affect on the orthophoto geometric quality and factors 1 and 4-6 on the orthophoto visual quality.

Definition of quality requirements for digital orthophotos is a difficult task. Often the requirements are derived from the specifications for mapping in certain scales and from the plotting scale of hardcopy maps (Schiewe et al. 1994, Manzer 1995, Lee et al. 1997, FGDC 1997). However, the digital orthophotos are scaleless products and they will often be used in digital format, at least when high accuracy measurements are performed. This gives a possibility to optimize with the quality and cost issues. For instance, the geometric quality requirements may be fulfilled using a smaller scale and poorer resolution than the visual quality requirements based on hardcopy quality.

There are only a small number of parameters to be set in the actual rectification process. Recommendation for the interpolation method is to use bilinear or better method, see (Schiewe et al. 1994, Manzer 1995, Honkavaara et al. 1998). Rectification method does not usually have significant effect on the quality. The application defines handling of 3D objects.

2.3 Estimating geometric accuracy of orthophoto

In this article the geometric error of an orthophoto is seen as displacement from the correct location in X and Y directions. Usually the point error is considered. It has been concluded that the significant factors affecting on the geometric accuracy of a digital orthophoto are accuracy of the DTM and the orientations (Honkavaara et al. 1998). When assuming these independent, estimate for the mean error of orthophoto is

$$m_{ortho} = \sqrt{m^2_{ortho\_ori} + m^2_{ortho\_DTM}} \qquad (1)$$

where

m_{ortho_ori}	mean error resulted by orientation errors
m_{ortho_DTM}	mean error resulted by DTM errors

In practice also the measurement errors (measurement method, object etc.) must be taken into account.

2.3.1 Error resulted by orientation error

Estimates for the error resulted by the orientation error can be derived, for instance, by using the laws of error propagation, by simulation or using some expected value. In the high accuracy photogrammety with additional parameters, plane accuracy of 3-5 μm is achieved. In typical applications 10-20 μm plane accuracy should be achieved.

2.3.2 Error resulted by DTM error

A special feature of the orthophoto error resulted by height error is that it's magnitude is dependent on imaging angle but not on the image scale.

Several different estimates can be used for the error resulted by the DTM error. The most useful ones are 1) error for a single point (equation 2), 2) RMS error, (equations 3, 4) and 3) the expected percentage of errors >*lim*. The expected errors can be estimated by simulation or by using closed formulas. In the following the latter approach is used. Examples of usage of the formulas are given in chapter 3.4.

Error in a single orthophoto point

The point error of a single point, derived from simple geometric relationships, is

$$v(X,Y) = dZ\frac{\sqrt{(X-X_0)^2+(Y-Y_0)^2}}{Z_0-Z}, \tag{2}$$

where dZ is height error, (X_0,Y_0,Z_0) is location of the perspective center and (X,Y,Z) is the object coordinate. Behavior of $v(X,Y)$ is illustrated in figure 1b.

RMS error

Closed formula for estimate of the point error resulted by DTM error, corresponding the RMS error, has been derived in (Orava 1994). The estimate is computed by taking a square root of the average of squared point errors on the whole orthophoto area. Estimate for the RMS point error of a rectangular image piece, with side lengths of (*2a,2b)* and centered at the nadir point is

$$m_{ortho\_DTM} = \frac{m_{DTM}}{H}\sqrt{\frac{a^2+b^2}{3}}, \tag{3}$$

where m_{DTM} is mean error of the DTM and *H* is the average flying height from the ground.

The expected error of a square orthophoto (*a*=*b*) is

$$m_{ortho\_DTM} = \sqrt{\frac{2}{3}}\frac{m_{DTM}}{H}a \tag{4}$$

Expected error of arbitrary rectangular orthophoto pieces, photo mosaics, different camera geometries etc., can be computed in a similar way. See also (Honkavaara et al. 1998).

The amount of errors >*lim*

The amount of errors >*lim* can be derived by first computing the location dependent errors using equation (2) and then computing the percentage of the area exceeding the limit.

3 PRODUCED ORTHOPHOTOS

3.1 Technical description

Orthophotos have been sampled to the Finnish map grid KKJ using 1 m x 1 m pixel size. Pixel size of original digital images was 1.2 m x 1.2 m. One orthophoto covers one base map sheet of approximate size of 10 km x 10 km. Approximately 70% of the orthophotos were mosaicked of more than one aerial photograph. The orthophotos have been written to CD-ROM's using unpacked TIFF-format. There are in total about 3600 orthophotos with these specifications. In North Lapland in uninhabited areas with neither existing photogrammetric points nor fields, specifications were different (in total 320 base maps). This area is not discussed in this article.

The requirement for the geometric quality of the orthophotos was that the RMS point error is <2.5 m in more than 95% of the field areas. Requirement for the visual quality was that it is possible to recognize and measure the land parcels in every part of the image.

During the orthophoto production different information (results of orientations, notes of the system performance, etc.) was written to a "log-file". Orthophoto meta data consists of relational data base including following tables: general information of orthophotos, composition of mosaicks, ground control points, DTM and scanned aerial photographs, see (Söderholm 1997).

3.2 Used materials

3.2.1 Photographs

Scanned 1:60 000 panchromatic aerial frame photographs were used. Production of the photographs is regular work of the Topographic Service of the Defense Forces of Finland, intention being existence of 1-5 years old photographs of the whole country. The original negatives were scanned by NLS. Technical details of the digital images are:

Scale:	1:60 000
Flying height:	9 200 m
Camera:	RC20, 15/4 UAGAF, f=152.52 mm
Film:	Panchromatic, Kodak PlusX
Overlaps:	End: 60%, Side: 30% (mostly every second photo was used)
Age:	Mostly 1992-1995 (oldest 1985)
Scanner:	Ortho Vision 950 roll film scanner
Pixel size:	20 μm
Gray values:	256

In theory, the quality of the photographs is adequate for the quality requirements. However, there existed uncertainty because quality control and requirements of imagery have been different from those of typical photogrammetric mapping flights. Because of this special care had to be paid on the quality control of images. Problems arising from the image material concerned hot spot, spatial resolution, contrasts, cloudiness, central projection, shadows, temporal problems and snow.

3.2.2 Ground control points

Several different ground control point (GCP) materials were used.

1. 1:16 000 aerial triangulation by NLS.
2. 1:31 000 aerial triangulation by NLS.
3. 1:60 000 aerial triangulation by the contractors.
4. GPS points.
5. 1:31 000 aerial triangulation by the Topographic Service.

Most of the aerial triangulation points used have been produced after 1975. The computation method has mainly been bundle block adjustment. In the following, materials 1, 2 and 5 are called *existing* GCP and materials 3 and 4 *new* GCP.

Geometric error of the GCP materials was evaluated as follows

GCP material	Requirement dX=dY=dZ	Inner precision dX=dY	dZ
1-3	<1 m	scale*10μm	2dX
4	<1 m	<0.2 m	<0.2 m
5	<2 m	scale*15μm	2dX

3.2.3 DTM

Korkeusmalli25 (DEM25) covering whole Finland was used. DEM25 is a grid with 25 m x 25 m grid spacing. It has been produced by NLS from the numerical contour and water elements of the Finnish base map. The original contours have been produced by stereo mapping. The contour interval has been 5 m in the largest part of Finland (about 80%), but in the Northern Lapland 10 m contour interval has been used. Methods used since the 70's (60% of map sheets) are expected to be more accurate than the methods used in the 60's (40% of map sheets) (Peltola 1996). NLS has computed average accuracy of 1.76 m (average of absolute values of height errors) in the whole country.

Accuracy of the DEM25 in the field areas was evaluated for the purposes of this project as follows

- 5 m contour interval: m_{DTM} <4 m
- 10 m contour interval: m_{DTM} <8 m

3.3 Methods

The contractors in the orthophoto production were NLS and Finnish Mapping Group (FMG, consortium of two private mapping companies).

Tasks performed by the contractors were:

1. Acquisition of the materials
2. Defining the orientations
3. Orthophoto computation
4. Mosaicking
5. Radiometric correction
6. Writing the CD
7. Creating meta-data
8. Quality control

Each of the companies used different software. The orthophoto systems were Leica-Helava Socet Set, OrthoEngine and EspaOrtho. The interactive radiometric corrections were made using the Adobe PhotoShop or the EspaOrtho. The orthophoto computation was based on the anchor-point or pixel-by-pixel method. Earth curvature and refraction corrections were made. In gray value interpolation bilinear function was used. Mosaicking was performed either interactively using polygon line or automatically. Radiometric corrections were made interactively.

Different methods were used in defining the orientations:

1. Resection using minimum of 9 GCP/image.
2. "Block adjustment" using ≈20% end lap and ≈30% side lap. In each image at least 9 GCP's is used. In the overlap areas, few "tie points" were measured to obtain good fit in the image borders.
3. Block adjustment with digital images using ≈60% end lap and ≈30% side lap.

3.4 Expected geometric error

The expected geometric error of the orthophotos has been computed using equation (1). Expected RMS errors of 1:60 000 imagery with 150 mm focal length, resulted by orientation (resection) and DTM errors, are shown in figure 1 and table 1.

Values for m_{ortho_ori} and m_{ortho_DTM} were derived as follows. m_{ortho_ori} was computed by simulation using an uniform 3x3 GCP distribution (Monte-Carlo simulation with 10 iteration rounds). GCP ground co-ordinates were deteriorated with $\mathrm{N}(0,\sigma_{GCP})$ distributed random errors (σ_{GCP} =0.2, 0.5, 1.0 and 2.0 m) and GCP image co-ordinates with $\mathrm{N}(0,10\mu\mathrm{m})$ distributed random errors. m_{ortho_DTM} was computed using equation (4) with m_{DTM} =2, 4 and 8 m, H=9000 m and a=5000 m. See also (Honkavaara et al. 1998).

In theory, the geometric accuracy requirements are fulfilled when using GCP with accuracy better than 2 m and DTM with accuracy better than 4 m. When using values m_{DTM} =4 m and σ_{GCP} =1 m (chapter 3.2), the expected RMS point error is about 1.9 m and the expected amount of >2.5 m point errors is about 12%.

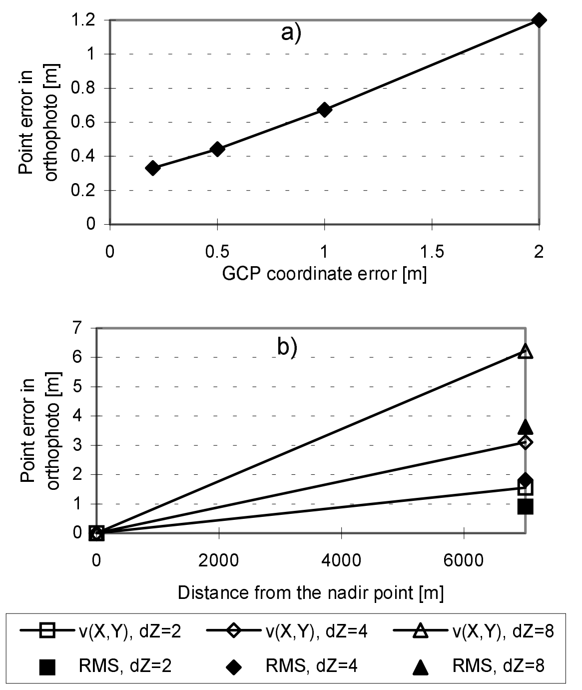

Figure 1. a) Orthophoto point error resulted by orientation error (resection, 3x3 GCP) as a function of the GCP quality. b) Orthophoto point error resulted by DTM error (error at different distances from nadir point and the RMS error).

Table 1. RMS point errors of orthophotos with varying GCP and DTM errors (meters).

GCP error/ DTM error	**0.0**	**0.2**	**0.5**	**1.0**	**2.0**
0.0	--	0.33	0.44	0.67	1.20
2.0	0.91	0.97	1.01	1.13	1.51
4.0	1.81	1.84	1.86	1.93	2.17
8.0	3.63	3.64	3.66	3.69	3.82

4 QUALITY CONTROL

4.1 General

Quality control was performed in different phases of the process. Statistical process control and acceptance sampling techniques were used (Mitra 1993). Furthermore, the users of the end products checked the results of the previous phase and if needed, the producers corrected the nonconforming items. Checking of different products is analyzed in table 2.

Following quality control actions were performed.

1. Process design. Before the process started the methods were adjusted so that the requirements are met. The adjustment was performed in co-operation with MAF, FGI and contractors.
2. On-line quality control. The on-line quality control was performed by the contractors during production.
3. Acceptance sampling. Acceptance sampling was performed by FGI. The sampling plan was a single sampling plan by attributes and no nonconforming

items were allowed. Because of the tight schedule the products were checked during the process and in some cases the results were used to adjust the specifications. Actions after finding nonconforming units were usually rejection of the whole lot so that the contractor made a full inspection and performed sufficient corrections.

Table 2. Quality control of different materials in orthophoto production. (Contractor1: scanning, Contractor2: orthorectification, Contractor3: land parcel digitizing).

Material	Performer	Check type	Extent
Analog images	Contractor1	visual*	100%
Scanner	FGI	geometric	sample
	FGI	radiometric	sample
Scanned photographs	FGI	visual	4%
	Contractor2	visual*	100%
	Contractor2	technical	100%
GCP	Contractor2	visual*	100%
DEM	Contractor2	visual*	100%
	FGI	geometric	3%
Orthophotos	Contractor2	visual*	sample
	Contractor2	geometric	sample
	Contractor2	technical	sample
	FGI	visual	3%
	FGI	geometric	3%
	Contractor3	visual*	100%
	Contractor3	geometric*	100%
	Contractor3	technical	100%

*) Check is made based on qualitative criteria.

4.2 Scanning

4.2.1 Requirements

Scanner geometric quality. Scanner geometric quality is defined using calibrated photogrammetric grid. RMS error should be $\leq 5\mu m$ and absolute values of residuals should be $\leq 15\mu m$ in 95% of the points, after affine transformation. The residuals should be non-systematic.

Scanner radiometric quality. Scanner density range should be at least 1.5D. Tolerances were given to the radiometric noise based on test scanning (tolerance area is shown in figure 2b).

Scanned photographs.

- Extent. The scanned photographs should cover the extent of land of Finland.
- Radiometric quality. The gray value range (0-255) should be efficiently used. Histograms shape is dependent on the scene. Values 0 and 255 are allowed only as single pixels in some special areas and on image frame.
- Spatial resolution. Spatial resolution should be adequate for measurement of land parcels.
- Completeness. The scanned photographs must be complete. Clouds should not disturb measurement of parcels.
- Other defects. Other defects, like snow, should not disturb measurement of parcels.

Technical properties and meta data. These should be perfect.

4.2.2 Process design

Criteria for the scanner and scanned photographs were defined by MAF and FGI. The contractor was free to define the technical realization of scanning process as far as quality requirements are fulfilled.

4.2.3 On-line quality control

The contractor performed on-line quality control during different phases of the scanning process.

1. Before. A preliminary check of the analog photographs (for clouds and spatial resolution).
2. After. Checking visual quality of scanned photographs. The photographs were classified to quality classes.

The details about scanned photographs were written to the "log-book" and to the image data base.

4.2.4 Acceptance sampling

Scanner quality. Scanner radiometric and geometric quality was checked in the beginning of the process weekly and later every second week. In the geometric quality control a calibrated photogrammetric glass grid (Zeiss), scanned using 10 μm pixel size, was used. Radiometric quality was controlled using the Kodak Photographic Step Tablet No. 3, scanned using 20 μm pixel size. The software for quality control has been developed at FGI.

Quality of scanned photographs. Quality of scanned photographs was checked by selecting about 2 images per a photo flight. Check was made interactively on a PC with a high quality screen using the Erdas Imagine software as follows.

- Histogram. The minimum and maximum values, shape and possible spikes were checked.
- General check of image. The photo was looked through in a scale of 1:500-1:5 000. Spatial resolution, completeness, existence of gray values 0 and 255 and existence of defects were checked.

4.3 Orthophoto production

4.3.1 Requirements

Orthophoto geometric quality. RMS point error should be <2.5 m, and more than 95% of the point errors should be <7.5 m. If the DEM25 error is >4 m, the requirements may be adjusted.

Orthophoto visual quality. Requirement is that it is possible to recognize and measure the land parcels in every part of the image. In the following specifications are given (100% quality is required unless otherwise mentioned).

- Quality requirements of scanned photographs have to be fulfilled (chapter 4.2.1).
- Radiometric quality. Requirements in 4.2.1. In addition, radiometric corrections should not destroy information in field areas.
- Contrasts. The land parcels should be measurable in every part of the image without making contrast adjustments. Gray value difference between the field and the border area have to be >10 in more than 70% of field areas.
- Mosaicking quality. Geometric differences in continuous objects on the mosaic border should be <5 m. Primary requirement for the visual quality of mosaics is that visual quality of each image is sufficient. In addition to this, too big gray value differences (>15 gray

values) should be avoided if possible.

Technical properties and meta data. These should be perfect.

4.3.2 Process design

Recommendations were given for orientations, orthorectification, radiometric corrections and mosaicking. Details are given in (Honkavaara et al. 1998).

4.3.3 On-line quality control

Quality control actions were performed by the contractors during different phases of the orthophoto production process:

1. Before. 100% check of the materials (scanned photographs, GCP's and DEM) was made visually to ensure that the quality requirements can be fulfilled.
2. During. The orientation results were checked.
3. After. Check was made on the technical properties and visual quality based on 100% or a smaller sample. One of the contractors checked geometric quality of a sample of orthophotos.

The details about orthophoto production were written to the "log-book" and to the orthophoto data base.

4.3.4 Acceptance sampling

The planned sample size was 3%.

Geometric quality. Geometric quality of orthophotos was checked using check points. Intention was to use minimum of 20 check points with accuracy better than 1 m, good distribution and lying on the ground or close to it. In practice the distribution and amount requirement could not always be fulfilled. Most of the points were crossings or corners of ditches, stones and road crossings. Existing control point materials (1:16 000, 1:31 000) and independent GPS points were used (note: orientation points were not used). Image measurements were performed by interactive mono measurement using software developed under Erdas Imagine.

Visual quality. The hardware and software is described in chapter 4.2.4. Controlled were:

- Histogram. See chapter 4.2.4.
- General check of image. See chapter 4.2.4. In addition contrasts and mosaicking were checked.
- Computation of contrasts. In case of low contrast image the contrasts were checked on a 4x4 grid. Contrasts had to be >10 gray values in more than 70% of the check points.

5 RESULTS OF QUALITY CONTROL

5.1 Scanning

5.1.1 Scanner

The scanner geometric quality was checked 30 times and the radiometric quality was checked 33 times. Most of the checks were performed between 24.6.1996-26.5.1997. The scanner was calibrated 4 times during the control period. The scanner fulfilled the quality requirements in general. Examples of results are given in figure 2.

5.1.2 Quality of scanned photographs

Out of 112 flights 89 flights were controlled, and in total 181 photographs were checked out of 4400 scanned photographs (4.1%). Following results were obtained:

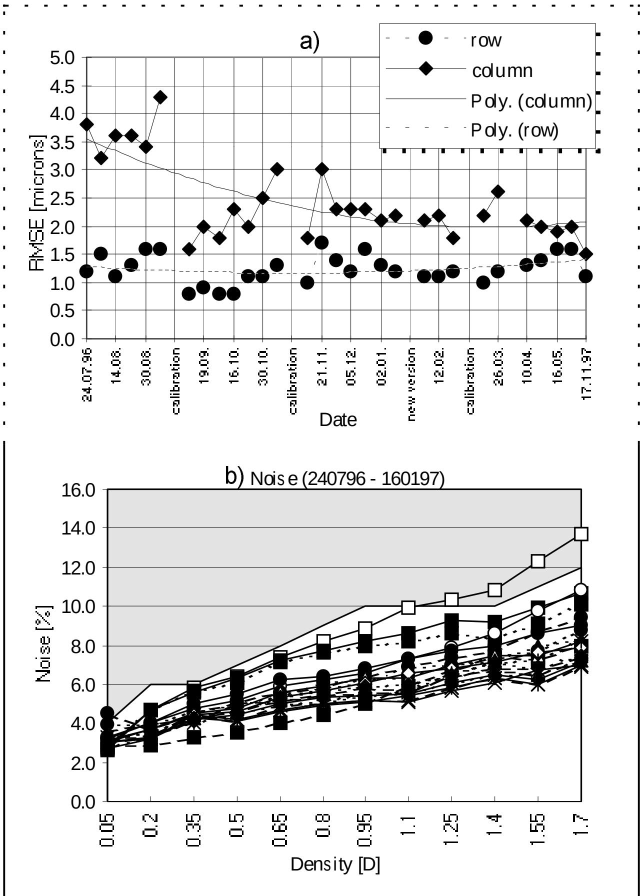

Figure 2. Results of quality control of scanning. a) Geometric quality of the scanner during the check period. b) Radiometric noise of the scanner through 24.7.96-16.1.97 (white area is the tolerance area).

- 4 photo flights were replaced partly or entirely by older flights because of bad quality
- quality of 2 photo flights was bad but no replacing flight was found
- one photo flight was scanned again
- 7 cloudy images were found

5.2 Orthophoto production

5.2.1 Geometric quality

Geometric quality of 140 orthophotos, out of 3600 orthophotos (3.9%), was controlled. Checked areas were further divided to areas with existing GCP (about 2600) and areas with new GCP (about 1000).

In the areas with existing GCP, 112 orthophots were checked. Three nonconforming orthophotos were found. Two of the errors were due to carelessness. The third error was due to problems with ground control on the Russian border.

In the areas with new GCP, 13 blocks out of 21 blocks were checked. Minimum of two orthophotos were checked per a block. Nine of the checked blocks were nonconforming, out of which four blocks were corrected successfully. Details are given in (Honkavaara et al. 1998).

5.2.2 Visual quality

First results of visual quality control were used to define specifications for visual quality. After these definitions, 164 orthophotos were checked out of 3900 orthophotos produced (4.2%). Results are given in table 2. Conclusion of the visual quality of the orthophotos was that it is not very high, because of the quality of the original images.

Table 2. Results of visual quality control of orthophotos.

Factor	N checked	N rejected
Tone	164	6
Contrasts	164	1
Spatial resolution	164	0
Completeness	164	3
Mosaicking	111	2
Other	164	1

6 GEOMETRIC QUALITY OF THE ORTHOPHOTOS

6.1 General

Analysis of the geometric quality of the orthophotos has not been finished yet. Following results are preliminary results of 3200 orthophotos in southern part of Finland. Also the DEM25 error has been investigated. The details and final results will be published in (Honkavaara et al. 1998).

Different accuracy measures have been computed.

1. Exterior accuracy. Exterior accuracy is the RMS value of the differences between the ground truth and the co-ordinates measured on orthophoto or DEM.
2. Interior accuracy. Standard deviation has been used as a measure of interior accuracy (systematic shift is compensated). In the case of orthophotos, the standard deviation has been computed separately to each orthophoto. In the case of DEM, the standard deviation has been computed to each check point class (see chapter 6.2). The final value is a weighted average of computed standard deviations (weights are based on number of check points).
3. Map accuracy. Effect of check point measurement errors is eliminated from the exterior and interior accuracy numbers.

6.2 DEM25 quality

Error of the DEM25 on the field areas, was computed in the areas of checked orthophotos, using check points close to ground level. The two DEM classes with 5 m contour interval (DEM1: 60's, DEM2: since 70's, chapter 3.2.3) were evaluated separately. Check points were classified to object classes *below* (mostly ditch crossings, 73%), *on* (24%) and *above* (mostly small stones, 2%) the ground. Total number of check points was 4161.

Results are shown in table 3. According to average errors, the class *below* is about 1.5 m below the ground level, which is the main reason for the big difference between the RMS value and standard deviation. Quality of DEM1 and DEM2 is practically the same. The DEM error seems to be less than 1.5 m in the field areas.

Table 3. RMSE and standard deviation of the DEM25 in field areas in meters.

DEM id	N points	RMSE	sdev
DEM1	1837	1.88	1.42
DEM2	2324	1.83	1.39

6.3 Orthophoto geometric accuracy

Effect of varying quality of materials was investigated (DEM25, GCP, image quality and contractor). Conclusion was that type of GCP material had effect. Five different classes were derived based on GCP materials:

1. 1:16 000 aerial triangulation.
2. 1:31 000 aerial triangulation.
3. 1:60 000 aerial triangulation, a) block fulfill quality requirements and b) blocks after the first check.
4. GPS points. (These areas were not checked).

Approximate amounts of orthophotos belonging to the classes are: 1-2: 70%, 3: 25% and 4: 5%.

Exterior accuracy. Results are given in table 4. The RMS point error of classes 1 and 2 is 1.5-1.6 m. The exterior accuracy of the classes 3a and 3b is clearly worse.

Table 4. Exterior accuracy (RMSE) in meters.

GCP	N points	N orthos	X	Y	XY
1	952	44	1.11	0.93	1.45
2	422	37	1.08	1.15	1.57
3a	253	16	1.32	1.31	1.89
3b	453	28	2.26	1.86	2.93

Interior accuracy. The amounts of orthophotos with significant systematic errors were in the classes 1-3b, 59%, 48%, 75% and 86% respectively. Interior accuracy values of the orthophotos with more than ten check points are given in table 5. Most obvious reason for the systematic error is orientation error. Effect of systematic error is biggest in classes 3a and 3b. The interior accuracy seems to be generally better than 1.6 m.

Table 5. Interior accuracy (sdev) in meters.

GCP	N points	N orthos	X	Y	XY
1	892	33	0.90	0.85	1.24
2	340	20	0.99	1.01	1.41
3a	227	13	0.95	0.90	1.31
3b	434	25	1.21	1.11	1.64

Map accuracy. Point error of the check points, m_{CP}, has been estimated as follows:

$$m_{CP} = \sqrt{2m_{CP\_ground}^2 + 2m_{CP\_ima}^2}, \qquad (5)$$

where

m_{CP_ground}	Check point coordinate error: AT: scale*10 μm; GPS: 0.3 m
m_{CP_ima}	Image measurement coordinate error: scale*10 μm=0.6 m

The estimates for the measurement errors are only approximate so they should be taken on caution. Results are shown in table 6. It seems that the real point error of the orthophoto is on a level of 1 m. The close distance accuracy will be investigated later.

Table 6. Map accuracy in meters.

GCP	m_{CP}	XY, RMSE, map	XY, sdev, map
1	0.88	1.2	0.9
2	0.96	1.2	1.0
3a	0.95	1.6	0.9
3b	0.95	2.8	1.3

Comparison to theoretical expectations. The expected point error of an orthophoto, with m_{DTM} =1.5 m and

σ_{GCP} = 0.2-1 m, is 0.76-0.95 m, which goes close to the values in table 6. Reasonable estimate for point error in the non-field areas is 2.29-2.36 m (m_{DTM} = 5 m, σ_{GCP} = 0.2-1 m).

6 CONCLUSIONS

Production of digital orthophotos covering whole Finland has been described. Phases of the project were scanning of photo negatives and orthorectification. FGI was responsible for defining quality specifications and for quality control. Total duration of the project was 18 months.

Preliminary results of geometric accuracy analysis in field areas were given for 3200 orthophotos in southern Finland. According to the results, the RMS point error is less than 1.6 m in the areas based on 1:16 000 and 1:31 000 GCP materials (about 60% of all orthophotos), and in most areas the RMS point error is less than 2.5 m. Interior accuracy seems to be better than 1.6 m. The geometric accuracy is expected to be better than 2.5 m in large part of the country, also in other than field areas. The geometric quality analysis will be continued.

Visual quality of orthophotos produced of 1:60 000 scale photography is not very high, but it is good enough for land parcel digitizing. The geometric quality is comparable to expected quality of 1:30 000 photographs with similar focal length and DTM. Important reason for selection of the scale 1:60 000 was that image material already existed and it is regularly renewed. Production of new, better resolution imagery of a large country, like Finland, would have taken several years. Future investigations will show adequacy of the orthophotos to different purposes.

Quality control was an important part of the process. Quality requirements concerned the field areas. Division to process design, on-line quality control and acceptance sampling was reasonable. In similar projects, especially the role of the on-line quality control performed by the producers, should be emphasized. At the time the process was going on, it seemed that the commercial orthophoto systems used did not have efficient tools for quality management and meta data production.

Method to predict and estimate the orthophoto geometric accuracy is published. It seems to give reliable estimates as long as the error sources are in control. RMS value has been used as a measure for the geometric error of orthophoto. In practice it would be better to give estimate to every measured object, because of the special feature of the error resulted by DTM error. Unfortunately the commercial systems for orthophoto production and measurement do not offer that option.

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