External Quality Control of Medium-scale Orthophoto Production – case Finnish Land Parcel Identification System

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Abstract. *Orthophotos are increasingly applied in Geogrphic Information Systems. Ministry of Agriculture and Forestry of Finland (MAF) is for a second time acquiring medium-scale orthophotos covering the whole of Finland to control the agricultural area-based subsidies of European Union. Orthophoto production has been outsourced to several contractors. Quality of the orthophotos is a central issue. MAF has decided to apply a comprehensive quality control (QC) based both in an internal QC of the producers and in an external QC of an objective QC consultant. Central ideas and results of the QC are presented in this article. These approaches can also be applied either as complete or as reduced in other similar projects, e.g. orthophoto production for municipalities or Forestry Centres. Also the quality of the resulting orthophotos is briefly discussed.*

Keywords: *geometric quality, orthophoto, quality control, radiometric quality*

1 Introduction

Orthophotos are aerial images rectified to an orthogonal projection. They can be used in various applications of Geographic Information Systems (GIS) either alone or in combination with other data.

The Ministry of Agriculture and Forestry (MAF) maintains Finnish Land Parcel Identification System (FLPIS), due to the European Union (EU) demand on controlling the agricultural subsidies. FLPIS is a GIS containing location information of all parcels and farmsteads of farmers that have applied for area-based subsidies. The second national medium-scale orthophoto mission for FLPIS is under way.

The first FLPIS mission was executed in Finland in 1996-1997. At that process the orthophotos were produced from existing 1:60 000-scale panchromatic images photographed by the Topographic Service of the Defence Forces of Finland. Three contractors with different systems produced the orthophotos. Finnish Geodetic Institute (FGI) functioned as the quality control (QC) consultant. The quality and production of those orthophotos has been thoroughly discussed by Honkavaara *et al.* (1999).

The five-year update process of the first orthophoto series began in 2002. Several contractors are involved in the orthophoto production. The orthophotos are produced from 1:31 000-scale colour infrared images (CIR) with 0.5 m pixel size. CIR images were selected to enable the use of the same material in forestry applications. In the update process FGI has created the quality system and Geoaudit Ltd has been responsible for the operational external QC.

The first FLPIS mission proved the importance of the image quality. Due to the strict timetable the orthophotos were produced from the existing image materials that were not intended for that kind of purposes. The main problem of the imagery was that the photo flights had been carried out under variable weather conditions. In large number of images, flying in poor conditions resulted in poor image contrasts and spatial resolution. This made the parcel boundary digitising very difficult. The digitising errors have now become disturbing when trying to combine the parcel vectors with new high quality images.

Thus, the quality of the FLPIS orthophotos is an important issue. The central quality components are spatial resolution, radiometric quality (especially contrasts) and geometric quality. The orthophotos are the basis for the quality of the land parcel boundaries derived from them. Legal decisions concerning agricultural area-based subsidies of about 70 000 farms are based on the data. A huge effort is put into the parcel boundary creation and diverse further utilisation of the data is expected. It is assumed that the quality improvement will decrease the maintenance costs of FLPIS.

Another foreseeable application of the FLPIS orthophotos is the forest planning in Finnish Forest Centres. The FLPIS orthophotos will be used also in other GIS applications as such and in combination with other data sources. These orthophotos also form a uniform part of the historical photographic material of the whole country.

Orthophotos are made available for the users via Internet. Finnish Administration has three countrywide orthophoto services for their internal use. One of these is the orthophoto service of National Land Survey of Finland (NLS); the Department of Agriculture of MAF owns other two containing the FLPIS orthophotos from the first and the second missions in two coordinate systems. One plan is to make the FLPIS Internet service available also for the farmers, for delivering their aid applications via Internet. Commercial orthophoto servers are also already available.

Several contractors are producing the FLPIS orthophotos with different systems; also the use of subcontractors is allowed. All-inclusive public instructions or specifications were not available at the start. The basic ideas of the QC-system created for the job are described in Chapter 2. The full specifications of the system are given by Honkavaara (2004). The system is based on recommendations given by European Commission (2004). In Chapter 3, the results of the 2002 and 2003 QC are discussed and the quality of the orthophotos is considered. Conclusions are given in Chapter 4.

2 Quality Control of FLPIS orthophoto production

2.1 Parties of the quality control (QC)

Parties of the production process are the client (MAF), contractors and external QC. The contractors in 2002 and 2003 have been NLS, FM-Kartta Ltd and Suomen Kartoitus ja Mittaus SKM Ltd; also subcontractors have been used. Geoaudit Ltd has been responsible for the operational external QC. FGI created the QC-system and is participating also as an expert in the process.

2.2 Phases of the orthophoto production

The orthophotos are end products of six sub processes:

1. First of all, the digital images have to be acquired.
2. After the image production the interior and exterior orientations of the images have to be determined.
3. Digital elevation model (DEM) is a prerequisite for the orthophoto calculation.
4. When digital images, orientations and DEM exist, the orthophoto calculation is a simple automatic process.
5. After rectifying the separate images, they can be mosaicked to provide orthophotos in the desired map sheet division.
6. The further necessary image processing actions are the image restoration, in order to eliminate various radiometric artefacts (e.g. illumination differences and hot-spot), and additional radiometric enhancements. The corrections can be made either before or after mosaicking.

Each of these six processes is critical when considering the quality of the orthophotos. The processes are clearly sequential, thus quality indicators can be developed to each phase. For instance, if failure in orientation process escapes internal QC's notice and the geometric error is not detected until the final acceptance control, the sub processes 2-6 have to be repeated.

In the MAF's process the orthophoto production has been divided into two phases: the image and ortophoto production. The process flows are shown in Figure 1.

The FLPIS orthophotos are based on scanned analogue 1:31 000-scale CIR-images, thus after the photographing, the images are developed and scanned. In 2002-2003 NLS and FM-Kartta Ltd have been the image producers.

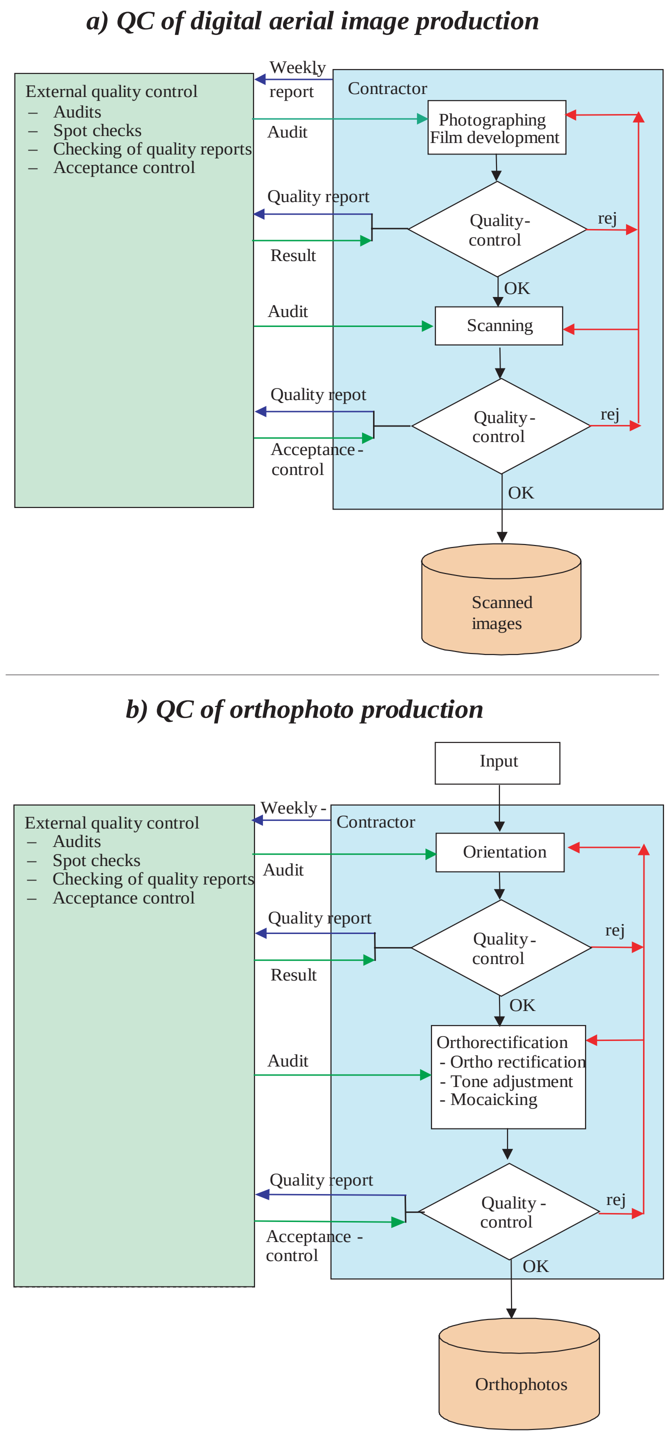


Figure 1. *Digital image production, orthophoto production processes and QC*

Exterior orientations are determined mainly using either GPS- or GPS/IMU-supported aerial triangulation. The blocks have 60% forward lap and 30% side lap. Typically stripwise drift parameters are estimated, but if the quality of the GPS-position observations is sufficient, blockwise parameters should be applied (the method has been described by Høgholen 1993). The photogrammetric points of NLS are used as ground control points (GCPs) whenever possible. The NLS points have been produced by aerial triangulation in scales 1:16 000 and 1:31 000; their expected internal accuracy is better than 0.3 m (Honkavaara *et al.* 1999). In the areas where NLS points do not exist, GCPs are measured by GPS with better than 1 m RMSE (root mean square error). The accuracy of the blocks is analysed in Section 3.4.

The existing National DEM with 25 m grid spacing is used (DEM25). The mean error of the DEM25 is less than 2 m (Maanmittauslaitos 1997, Honkavaara *et al.* 1999); gross errors and large interpolation errors in hilly areas sometimes occur. The effect of DEM errors is analysed in Section 3.4.

The orthophotos are mosaicked to the base map sheet division; one orthophoto covers a base map sheet quadrant, which size is normally 5 km x 5 km. In the mosaicking the most nadir method is used; in the process both automatic and interactive mosaicking can be applied.

In 1:31 000-scale images the illumination differences are evident. These and other radiometric differences are corrected interactively or automatically. An attempt was made to develop a model for the tone level of the images. The model was well suited for the forest applications, but for the agricultural applications the loss of grey values in the shadows was too serious; Markelin and Honkavaara (2004) reports the results of this study.

2.3 Quality control actions

The QC actions applied are process design and internal QC performed by the contractor, and the external QC organised by MAF (Figure 1).

2.3.1 Process design

The contractor must design the processes so that the required quality of the end products can be reached. To ensure that the procedures are acceptable, the external QC audits them. Also spot checks can be made during the processes.

The contractors tend to improve their processes continually by applying new technology. In the QC-system it has been specified that the contractor is responsible to inform the external QC if new procedures are taken into use; a new audit is performed if considered necessary. This requirement is to stress the importance of proper implementation, training and testing of the new methods.

2.3.2 Internal quality control

The internal QC is based on the quality system of the contractor. The internal QC is performed before production (e.g. training, calibration, testing of software and equipment), during production (e.g. follow-up calibration, environmental conditions, parameters assigned to the programs, quality measures given by the algorithms, intermediate products) and after production (e.g. acceptance sampling). The external QC audits the QC-system of the contractor in connection with the process audit.

Table 1. *Quality indicators of GPS-supported aerial triangulation, when stripwise parameters are used for GPS observations. Recommended upper limits for RMSEs and maximums are given for residuals and standard deviations. The limits for standard deviations are based on simulations, and their values can be improved based on results of practical blocks. In addition to the below statistics, also plots of blocks and block adjustment reports, given by software, belong to the exterior orientation report.*

	RMSE			MAX		
	x/X/ω	y/Y/φ	Z/κ	x/X/ω	y/Y/φ	Z/κ
Residuals						
Image observations						
Tie (interactive) [μm]	10	10	-	30	30	-
Tie (automatic) [μm]	20	20	-	60	60	-
GCP[μm]	10	10	-	30	30	-
GCP observations [m]	1	1	1	3	3	3
GPS observations [m]	0.3	0.3	0.3	0.9	0.9	0.9
Standard deviations						
Point unknowns [m]	0.9	0.9	1.3	1.3	1.3	1.6
Persp. cent. [m] (depend on fly. dir.)	1.5	1.0	1.0	2.0	1.5	1.5
Rot. [mgon] (depend on flying dir.)	7	14	6	15	20	10

Results of the internal QC are quality reports (see European Commission 2004) maintained in the contractors' premises. The quality manual (Honkavaara 2004) specifies quality reports for GPS processing, scanning, internal orientation, exterior orientation and orthorectification (Figure 1). The external QC checks the most important internal quality reports. Special weight is put on the exterior orientation, typically aerial triangulation reports; the content of the exterior orientation report is given in Table 1.

2.3.3External quality control

Methods of the external QC are quality audits (Section 2.3.1), control of the internal quality reports (Section 2.3.2) and acceptance control. The process is illustrated in Figure 1.

The acceptance control is made after the image and orthophoto production if results of internal QC are acceptable. The quality requirements and control methods are described in Section 2.4. The geometric quality check is made by inspection by variables according to the ISO 3951 standard. The other properties are inspected by attributes according to the ISO 2859 standard. The parameters of the sampling plan are at the moment: AQL=4; special inspection level S4 for scanned aerial photographs; general inspection level II for orthophotos; single sampling plan. The products are arranged to lots so that the products belonging to one lot have been produced in similar conditions. The sample is selected randomly from the lot. In the image production, images flown on a single day form a lot. In orthophoto production, orthophotos of a delivery set produced from a single adjustment block form the lot.

2.4 Quality requirements

Definition of the quality requirements has been problematic. The EU has specified the limits for the geometric quality, but for other image properties collectively accepted quality criteria do not exist, especially in the case of CIR-images. Such criteria should be determined based on evaluation of practical processes and needs, and both the image users and the image producers should accept them. Digital format gives a possibility for an automatic QC, which could make the QC very efficient.

For FLPIS images, quality requirements concern disturbances, spatial resolution, radiometric quality and geometric quality. Most of the requirements are qualitative, and their control is strongly relying on the controller's skills.

In addition to the requirements of the image products, recommendations have been given for the sub processes. As an example, the quality criteria for exterior orientations are shown in Table 1. Recommendations for other sub processes can be found from the quality manual (Honkavaara 2004).

2.4.1 Disturbances

Requirements

Certain disturbances (clouds and their shadows, dust, smoke, haze, etc.) are unavoidable. The requirement is that they may not hinder the utilisation of the orthophotos. The most stringent requirement concerns the existence of clouds in the final orthophotos: amount of cloudy images should be less than 4% and size of a cloud should be smaller than 5 hectares.

Quality Control

Disturbances are checked by viewing through the images using a feasible magnification. Sizes of clouds and amount of cloudy images are evaluated.

2.4.2 Spatial resolution

Requirements

The pixel size must be 0.5 m x 0.5 m. The spatial resolution can, however, be deteriorated due to atmospheric conditions, image motion etc. The spatial resolution should be sufficient for the measurement of parcel boundaries and allow detection of the crowns of normal-sized trees.

Quality Control
Spatial resolution is checked visually by viewing the image using a suitable magnification.

2.4.3 Radiometric quality
Requirements
The images should have sufficient contrasts and radiometric quality for the interpretation of the parcel boundaries and trees. An efficient tool for the radiometric QC is the grey value histogram. The histogram control is taken to the FLPIS QC in 2004. The best histogram quality indicators are the efficiency, 99%-efficiency and saturation (Markelin and Honkavaara 2004). European Commission (2004) has recommended that the grey values should be efficiently in use, the saturation should be less than 0.5% at the tails of the histogram and the variation coefficient (standard deviation of grey values/number of grey values) should be 10-20%; statistics are calculated to the luminosity histogram. In 2004 FLPIS QC the tolerance values suggested by Markelin and Honkavaara (2004) will be tested (efficiency ≥ 230 digital numbers, 99%-efficiency ≥ 160 digital numbers and saturation <0.5% in both ends of histogram). Because the scanning parameters have been set so that they suit for an average image, average statistics of a lot are tested.
Quality Control
In the QC of scanned images, either the image producer calculates the histograms of all the images or the external QC calculates histograms of a sample of images. Histograms of orthophotos are not effectively tested. In the orthophoto control it should be recognised that due to interpolation and other processing of the grey values, the quality indicators obtained from the histograms may be biased. Both in the scanned image QC and in the orthophoto QC, the histogram statistics do not show up all the possible radiometric errors. Therefore also a visual check is essential.

2.4.4 Geometric quality
Requirements
Geometric QC of scanned images and orthophotos differ significantly:
- Scanned images. The residuals of the fiducial transformation are controlled. Because the transformation is calculated for all the images, 100% check can be easily made. The maximum residual should be less than 30 µm in 96% of the images.
- Orthophotos. The RMSE (point error) should be less than 2.5 m. In mosaic boundaries the discrepancies in continuous objects should be less than 5 m.

Quality Control
- Scanned images. The maximum residuals are checked after the fiducial transformation. Typically the fiducial transformation is calculated immediately after the scanning, and this information can be utilised in the quality check.

- Orthophotos. The check of the geometric quality of orthophotos is the most tedious phase of the external QC. In the FLPIS QC, the photogrammetric triangulation points of NLS (Section 2.2) are used as check points whenever possible. If photogrammetric points do not exist, points measured by GPS are used. Also other existing GIS materials can be used to detect gross errors. Geometric quality can also be evaluated on the mosaic boundaries or between the edges of neighbouring images. These boundaries are not, however, always reliable quality indicators. They do not necessarily reveal local deformations of the photogrammetric block, especially if the images are on the same strip. The other problem is that quite often the mosaic boundaries are so perfectly hidden that they cannot be found.

3 Evaluation of end products

The numbers of produced and controlled orthophotos are shown in Table 2. Approximately 2600 orthophotos of size 5 km x 5 km have been produced both in 2002 and 2003, but only about half of these have undergone the external QC.

Table 2. *Numbers of produced orthophotos (total, undergone QC process) and number of checked orthophotos in 2002 and 2003*

Year	Produced		QC
	Total	Controlled	
2002	2613	1412	218
2003	2678	1256	186

The results of the external QC have shown that the end products fulfil the quality requirements. Some rejections have been made mainly due to geometric errors. The quality of the orthophotos is further analysed in the following.

3.1 Disturbances

Certain disturbances are present in the images, but they do not hinder the use of the images in the intended applications. Clouds are rare, and their existence is mentioned in the orthophoto metadata.

3.2 Radiometric quality

In radiometric processing several approaches have been applied: no processing, automatic statistical correction and interactive correction. The radiometric processing always destroys information content of the images; in the FLPIS orthoimages only slight radiometric processing has been applied. Quite large radiometric differences can appear between images. The images originating from the analogue process probably are not ideal to automatic interpretation tasks, which utilise radiometric and spectral information of the images. The images are excellent for interactive interpretation tasks.

3.3 Spatial resolution

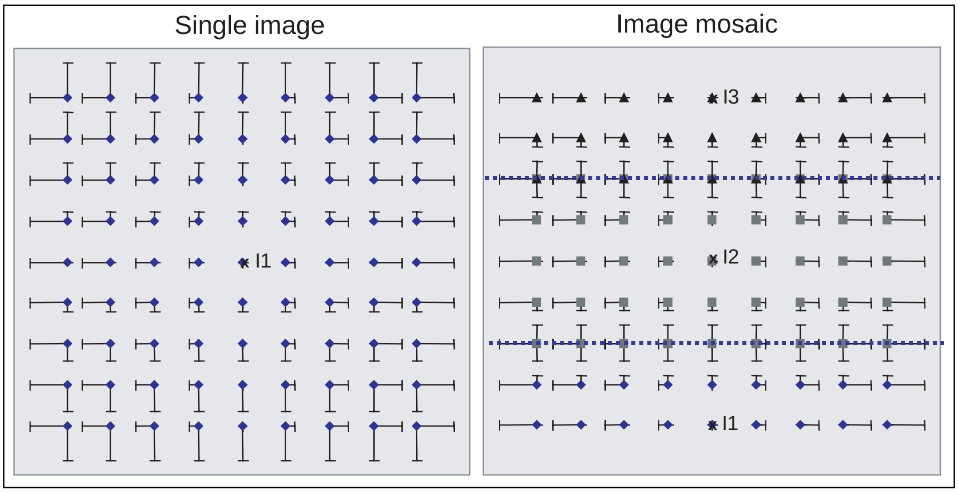
The images have been produced from 1:31 000-scale analogue images by scanning with about 15 µm pixel size; pixel size of the end products is 0.5 m. The quality inspection has proved that the quality of the images is high. Based on the photogrammetric experiences it can be expected that the smallest detectable object detail is on the level of 3 x pixel size = 1.5 m (e.g. Graham *et al.* 2002).

3.4 Geometric quality

The RMSE (point error) of the orthophotos is less than 2.5 m and in general less than 2 m.

The two major factors affecting the geometric accuracy of orthophotos are DEM and orientation errors (Honkavaara *et al.* 1999). Also the datum transformations may result in some discrepancies. Typically the error sources are independent.

The planimetric error of an orthophoto, caused by height error, increases when the distance from the nadir point increases. The mean error of DEM25 is about 1.8 m (Maanmittauslaitos 1997). The effect of 2 m height error is illustrated in Figure 2. The error is shown in Figure 2a for an orthophoto composed of one image and in Figure 2b for an orthophoto mosaicked of 3 images with 60% overlap. The error is 0 in the nadir point. The maximum coordinate error is about 1 m in the maximum distance from the nadir point (2500 m) in both cases; in the mosaic image the maximum coordinate error in the mosaic direction is about 0.6 m. Correspondingly, 5 m height error results in about 2.5 m maximum error in the orthophoto border. The orthophoto RMSE resulted by 2 m DEM error is less than 1 m.



a) b)

Figure 2. *Geometric error of an orthophoto caused by 2 m height error. a) FLPIS orthophoto consisting of a single image; the maximum error is 1 m in both directions. b) FLPIS orthophoto mosaicked from 3 images (I1, I2, I3); dashed line shows the mosaic border; the maximum error is 1 m in X-direction and 0.6 m in Y-direction (flying direction).*

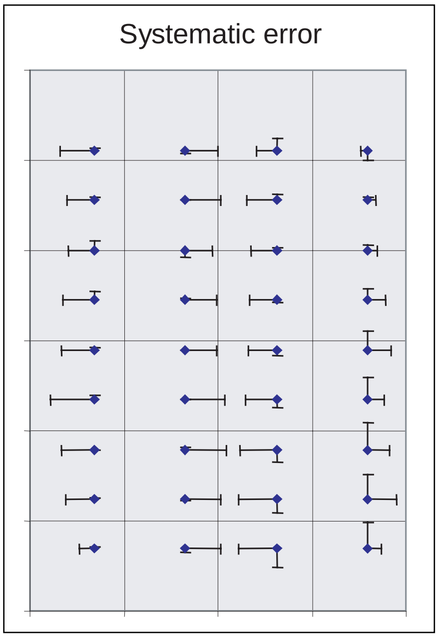


Figure 3. *Systematic errors of images of a photogrammeric block with stripwise corrections for GPS observations (4 strips, 9 images/strip, 1 GCP in each corner and height control strips in 8 bases distances)*

Systematic stripwise errors can appear in a photogrammetric block, when stripwise drift corrections are applied to GPS observations. Performance of a block (60% forward and 30% side lap; height control strips in 8-base distance; GCPs in block corners; GPS support; stripwise drift parameters) was investigated by simulation. The error of orthophoto, resulting from incorrect exterior orientations, was determined by calculating differences of back-projected image coordinates (errorless object coordinates transformed to image using the adjusted exterior orientations) and errorless image coordinates. Systematic error for each image was obtained by calculating an average of the differences in the image (Figure 3). When GCP and height control accuracy was 1 m, the systematic error was less than 1.5 m. The systematic error decreased as the quality of GCPs improved; with 0.3 m control point accuracy the systematic error was less than 0.6 m. If stripwise parameters are not used, these kind of systematic errors do not appear. In the evaluated case the orthophoto RMSE resulting from the exterior orientation errors was less than 1.3 m.

The geometric accuracy requirements can be achieved with the methods presented in Section 2.2. Systematic discrepancies of size 1-5 m can be expected between the existing parcel boundaries and the new orthoimages. Lager errors can appear due to the gross errors or interpolation errors of DEM25. Errors are also larger on 3D objects not belonging to the DEM25 (e.g. houses, trees).

3.5 Mosaicking

Orthophotos have been mosaicked using the most nadir method from three images. The mosaicking has been made either automatically with straight edges or interactively to the natural boundaries. Perspective effects are present on the mosaic boundaries. In most cases the mosaic borders cannot be detected from the images; mosaic boundaries have not been recorded. The larger than 5 m discontinuities in mosaic borders are reported in the orthophoto metadata.

4 Conclusions

In the FLPIS orthophoto production, the external quality control (QC) is an important part of the process. The strict control has motivated the contractors into accurate processes and also the processes have been improved as the result of the external QC; both the producers and the client have benefited from this. Owing to the rigorous QC process, the end products are well controlled and reliable. Another approach would have been to purchase the QC from the producers, but the objective external QC was considered to be more reliable.

Many other communities, e.g. municipalities and Forest Centres, also procure orthophotos. The experiences gained in the FLPIS QC are also useful for them. To perform efficient QC, the process has to be split into sub processes (e.g. 6 phases described above), and the importance and quality evaluation of each sub process should be considered. The major parts of the external QC of FLPIS are quality audits and an acceptance control after image and orthophoto production. ISO-standards are applied in the acceptance control. Also check of some central quality reports, e.g. histograms, GPS-processing, fiducial transformation and block adjustment, can be profitable.

The FLPIS QC has generated research projects concerning automatic quality evaluation methods of digital images. Results of these studies can be used in future in order to make the QC more efficient. It seems, however, that visual inspection will remain as an important part of QC.

The quality system is still under development; at least the final criteria for the radiometric quality have to be determined. Also the application of the new ISO standards concerning the quality and metadata (19113, 19114 and 19115) could be considered.

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