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Guidelines for Best Practice and Quality Checking of Ortho Imagery

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1. Introduction

1.1. This document

1.1.1. This document contains guidelines used by the European Commission for quality checking of geometrically corrected remotely sensed imagery, and the expected best practice approaches required to achieve good results. The guidelines here apply to digital orthoimagery products, generated from either film cameras or digital instruments, on both airborne or satellite platforms. for the scope of applications covered relates to the management, monitoring and control of agricultural subsidies and to some degree (particularly very high spatial resolutions) large scale mapping or cadastre applications. All stages of the production chain affecting geometric accuracy of the final product are considered, including data capture (film scanning) specifications.

1.2. Justification and applicability

1.2.1. The EC has always adopted an accuracy specification for geometric correction of images, but the basis of this specification is product-based and formal methods for testing conformity with the specification have not been defined in the usual technical specification documents or the ITTs associated with the projects. It is therefore the purpose of this document to set out stable, definitive and robust methods for effective quality assurance of image geometry.

1.3. Nature, scope and contents of these guidelines

1.3.1. The nature of these guidelines is to be descriptive, that is: to state what is to be done, usually without explaining why. These guidelines aim to also avoid assumptions that specific software or equipment will be used. However, in order to assure quality it has been assumed that the equipment/software used does possess certain features or functions.

1.3.2. The scope of these guidelines is defined both by the processes to be considered – mainly radiometric preprocessing (scanning) and orthorectification – and by the type of digital image data to be processes.

1.3.3. Concerning the contents, §2 reviews the general thresholds and tolerances that products will be tested against and describes the anticipated generalised QA to be carried out by the contractor or the Commission during the project. §3 covers the specific task of scanning aerial film data and sections §4, §5 and §6 (Orthocorrection QA) discuss how an internal QA *could* be carried out on a model production chain; these are essentially recommendations, modifications to which are likely to be questioned or examined in detail by the Commission during the project.

1.3.4. By contrast, §7 covers external QA to be carried out by the Commission. Annexes cover acronyms used in this document, as well as definitions.

1.4. Document history

1.4.1. This original version of this document provided as a contract deliverable executed by Remote Sensing Applications Consultants Ltd. and the Geomatics Department of University College London, in 1998. The contract was funded by DG IV (AGRI) and supervised by the MARS project of the JRC.

1.4.2. The draft specifications were revised, expanded, and in some cases reformulated by the MARS project, resulting in the version 1.5 that was made available in 1999.

1.4.3. This version (v2) has built further on the earlier document, updating in particular the sections on scanning, digital airborne data, and Very High Resolution satellite image ortho-rectification best-practice. This revision has been done in consultation with image suppliers, system manufacturer, and orthoimage producers.

2. Requirements of Quality Assurance

2.1. Quality Assurance

2.1.1. Quality assurance (QA) is a set of approaches which is consciously applied and, when taken together, tends to lead to a satisfactory outcome for a particular process. A QA system based on these guidelines will employ documented procedural rules, templates and closely managed processes into which various checks are built. Quality controls (QC) and quality audits are important checks within a QA system.

2.2. Quality Control

2.2.1. A quality control (or check) is a clearly specified task that scrutinises all, or a sample, of the items issuing during, or at the end of, the geometric correction process in order to ensure that the final product is of satisfactory quality. The scrutiny involves review, inspection or quantitative measurement, against well defined pass/fail criteria which are set out in these guidelines.

2.3. Quality Audits

2.3.1. A quality audit is a qualitative quality control that covers an area of activity as a whole. The EC will normally appoint an independent quality auditor to inspect geometric correction work in progress at the contractor's site. Quality audits will be carried out by comparison of actual practice with the applicable quality assurance procedures contained in these guidelines.

2.4. Quality Control Records

2.4.1. The information used in a Quality Audit will mainly be provided by quality control records (QCRs) which are generated during the work, by the people doing the work. QCRs take a variety of formats, such as paper forms completed manually, printouts or computer files recording the result of a particular procedure, or just simply hand-written records in log books.

2.4.2. The key features of any QCR are that it

- is marked with a date
- uniquely identifies the item, operation or product to which it relates
- identifies the operator who generated the QCR
- may be countersigned by a supervisor or other independent inspector (only for the most important records)
- is stored in a well defined and predictable location so that it can be found easily by others.

2.4.3. These guidelines identify the essential (minimum) set of QCRs required for QA of geometric correction.

2.5. QA Phases

2.5.1. Procurement of geometrically corrected images by the EC almost always occurs through a process of competitive tendering. The technical execution of the work is therefore not directly under the control of the EC so the QA process takes this into account. There is a sequence of three activities which can be controlled by the EC and which affects the quality of the outcome:

a) ITT specification and tender evaluation

- *These guidelines distinguish between work components that are explicit requests in an ITT and those that are looked for in the response.*

b) Quality Control during the geometric correction work, including input data

- *The purpose of QC during the work is to identify potential problems early. Potential problems are defined as those that could cause the geometric error in a product to exceed the specified tolerance.*
- *Internal quality assurance will be the responsibility of the contractor and will result in the production of QCRs.*
- *A representative of the EC who is independent of the contractor will carry out external quality audits (physical checks of conformity to specifications and scrutiny of QCRs produced by the internal QA) and a limited amount of sample-based QC.*

c) Measurement of geometric error in the output images

- *An independent external quality control will be carried out by the EC on a sample of geometrically corrected image products in order to establish an overall accuracy. The acceptance criterion for this check is the tolerance stated in the ITT.*

2.6. Thresholds

2.6.1. In general, the orthoimage products (and associated DEMs) will be assessed from three geometric perspectives:

- *RMSEx*
- *RMSEy*
- *For DEMs, RMSEz* [1]

2.6.2. Product deliveries determined to be outside this specification will be returned to the contractor for evaluation by the contractor (internal QA) and redelivery, followed by further (possibly repeat) checks (external QA).

2.6.3. Thresholds for scanning are described in §3.

[1] *Twice the RMSEx will be applied*

3. Scanning

3.1. Scope

3.1.1. This section covers the expected requirements and best practice approach to be applied concerning image scanning for orthophoto production.

3.1.2. It can be applied analogously to images produced by digital frame cameras/instruments.

3.2. General requirements

3.2.1. The original film (or, alternatively, the diapositives) will be scanned with a photogrammetric quality scanner of the following general characteristics:

- Scan resolution of 20μm or better; typically, up to 12μm scan resolution will be applied.
- Final radiometric resolution of at least 8-bit per channel. However, it is strongly advised that 11- or 12-bit scanning systems are used.
- Geometric precision of scanner < 5μm

3.3. Scan process

3.3.1. The scanning process will be checked frequently by the contractor who should perform and submit a quality assurance report at delivery of data; the quality control data ("scan file") produced by the scanning software would normally be a suitable information source to include. The quality assurance report should also contain information on:

- frequency, execution, and details on geometric quality control using e.g. a calibrated photogrammetric grid performed before and during project
- frequency, execution, and details on radiometric quality control using e.g. a photographic step tablet performed before and during project
- details on quality tests of the scanned photographs including the following checks:
    - ❑ Saturation should not exceed 0.5% at each tail of the histogram (e.g. the resulting 0 and 255 values for an 8-bit image), for the full image[2]. For colour/multispectral images, this assessment should be made in the Luminosity histogram.
    - ❑ Effective use of the radiometric resolution; this should be determined by a check for grey-values which contain no pixels in the output image.
    - ❑ Contrast: The coefficient of variation[3] of the image DN values should be in the range of 10-20%. Exceptions will, however, occur where the scene contains features like sun-glint on water bodies, etc.
    - ❑ Clear visibility of fiducial marks
    - ❑ In addition, a table (Excel 2000 compatible) should be provided giving the meta-data characteristics of the files delivered (file name, photo number, CD number, radiometric statistics, results of sample tests, date and time of scanning, operator, etc).
- in addition, sufficient checks should be carried out to ensure that the following parameters are respected:
    - ❑ Geometry; a photogrammetric interior orientation (affine transformation) of the images will be expected to produce an RMSE of <10μm (four corner fiducials), with no residual greater than 30μm. In the case of use of eight fiducial marks, the RMSE can increase to <20μm (although again, no residual should exceed 30μm).

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[2] The full image is defined as the largest included rectangular region that does not include the surrounding film clear base, in order to prevent this extreme outer region from skewing the statistics

[3] Represented as the Standard Deviation of the DN values as a percentage of the available grey levels

- Correct labelling of files; this should follow a standard Windows platform naming convention, without spaces and with a name plus extension (file type) e.g. *photo_nr.tif*. The naming used should correspond with that used in the meta-data table described above.
- Overall quality of data delivered (lack of dropouts, etc.), visual appearance: Colour images shall be scanned to reproduce as far as possible the characteristics of the original photographic image in the case of film positives. In the case of film negatives, where no visual standard exists, the reproduced image should be rendered to represent the colours in the original scene as far as reasonable.

3.3.2. The images should be delivered with an orientation to ensure that the Northern edge is the top-most (usually first-line) in the file.

3.3.3. All the scanned images will be delivered at the end of contract generally on hard-disk media, or CD- or DVD-ROM in plain TIFF 6 format (no compression, no tiling).[4] It is recommended that an image in the proposed format be supplied ahead of the delivery to confirm acceptance of the format used[5].

3.3.4. Meta data concerning the image (date, source, photo number etc.) should be included as a tag in the TIFF6 header.

3.4. Image radiometric quality assurance

3.4.1. It is recommended that these controls are implemented in automated processes that permit the generation of QCRs for each file produced.

[4] A precise definition of this format can be found at http://partners.adobe.com/asn/developer/pdfs/tn/TIFF6.pdf. Further information can be found at http://www.libtiff.org/support.html.

[5] Alternatively, a different format ***to be agreed upon with the Commission at the beginning of the contract*** can be proposed.

4. Air-Photo Orthocorrection QA

4.1. Scope

4.1.1. This section outlines the process of creating digital orthophotos from air-photos, from the perspective of assuring final product quality. The points are "indicative" and give **guidelines** as to the Commission's current understanding of "best-practice". In this sense, they can be adopted **as far as the contractor considers they are sensible and plausible** in a production environment.

4.2. Input data

4.2.1. The quality of materials and equipment used to create the input data is critical to a satisfactory result. Any digital processing must carry out an input data quality assessment (IDQA) which will check that the images were captured and digitised correctly (Table 4-1).

4.2.2. Note that the above table does not include radiometric QA and QC, however these are usually mandatory and it is efficient to carry out such checks on the original photographic negative/diapositive followed by further checks on the digital (scanned) data at the same time as the QC for geometry. Initial checks will usually ensure that solar angles relative to the flight direction and time are acceptable to avoid excessive glare/shadowing, and that individual photos are free of cloud and have sufficient contrast in the features of interest. Post scanning checks may examine image histograms to ensure that the available dynamic range is fully used but without saturation or cut-off.

Item	Best practice	Internal QCR/QA
Film	High resolution panchromatic aerial film	Physical verification of film (interior/relative orientation on diapositives (if produced)), development and print media, manufacturer's technical documentation.
Camera	High quality, modern aerial camera with forward motion compensation and computer managed exposure mechanism.	Physical inspection. Date-stamped camera calibration certificate (normally valid for 2 years)
Flight Navigation	Camera linked to on-board INS. GPS controlled photo logging.	Physical inspection. Inspection of flight log data. Check that air camera positions usable in GPS-block adjustment.
Overlap Completeness	Forward 60%, Lateral 15 - 25% Contractor could specify lateral overlap up to 60% for fully automatic aerotriangulation. 100% coverage with specified overlap	Analyse log of photo centres and flying height for conformance with completeness, overlap and scale variation. Or if no flight data: Photo-laydown.
Scale Variation	<±10% Scale variation (for flights >4000m) <±15% Scale variation (for flights <4000m)	Use GCP positions and DEM to generate scale for each photogramme
Scanning Equipment and Materials	Use precision scanner, according to requirements in Chpt. 2 Negatives should be scanned (positive output) if possible.	Physical inspection Interior orientation of an early *scanned* sample must be tested (5%). Reject entire batch if RMSE on four corner fiducials is >15µm for >5% of sample.
Scanned Pixel Size	Typical practice: B&W 14µm, Colour 20µm	Printout of metadata for digital files (listing and file size in bytes) Calculate resolution from file size (pixels/lines).
Scanner Accuracy	Scan geometry RMSE < 5µm No residual > 15µm	Repeated test scans using a photogrammetric grid, measure at least 5 x 5 points. Compute x, y residuals and RMSE (x and y) after an affine transformation. First test before start of photo-scanning then repeated regularly at intervals depending upon stability of system. Plot RMSE and maximum residual for row and column on a control chart.

Table 4-1 : Best practice for Input data quality assurance

4.2.3. Input files should be self-documenting (e.g. flight, photo number), with additional metadata in tables linked to the file name. The following information should be recorded:

- For each flight: Camera identifier and Calibration certificate, Type of film, Identifiers for film rolls used, start/finish time, Weather Conditions (as recorded at airport Meteorological station: should include temperature, pressure, wind speed/direction at one standard time during day).
- For each photo: Flight identifier, Film roll and Exposure number, Flying height, Ground coordinates of Exposure station (from INS/GPS), Time of exposure, Date of Scanning

4.3. Digital frame instruments

4.3.1. In so far as digital frame instruments are expected to operate under a similar workflow practice, such systems would be subject to the same QA requirements as standard, scanned, film cameras. The general requirement for the instruments would be those applicable to the scanning of film, with respect to geometry and resolution.

4.3.2. Appropriate geometric calibration, for example factory calibration or field calibration of the instrument using an official test field (or validated by the instrument manufacturer), should be current (within past two years). This should be at least equivalent to the best practice requirements listed in Table 2 above.

4.3.3. Radiometric calibration would normally be expected to be dependent upon factory certification and state:

- The level of live cells for each CCD array should be certified.
- Statement of radiometric resolution performing to at least 12-bit.

4.4. Geometric correction requirements

4.4.1. These guidelines detailed here are generally valid for medium scale (1:20 000 to 1:40 000) scale source air photos. This tolerance is based on the ASPRS map accuracy standard for 1:10 000 scale maps (ASPRS 1989, FGDC 1998) and it is known to be achievable if the data capture and processing specification given in these guidelines is followed.

4.4.2. Geometric correction tolerance is defined using one parameter: the maximum permissible RMSE of the check points. Tolerances are as stated in the relevant ITT.

Purpose/Method	Number of GCPs
Orientation of a single model	Four (allows for testing of residuals)
Block adjustment for aerial triangulation, without airborne DGPS	One 2D GCP every five base lengths (minimum) on the perimeter of the block. One Vertical GCP in every strip across flight strips, every four base lengths.
DGPS controlled flight with cross strips (CBA-Method: Combined Block Adjustment)	One 3D ground control point in each corner of a block (but double point selection advised). Possible additional requirement of cross strips and more control within irregular blocks. Ambiguities which are not solved are removed as systematic errors in the Block Adjustment at great distances possible
DGPS controlled flight (no cross strips) (OTF-Method : Ambiguity resolution “on the fly”.)	At least three 3D GCP randomly distributed within the block. Double point selection in each block corner advised. GPS Reference stations should not be further than 50kms from survey area.
DGPS/INS controlled flight (no cross strips)	One 3D GCP possible, but one 3D GCP in each corner of a block is recommended

Table 4-2 Number of GCPs recommended for Orthocorrection of Air Photos

4.4.3. GCPs should ideally be determined from field survey, however in exceptional cases if this is not possible they may be scaled from maps of sufficiently high precision, or taken from an oriented flight of an appropriate scale measuring in stereoscopic mode; this is especially so in the case of vertical control, should the maps provide photogrammetric spot heights of sufficient quality.

4.4.4. In any case, GPCs should be three times more precise than the target specification, e.g. in the case of a target 2.5m RMSE, the GCPs should have a specification of 0.8m RMSE or better.

4.4.5. Where ground control is obtained from topographic mapping, map accuracy and generalisation must be allowed for, thus an accuracy improvement factor of at least *five* is recommended when estimating a suitable map scale for planimetric ground control points[6]. For vertical control, precision should be to at least 1m and accuracy better than 2m RMSE.

4.4.6. With air-photos the recommended source of ground reference is ground surveyed control of *well defined points* (FGDC, 1998*)*. The method of survey could be by DGPS supported with geodetic control points or a GPS reference station network, though direct measurement survey methods for precise ground control are also acceptable.

4.4.7. The number of points recommended for corrections are listed in Table 4-2 for possible flight configurations.

4.4.8. The contractor should also obtain check points for internal QC.

4.5. Documentation associated with ground reference data

4.5.1. Ground reference data (GCPs and check points) must be well documented, in order to provide traceability. In essence, this documentation is a vital QCR to be created by the contractor. A list should be maintained showing:

Stage	Practical procedure	Recommended Acceptable tolerance
DEM grid spacing	Specify according to output scale and terrain For medium scale flights, break lines not required.	5 to 20 times output pixel size*
DEM height accuracy	Automatic DEM generation using stereo-matching and surface generation methods*. Visualisation and cleaning of the output is normally required.	2 x planimetric 1-D RMSE required
Tie points for aerial triangulation	Can be done manually but should be done automatically* if supported in software.	Automatic AT: Minimum of 12 per model, with good (Von Grüber) distribution Manual selection: Minimum of 6 per model
Interior orientation	Affine transformation of fiducials. Use eight fiducials*, otherwise all four corner fiducials if not available.	RMSE < 10μm (4 corners), or <15μm (8 fiducials) Maximum residual of 20μm
Relative orientation	*Not applicable if using automatic aerotriangulation in a DPW environment*	*Maximum RMSE on y parallax of 10μm*
Absolute orientation	Measure model co-ordinates and transform to the ground	RMSE on GCPs from Block Adjustment <0.5x product RMSE specification
Relative Block Accuracy	Block Adjustment from tie points and GCP (and GPS/INS data if available at image level	RMSE ≤ 0.5 x input pixel size
Absolute Block Accuracy	Block Adjustment from tie points and GCP (and GPS/INS data if available) to ground level.	RMSE ≤ 1/3 specification ((RMSE required is normally 2,5 times output pixel size)
Resampling method	Cubic convolution or bilinear interpolation	N/A

*Recommended

Table 4-3 Tolerances for Air-Photo ortho processing

[6] for example if output specification is 2.5m 1-D RMSE (equivalent to 1:10,000 scale), then control data derived from mapping must be 0.5m 1-D RMSE, i.e. not derived from maps smaller than 1:2,000 scale.

- point identifier (unique to project)
- X, Y, Z coordinate
- Source (GPS; photogrammetric mapping service archive, geodetic survey, topographic map, etc.)
- Expected (or proven) planimetric quality of the point in meters (RMSEx, RMSEy)
- Expected (or proven) vertical quality of the point in meters (RMSEz)
- Other remarks

4.5.2. In addition, supporting information included with the ground reference coordinates must state all parameters for the coordinate system, including the ellipsoid and identification of all geodetic controls used during the field survey.

4.5.3. Each point should be marked on an image or map and labelled with the point identifier used in the list. Marking should ideally be done in the field at the time of survey, *preferably* on the scanned digital images (or full resolution hardcopy extracts from them). The entire dataset should be archived with a image extracts (hardcopy or image file) clearly marked with precise GCP locations and identifiers. An ideal approach for storing and manipulating these data is in a GIS environment linked to the final orthoimage dataset.

4.6. Geometric Correction Process for Air-Photo orthocorrection

4.6.1. Table 4-3 provides tolerances for each stage of the air-photo orthocorrection process. The measurements corresponding to each tolerance can be used to provide quantitative input to QCRs.

4.7. QCRs and quality audits for air-photo orthocorrection

4.7.1. Contractors should generate the following QCRs for their internal QA. They should be made available for inspection during a quality audit by an EC representative. The type of quality audit is shown in Table 4-4 as “Normal” or “Tightened”.

4.7.2. “Normal” audit checks which are carried out ‘Once’ will be repeated again if a corrective measure is requested.

4.7.3. “Tightened” audit checks will follow an audit trail for suspect products or regions and will be introduced if

- earlier audits result in doubts about performance
- results from QC do not meet the specifications given in previous sections
- results from external QC do not meet the tolerances in the ITT.

4.8. Updating of zones covered by existing orthophotos

4.8.1. Two strategies are considered applicable for the updating of zones with existing orthophotos:

- Use of GPS controlled flight: repeat of (automated) aerotriangulation
- Model-based approach, using ground and photo point data used in initial orthophoto creation

4.8.2. Both approaches make use of existing ground control and DTM/DEM data: neither approach should require re-visits in the field, nor serious revisions of block adjustment data (GCP positioning, quality). Where the terrain has changed the DTM/DEM should be edited. Such areas may be detected with correlation techniques from new flights and a comparison with the existing DEM/DTM.

4.8.3. Since many of the steps for production are the same as for the initial creation, these are not re-specified here; reference is made to the preceding sections. However, the revision flight should be compatible with (although not necessarily identical to) the initial flight, hence a preference for GPS controlled/pin point execution.

4.8.4. Furthermore, a technical preference based upon quality considerations reinforces the application of a GPS based flight, with a full aerotriangulation and block adjustment, over the model-based approach. Again, this introduces no new technical considerations not treated above, so no further details are included here; internal quality assurance will be expected to comply as previously described.

4.8.5. However, where a dense GCP network of sufficient quality (see §4.3 above) already exists, an alternative approach is to produce orientation parameters by model. Again, the above sections contain guidelines as to the quality of the various input data and the expected tolerances for the results.

4.8.6. In all cases, final acceptance will be made by applying the external quality control guidelines detailed in §7.

	QCR	Format of QCR	Contractor Production Level	EC Inspection level (Sample)	Normal EC Audit Stage
1	Camera calibration certificate	Paper	100%	Normal (100%)	Before flight
2	Flight data including log of photo centres and flying height	ASCII or GIS files	100%	Normal (100%)	Before scanning (or 10 days after flight)
3	Control chart for the scanner performance (geometric)	Paper/ Graph	Every 7 days, then 14 days if stable	Normal (once)	From start of scanning onwards
4	CV/Training certificate for DPWS operators	Paper	-	Normal (100%)	Start of AT
5	Table of ground reference data for GCPs and check points (used for internal QC)	ASCII	100%	Normal (100%)	End of AT
6	Interior and exterior orientation results	Paper or ASCII files	100%	Normal (first few) Tightened (trail)	End of AT
7	Number of items rejected/reprocessed at each stage of internal QC	Progress report	Complete list	Normal (monthly)	N/A
8	Visualisation of the DEMs: Preferably digital stereo image with DEM data overlain	Paper or digital	100%	Normal (Once) Tightened (trail)	Start of Ortho-correction
9	Comparison of DEMs with vertical checkpoints (if available, AT vertical points)	Paper/Graph	Sample	First DEM	Start of Ortho-correction
10	Residuals of block adjustment on control points	Paper or digital, software reports	100%	Normal (Once) Tightened (trail)	Orthoimage production
11	RMSE of finalised block adjustments using contractors' check points, including individual residuals	Paper or digital, software reports	100%	Normal (100% of blocks)	Orthoimage production
12	Ortho-image metadata	Database	100%	Normal (10%) Tightened (100%)	Start of Orthomosaic production
13	Ortho-images (inspection result)	Paper or metadata	100%	Normal (10%))	Orthoimage production

Table 4-4 QCR Production and Use for Aerial Ortho-images

5. Airborne digital image acquisition and correction QA

5.1. Scope

5.1.1. The scope of this chapter is limited to pushbroom airborne scanners[7]. Since pushbroom scanners have different geometric configuration, image characteristics, and processing requirements, these aspects need to be covered under a separate section. In particular, since flight planning and execution present specific requirements, these are covered here in more detail[8].

5.1.2. As in previous sections, the points below are "indicative" and give **guidelines** as to the Commission's current understanding of "best-practice". In this sense, they can be adopted **as far as the contractor considers they are sensible and plausible** in a production environment.

5.2. Sensor calibration

5.2.1. Appropriate geometric calibration, for example factory calibration or field calibration of the instrument using an official test field (or validated by the instrument manufacturer), should be current (within past two years).

5.2.2. Radiometric calibration would normally be expected to be dependent upon factory certification and reflect

- A level of 100 % live cells for each CCD array should be certified.
- Statement of radiometric resolution performing to at least 12-bit.

5.3. Flight plan and execution

5.3.1. The flight planning should ensure that issues related to sidelap, run length, height above ground, traffic control clearance etc. issues are adequately addressed.

- Sidelap: normally 15 - 25%, for specialist products this would increase to 80%.
- Flight direction: alternate (e.g. W→E, E→W, W→E…) for inter-track redundancy
- Run length/duration :
    - o < 15minutes (to keep the highest achievable accuracy without IMU drift),
    - o alternatively typically less than 30 minutes of flying time (usually <80km) for medium scale (1m pixel GSD) products
- Scale variation should remain less than ±10% for GSD of 0.4m to 1m. Ground sampling distance (or final product pixel size) will be determined by:
    - o Flight altitude : will determine the Ground Sampling Distance across-track
    - o Aircraft speed : will determine the Ground Sampling Distance along-track, together with the CCD timecycle
- Sensor configuration:
    - o Angle of CCD bands used for orthoimage product as close as possible to nadir
    - o RGB, or CIR composite at same angle
    - o Use of staggered arrays for resolution enhancement is not currently considered to be appropriate for best practice operations

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[7] Frame cameras are covered under the general air-photo acquisition workflow.

[8] For standard frame air survey, the JRC's guidelines for air survey flight would normally provide a clear description of flight planning and execution requirements.

  - Need for Forward and Rearward stereo bands for DEM generation

5.3.2. Due to the important reliance upon DGPS processing, proximity to GPS base station(s) should be under normal circumstances:

- <20 km for in flight alignment of IMU
- <50km for image acquisition
- Interval/frequency: every 1 to 10 second

5.3.3. The specificity of such systems will require specialist/experienced instrument operators to ensure that the above conditions are met.

5.4. Overlap Completeness map

5.4.1. This check should permit control in GIS that the full zone is covered with the prerequisite number of overlapping images.

5.4.2. Attention should be paid to start and end of flight lines (forward/rearward viewing scanners).

5.5. GCP report location

5.5.1. Five well distributed 3D ground control points[9] normally used per block (or flight session). Furthermore, for irregular blocks, this number should be doubled.

5.5.2. A check should be undertaken to permit the comparison of positions of ground control in relation to the flight block.

5.6. Image check

5.6.1. An image check should be carried out before orthoprocessing; a QC report should be available. Validation should be made of the rectification trajectory (over the raw image) using GPS/INS data.

- Cloud cover: A quicklook should be provided as a QCR, either run by run or mosaicked.
- Radiometry: Basic level check should be executed on image histogramme, saturation

5.6.2. A Flight and Geometry validation report should be made giving a clear diagram of the flight plan. The flight report should include a 4-D (X, Y, Z, time) track of the flight and permit the quantitative analysis of the flight characteristics.

- Interval/frequency: every second
- Ancillary data: uncertainty parameter (if applicable) of position

5.7. Analogous sections from air-photo survey

5.7.1. In general, the sections 4.5, 4.7, 4.8 above will apply also to digital scanner flights.

5.7.2. A QC report should be issued on the post-processing of GPS and IMU data, and on the aerotriangulation results (residuals).

5.7.3. Assuming that the DEM is produced internally, the following QCRs should be provided

- Meta data
- Quality Report

5.7.4. QCR reporting listed in Table 4-4 above, specifically 1, 2, 4, 5, 7, 8, 9, 11, 12, and 13 will in general be generated during the production process.

[9] However, double point selection advised to guard against failure of point identification in the image.

6. Satellite Image Correction QA

6.1. Introduction

6.1.1. This section outlines the process of creating digital orthoimages from satellite imagery. The points are "indicative" and give **guidelines** as to the Commission's current understanding of "best-practice". In this sense, they can be adopted **as far as the contractor considers they are sensible and plausible** in a production environment.

6.1.2. The chapter will refer to systems with a standard pixel size of <5m as “Very High Resolution” (VHR), and >5m as “High Resolution” (HR). Note that, with the consideration now of VHR data orthorectification, many of the minimum ancillary data (DEM, ground control etc.) requirements are now roughly equivalent to those for aerial photography processing.

6.2. Input data

6.2.1. The image quality control record requirements are outlined in Table 6-1. Ortho-correction of satellite images may require externally procured DEMs, particularly the correction of VHR data. However, the definitive factor is dependent upon how well the terrain surface can be modelled. In general, for moderate angle space imagery (up to 15°off-nadir, greater than ~75° incidence angle) a terrain model which gives a vertical $RMSE_z$ of <5m will be required.

Item	Requirement	Internal QCR/QA
Image Check	Image must be readable and image visual quality must allow accurate GCP placement.	Confirm image can be read by displaying it on-screen. Note any format, cloud or other quality problems (e.g. low sun angle, quantisation).
SAR Image	Possibility of positioning GCPs accurately must be maximised.	Apply speckle-reducing filter to single date images. Composite multi-temporal images from the same satellite/orbital node.
Image Format Check	Data provided with the image must include additional information to allow ortho-correction (RPC coefficients, view angle, orbit model, etc.).	Note the input product level; generally no geometric processing is desirable beforehand. Confirm compatibility with the correction software. Record view angle (or beam number for some SARs) in the metadata.
DEM height accuracy	For High resolution: 10 to 20m RMSEz is generally required For VHR: • view angle <15°, <5m RMSEz is required • view angle >15°[10], <2m RMSEz is required	Confirm product specification. Vertical accuracy of an internally produced DEM must be checked by comparison against independent control.
DEM	The DEM should be of sufficient detail, complete, continuous and without any gross anomalies[11]. QC should confirm that the DEM is correctly georeferenced and elevations have not been corrupted or accidentally re-scaled during re-formatting/preparation. Attention should be paid to datum references (mean sea level vs. ellipsoidal heights, for example)	Visualise on-screen. Look for completeness in the project zone and continuity along tile boundaries. Possibly use histograms/3D views to check for spikes/holes. Overlay available map data to check georeferencing is correct. Check corner and centre pixel values against heights on published maps.

Table 6-1 QCRs for Geometric Correction of Satellite Images

[10] For EROS B, the off-nadir angle would be limited to max 30° (elevation angle 57-90°)

[11] Additionally, for EROS B the grid size should be 10-50m depending on the relief (mountainous-plain)

6.2.2. The most common raw Image formats suitable for orthocorrection are the following:

- Quickbird: "**OrthoReady** Standard" product.
- Ikonos: **Geo Ortho Kit**
- Eros A and B: **Level 1a**.
- SPOT (5 and previous instruments): **Level 1a**.
- Formosat -2 Level 1a

6.3. Ground control requirements

6.3.1. In general, the control should be of a quality three times better than the final product specification, e.g. in order to achieve a final product of 3m RMSE, ground control of 1m RMSE quality is required.

6.3.2. The most cost-effective option for ground control for HR satellite images – where the final product is not expected to exceed a quality of RMSE1d of 10m – is topographic mapping or large scale orthophotos; the map scale used should be of 1:10,000 scale or larger.

6.3.3. For VHR imagery, where in general the target specification is <2.5m RMSE1d , only ground control with a specification of <0.8m RMSE will be suitable. Table 6-3 gives guidance as the number and distribution of GCPs required for different images and orthocorrection methods.

6.4. Geometric correction process

6.4.1. Most orthoimage rectification in the scope of EC work is carried out with respect to national mapping or land parcel systems of high geometric precision. Images are corrected to their absolute position, and only in rare cases will images be corrected to a "master image" in a relative manner (for example, without formal projection systems). The only notable exception to this is when a VHR image is used as a reference for other, lower resolution images; in general, the pixel size should be at least 3 times bigger than the VHR image.

6.4.2. As for other orthoimage processing covered in this guideline, ground control for satellite image processing must be at least three times as good orthoimage product specification.

6.4.3. For **HR image**s (SPOT, Landsat, IRS), a decision may be required as to whether a particular image should be corrected by ortho-correction or polynomial warping as set out in Table 6-2.

Image/Terrain	Correction Procedure
Resolution ≤ 10m AND terrain variation > 250m over whole image	Orthocorrect
View angle at centre of image > 15° from nadir (any resolution or terrain)	Orthocorrect
Other HR images	Polynomial warp acceptable

Table 6-2 Geometric Correction Procedure choice for HR images

6.4.4. For **VHR imagery (Ikonos, QuickBird, EROS A and B, SPOT Supermode,** Formosat-2)**, orthocorrection will be required**. Polynomial correction with VHR images will only provide acceptable results in a few restricted circumstances (flat terrain, vertical imagery). In practical terms, planning and provision for the orthocorrection will mean that this choice will rarely be made. However, the number of GCPs required when using the recommended approach (using vendor-supplied RPCs) is as few as two GCPs per image frame (i.e. probably 15 to 20 per control zone).

6.4.5. For Formosat-2 orthorectification, the number of Ground Control Points required is 15 per image scene[12]. GCPs should evently distributed over the entire image. GCPs should be available in the corners of the scene. Clearly visible and permanent landmarks should be used. For the orthoimage in order to achieve the expected planimetric accuracy of 2.5m $RMSE_{1-d}$, the planimetric accuracy of the GCPs should be <0.8m $RMSE_{1-d}$ and the absolute Z accuracy <1.6m $RMSE_{1-d}$ (par.6.4.2).

6.4.6. For EROS B orthorectification a minimum of 9 very well-defined GCPs required per image scene, one GCP at each corner and the rest evenly distributed[13]. For the orthoimage in order to achieve the expected planimetric accuracy of 2.5m $RMSE_{1-d}$, the planimetric accuracy of the GCPs should be <0.8m $RMSE_{1-d}$ and the absolute Z accuracy <1.6m $RMSE_{1-d}$ (par.6.4.2).

6.4.7. As an **alternative to single frame processing**, and if appropriate software is available[14], multiple image frames – or a "block" of images – for the same zone can be processed together. The block processing uses ground control points (GCPs) and tie points (points observed on images but not on the ground), combined with sensor geometry to calculate the best fit for all images together. It is not recommended to use less than one GCP per image frame in the block.

6.4.8. Table 6-3 provides a summary of this guidance and tolerance specification for each stage of the satellite orthocorrection process. The measurements corresponding to each tolerance should be used to provide quantitative input to QCRs.

Stage	Practical procedure	Acceptable tolerance
Orbit model	No check required.	Present in header information
GCP selection, HR (SPOT, IRS, Landsat)	GCPs should be well distributed – for example one in each cell of a 4x4 grid dividing the image with additional points as near as possible to each corner/edge.	Polynomial warp (not for VHR) Quantity: > 15 GCPS per image frame or physical model orthorectification (at least 9 GCPs per frame): Record number in metadata/QCR.
GCP selection, VHR with vendor supplied RPC processing	Recommendation is to use supplied RPC data - as few as two GCPs per image frame or 100 - 200km^2 could be used, although 4 points located in the image corners should be the preferred approach. For Ikonos strip scenes, add minimum two GCPs per extra 100km^2.	Minimum, 2 - 4 per image frame, plus 2 per additional 100km^2 of strip scene GCP distribution not critical, but well distributed preferred. Record number in metadata/QCR.
	For VHR block processing (multiple frames), ground control may be reduced up to 1 GCP per frame if sufficient good tie points available between imagery	GCP can fall in overlap zones (image corners) but not critical
GCP selection, VHR with physical model or RPC generation from ground control	For VHR orthorectification using a physical sensor model, at least 9 GCPs will be required, usually per image (100km^2). For EROS B and Formosat 2 the GCP's should be evenly distributed (par. 6.4.5. and 6.4.6). For EROS A vector scenes, this number should be doubled. For Formosat-2, the amount of GCP's should be 15 per scene RPC generation is GCP intensive: not recommended.	More than 9 GCPs (physical model) or 16 GCPs (RPC generation) required per image frame. Distribution of GCPs should cover full AOI. Record number in metadata/QCR.
GCP Selection, Formosat-2 **level 3 (ortho) by JRC**	Where the JRC will be managing orthoimage creation, **30 GCPs** will be required per scene.	Min 15 GCPs should be used (par. 6.4.5.).
GCP Blunder Check	HR: Fit a first order polynomial to the GCPs VHR: Residuals should be calculated when redundancy available in GCPs; otherwise check independent points.	Maximum residual should not exceed 3 x the target RMSE. Record result in metadata/QCR.
Polynomial warp	*Use a first or second order polynomial, third order must*	*Record the polynomial order in the*

[12] The orthorectification of Formosat -2 raw imagery is currently possible with the following sw suites:PCI Geomatica 10.0 with PATCH 10031; Erdas Imagine 9.1 with FIX for F2 or 9.2, SIP Ortho and Socet Set).

[13] The guidelines for EROS B are based on the information from the Image Provider only. No current tests have been made by JRC.

[14] Currently, the only mainstream package tested by the JRC is PCI Geomatica v10

(only)	*not be used.*	*metadata/QCR.*
Rectification results	Calculate RMSE discrepancy on 10 check points (if available)[15] OR Record the prediction sum of squares (PRESS) – if available. Record the residuals for each GCP and their RMSE compared to the fitted model.	Checkpoint RMSE < tolerance for geometric accuracy. √PRESS < tolerance for geometric accuracy. RMSE if calculated on residuals on residuals should < 0.5 x tolerance for geometric accuracy: Save GCPs/residuals to file Record summary results in metadata/QCR.
Resampling	For imagery unlikely to be quantitatively analysed/classified – particularly panchromatic imagery or pan sharpened – bilinear interpolation or Cubic convolution is appropriate; output pixel size ≅ input pixel size. Nearest neighbour may be used if justified (e.g. classification), but output pixel size should be 0.5x input pixel size.	Record resampling method and output pixel size.
Visual accuracy check	Overlay digital map data on the image and inspect systematically.	Independent check by supervisor. Log Pass/Fail and inspection date for this image in QCR.
Accuracy of the master image	Measure the accuracy of the master image using check points which were not used as GCPs during geometric correction.	Minimum of 20 check points distributed on a regular grid. Accuracy: 3 x tolerable RMSE. File dated record of the check results. Record result in metadata and identify as master image.

Table 6-3 Specification for Satellite Image Rectification

6.5. QCRs and quality audits for satellite image rectification

6.5.1. A file naming convention should be introduced and a meta-database (e.g. spreadsheet) developed which allows the following information to be associated with each image product and any supplementary files (e.g. GCPs, checkpoint results):

- *Image ID, Master Image ID, Project site ID, Sensor, Acquisition date, View angle or beam number, Cloud, Product level, Initial QC (OK/Problem), Pre-processing (e.g. filtering), DEM grid size, DEM accuracy, Result of DEM QC.*

- *Software Used, Blunder check completed, Number of GCPs, Residual RMSE(metres), √PRESS(metres), Correction method (poly, ortho), Order of Polynomial, Resampling method, Output pixel Size, Number of checkpoints, Checkpoint RMSE, Maximum Checkpoint Discrepancy, Production Date, Comments, Operator name.*

6.5.2. Further information (e.g. recorded on a paper form) could include input and output file names, sources of ground control, projection details, detailed results of the DEM checks, corner co-ordinates and result of visual QC signed and dated by a supervisor.

6.5.3. It is strongly recommended that a paper *pro-forma* designed to record all the information listed above is devised by the contractor, there should be one form for each output image and the relevant data from these can then be entered into the meta database.

6.5.4. A procedure should be applied to ensure that the final product is clearly labelled as such and that the information retained in the QCRs is that which applies to this final product

6.5.5. Contractors will generate the QCRs identified above for their Internal QA. They should be made available for inspection during a quality audit by an EC representative. The type of quality audit is shown in Table 8 as "Normal" or "Tightened".

[15] 15 check points per scene in case of Formosat-2 and EROS B

6.5.6. “Normal” audit checks which are carried out ‘Once’ will be repeated again if a corrective measure is requested.

QCR	Format	Contractor Production Level	EC Inspection Level (Sample)	EC Audit Stage
Image Check (esp. view angle record)	Paper	100%	Tightened (trail)	Any time
DEM (esp. anomalies and height accuracy)	Paper	100%	Tightened (trail)	Any time
Ground reference	Source	100%	Tightened (trail)	Any time
Software	-	-	Normal (once)	Before any correction
CV/Training certificate for operators	Paper	-	Tightened (trail)	Any time
File of GCPs, check points and residuals (used for Internal QC)	Paper	100%	Tightened (trail)	Any time
Adjustment/warp results	Paper and metadata	100%	Normal (first few) Tightened (trail)	Any time
Resampling	Paper and metadata	100%	Tightened (trail)	Any time
Visual accuracy	Paper result Or on-screen	100%	Normal (Once) Tightened (trail)	Start of Image-correction
Accuracy of the master image	Paper or metadata	100%	Normal (100%)	Start of image production on each site
Image metadata	database	100%	Normal (100%)	Start and end of image production

Table 6-4 QCR Production and Auditing for Satellite Image Rectification

6.5.7. “Tightened” audit checks will follow an audit trail for suspect products and will be introduced if

- earlier audits result in doubts about performance
- results from QC do not meet the specifications given in previous sections
- results from External QC do not meet the tolerances in the ITT.

7. Method for External Quality Checks

7.1. Introduction

7.1.1. This chapter describes a method for independently checking the accuracy of geometrically corrected images.

7.1.2. The check is **intended to be carried out independently by the Commission** (or a separate contractor, or in collaboration with the original contractor) using a sample of the final products provided by the contractor carrying out the geometric correction work. It may, however, depend on products from the original contractor.

7.2. Digital image delivery (scanned aerial photographs and digital airborne imagery):

7.2.1. The Commission will check according to the criteria specified in §3 at least a sample (minimum 10%) of the images delivered. If on this sample test, more than 5% of the images tested fail on one or more of the specifications marked above, the entire delivery may be returned to the contractor for quality checking and re-delivery. In other cases, imagery failing the specification on one or more of the tests may be required to be re-scanned until the specification is met in full.

7.3. Inputs to orthocorrection external quality check

7.3.1. For the external checking of orthoimage accuracy the following information is required as input.

Item	Specification	Format
Ortho-image	Selected extracts from the final products, georeferenced to the (national) map projection.	Digital format (as agreed in specification)
Mosaic description	Record of the location of seamlines for the mosaics, or image file structure	Vector file
GCPs	Document listing the GCP id and coordinates: Short text explaining how the GCPs were collected (equipment, vertical and horizontal control(s) used), estimated precision and accuracy: see §4.5. Image extracts (hardcopy or image file) clearly marked with precise GCP locations and identifiers.	Hardcopy and softcopy (ASCII, Tab delimited) or GIS layers.
Check points	Check Points (acquired by Commission), generally a minimum of 25 per block/site	Document with image extracts (image chips) showing position and coordinates

Table 7-1 Inputs to External QC of airborne orthoimages (digital or photographic)

7.3.2. The checkpoints should (ideally) be provided from a different source than the contractor; however, QCR information may permit use of contractor data where these show that the data are reliable.

7.3.3. For orthophotography, around 5-10% of orthoimage files will be checked externally. For satellite image products, in general the whole set of data will be assessed. Product files will be selected on a systematic basis to ensure that QC covers the entire block/site area. The results for separate photos will be analysed together as a guard against systematic errors. Additional blocks/images will also be selected, possibly on a random basis but also potentially to provide closer inspection in areas where problems are anticipated (e.g. known quality problems with specific batches of original photos or significant terrain variation, high view angles, etc.).

7.4. Check point selection

7.4.1. Conformance with tolerances will be assessed on a sample of images using **independent** measurements of image accuracy (i.e. not the GCPs used for correction) using a checkpoint reference which is at least three times more accurate than the product specification.

7.4.2. Each check point must be considered to be "well defined" (ASPRS 1989) in the context of the image resolution, contrast and features that are present. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable:

a) on the ground,

b) on the independent source of three times higher accuracy[16], and

c) on the product itself.

7.4.3. The selected points will differ depending on the type of dataset and output scale of the dataset. For orthoimagery with a 1m pixel size, suitable well-defined points may represent features such as small isolated shrubs or bushes, road intersections (corners) in addition to right-angle intersections of linear features. For lower resolution images, the same principles should apply, although the features to be detected may be more often similar to cartographic representations. Care will be taken not to choose features which are over-generalised on maps.

7.4.4. Buildings which represent vertical displacement (corners of buildings, telegraph poles) should in all cases not be selected as checkpoints.

7.4.5. The points will be (ideally) selected on a grid of evenly distributed checkpoints located across the image. For example, where a single photogramme acts as the framework for one set of checkpoints, a grid of three by three will be applied. The selected check point positions may be (re)located with reference to the positions of the GCPs used to correct the imagery in order to ensure that the two sets of points are independent.

7.5. External quality checking method for image accuracy

7.5.1. The operator identifies the location of each checkpoint on the image and enters this and the 'true' co-ordinate in a table. A discrepancy is then calculated for each checkpoint together with an overall RMSE. These calculated values are then compared to the project tolerances and a 'Pass' or 'Fail' status applied to the final result. The operator applies a 'Fail' to an image where the calculated RMSE is greater than the tolerable RMSE entered. Normally the tolerable RMSE will be the same as the tolerable RMSE specified in the ITT or contract.

7.5.2. The concept of *maximum tolerable discrepancy* is defined as three times the **calculated** RMSE. A point that exceeds the maximum tolerable discrepancy may be considered as a blunder error if further inspection of the point reveals that this decision is justified (type of point, uncertainty of location, etc.). In addition, justification for the elimination of such a point must be documented (equipment failure, change of feature between photography and survey, etc.). No point that is within the maximum tolerance may be eliminated from the sample dataset.

7.5.3. The recommended output is a three-page report showing an analysis of the results. A text page contains a table of check points with the individual discrepancy between the image and their 'true' location, together with the 'Pass' or 'Fail' status and summary statistics (mean error in x and y, RMSEx, RMSEy, maximum discrepancy). A graphical report shows the position of each checkpoint relative to the grid, together with the size and direction of the discrepancy.

7.5.4. Figure 1 is an example of the output showing checkpoint distribution and discrepancies (in this case for a SPOT image; the principle for aerial photography analysis however remains the same).

[16] Should the point not be surveyed directly

7.6. Result calculation - within block

7.6.1. A block is normally considered to be a **geometrically homogeneous group of image products** (orthoimage, DEM), such as a photogrammetric aerotriangulation block, or RS Control site. However, in the case of orthoimages created by space resection (either per image or per photogramme), each will be treated as a block.

7.6.2. The absolute RMSE of all check points in the block/site will be calculated[17]: should this exceed the project specification, **all products** associated with the block/site will be rejected. However, further investigations may be necessary to increase confidence in the result should the final result be marginal (just below or above the tolerance). These may involve the acquisition of further points, or may involve the follow-up of specific production problems (tightened auditing checks).

7.6.3. The planimetric threshold will be **applied independently** in X, and Y. Failure to meet the specification in either of these two dimensions (i.e. RSMEx or RMSEy) will reject the block.

7.6.4. Where the DEM is also a deliverable in the contract, the **DEM will be checked using the Z threshold** tolerance. Again, exceeding the RMSEz tolerance will reject all products for the block.

7.7. Result calculation - project level

7.7.1. At least 10% of the sites or photogrammetric blocks (or a minimum of one site) will be independently checked following the method outlined above. **All blocks** that fail will be examined by the contractor, corrected, and redelivered.

7.7.2. Should **more than 5% of the blocks that are subjected to external QC fail**[18], **all products** will be returned to the contractor for further QA. In effect, the Commission will pass responsibility to the contractor to provide adequate and clear internal Quality Audits to identify the extent and cause of the problems so established. The contractor will be expected to rectify these problems, and (where necessary to comply with the specification) make new products.

7.7.3. Redelivery of products will be followed by a further independent check on a new sample[19] of the products. This procedure will continue until the products are finally acceptable under the terms above.

[17] Although in the case of RS Control sites with differing image resolutions, these may be computed separately.

[18] In practice, RS Control projects will have few blocks: in these cases, should any block fail, the dataset will be subject to redelivery. Projects with many blocks are usually situations where space resection has been used in the production of individual orthophotos.

[19] Which may include the existing data acquired for external QC.

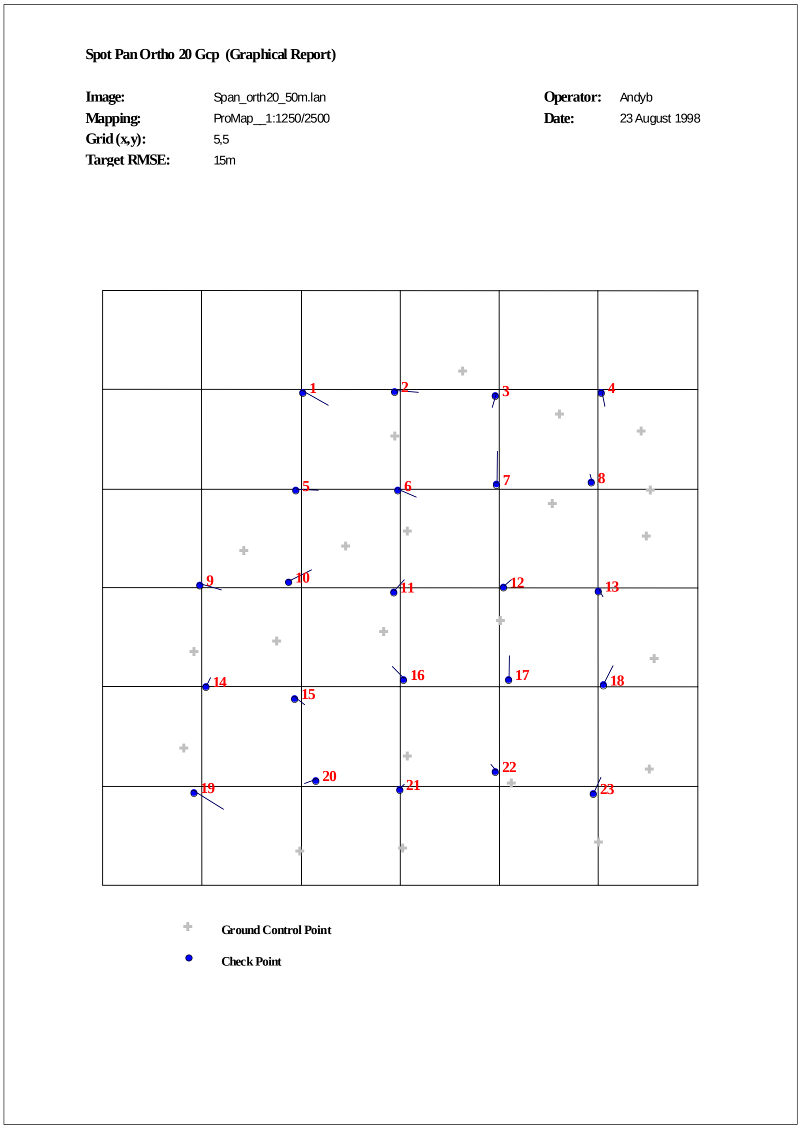

Figure 1 Output from External QC Showing Check Points, Discrepancies and GCPs

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Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
ASPRS	American Society of Photogrammetry and Remote Sensing
AT	Aerotriangulation
BI	Bilinear Interpolation
CAPI	Computer Assisted Photo-Interpretation
CC	(bi-)Cubic Convolution
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DPW	Digital Photogrammetric Workstation
EC	European Commission
ERS	European Remote Sensing Satellite
EU	European Union
GCP	Ground Control Point
GIF	Graphics Interchange File
GIS	Geographical Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HR	High Resolution
IACS	Integrated Administration and Control System
IDQA	Input Data Quality Assessment
IRS	Indian Remote sensing Satellite
ITT	Invitation to Tender
NN	Nearest Neighbour
OS	Operating System
PIS	Parcel Identification System
PRESS	Prediction Error Sum of Squares
QA	Quality Assurance
QC	Quality Control
QCR	Quality Control Record
RF	Representative Fraction
RMSE	Root Mean Squared Error
RSAC	Remote Sensing Applications Consultants
SAR	Synthetic Aperture Radar
SNR	Signal to Noise Ratio
SPOT	Satellite Pour l’Observation de la Terre
TM	Thematic Mapper
TM	Transverse Mercator
UCL	University College London
VHR	Very High Resolution
WP	Work Package

Definitions

Within the separate literature on geometric correction of satellite images, map accuracy assessment and photogrammetry, different terms are sometimes assigned the same meaning when they can usefully be assigned more precise and distinct meanings (e.g. discrepancy and residual). The following definitions *apply to terms as used in this document* and have been phrased, where possible, to be applicable both to air-photo and satellite image correction. Cross references to other definitions are indicated with italics.

Term	Definition	Adapted from
Accuracy	Accuracy is the relationship of a set of features to a defined reference system and is expressed as a multiple (1 or more) of the *rms error* of a set of derived points (if possible expressed as a ground distance in metres, but sometimes given as pixels or microns).	
Aerotriangulation	The process of aerial triangulation is the densification of geometric control to the individual *stereomodel* level by the identification of ground co-ordinates for *tie points* based on the network of known survey data. This process computes a project-wide network of control and confirms the integrity of the *ground control points*.	Wolf 1983
Blunder	See *Error*	
Block, block processing	Two or more image strips (or *image frames*) having a lateral overlap, usually a set of aerial images or a set of VHR *image frames*.	Wolf 1983
Check Point	A well-defined *ground reference* point used for checking the *accuracy* of a *geometrically corrected* image or image mosaic. The location accuracy of the check point must exceed the tolerable accuracy of the image by a factor of at least three. Check points must not be the same as *GCPs*.	Wolf 1983
COTS	Commercial Off The Shelf (software)	
Digital Elevation Model	A digital, raster representation of land surface elevation above sea level. DEM is used in preference to digital terrain model (DTM) because the term 'terrain' implies attributes of the landscape other than elevation.	Burrough 1986 p39
Discrepancy	A discrepancy is the linear distance between a point on the image and a *check point*. A discrepancy is not the same as a *residual*, because a discrepancy is an *error* at each point measured using a reference point known to a higher order of accuracy.	
Ellipsoid	For conversion to a flat surface (ie for mapping), a projection process is applied to a world reference system (*Geodetic Datum*) with its associated ellipsoid. Ellipsoidal models define an ellipsoid with an equatorial radius and a polar radius. The best of these models can represent the shape of the earth over the smoothed, averaged sea-surface to within about one-hundred meters. WGS 84 is a standard for the whole world but may give not an exact fit in a given area.	Dana, 1998
Error	Geometric error in an image which has been corrected to fit a map projection. Three classes of error are commonly recognised: A <u>random error</u> is not predictable at any given location but the population of random geometric errors commonly follows a normal (Gaussian) probability distribution. If random errors are normally distributed the mean error is zero for a large sample of points. A <u>systematic error</u> is predictable at any given location once it has been identified and its pattern of variation is understood. For a large sample of points, a mean error that is not zero can sometimes indicate presence of a systematic error. A <u>blunder</u> is a (large) error at one location arising from a mistake or equipment fault whilst marking the location or recording its coordinates. An error at a single	Harley, 1975

	point that exceeds 3 x RMSE of a sample population is usually due to a blunder.	

Exposure Station	The 3D position of an aerial camera at the time of film exposure, projected XYZ; typically given by GPS, or post-AT.	Adapted from Wolf 1983
Geocoding	Synonym for *orthorectification*, but more commonly used when discussing SAR data. Generally avoided here because the same word is also used for automatic postal address matching in GIS.	
Geodetic datum	When an *ellipsoid* is fixed at a particular orientation and position with respect to the Earth, it constitutes a so-called `Geodetic Datum'. WGS 84 is one such Geodetic Datum. An ellipsoid itself is therefore insufficient to define a Geodetic Datum, the position and orientation of the ellipsoid to the Earth need to be defined also.	Dana, 1998
Geometric correction	Informal term for *rectification.*	
Georeferencing	The process of assigning ground coordinates to an image. The image grid is not changed by this process.	
Ground control point	A well-defined point used for orientation and *rectification*. The position of a GCP is known both in *ground reference* co-ordinates and in the co-ordinates of the *image* to be corrected. If 2D (x,y) ground reference co-ordinates are given, it is a horizontal or planimetric GCP; if the height (z co-ordinate) is known, the point is a vertical GCP.	
Ground Reference	The source used to obtain ground reference coordinates for a *ground control point* or *check point*. May be a topographic map, a field survey by triangulation, a geodetic bench mark, a field survey by GPS, or a *geocoded image*. Ground reference coordinates are given in (or converted to) the national map projection.	
Image	A digital Earth observation picture in raster form, may be scanned from an aerial photograph or produced directly from a satellite sensor.	
Image Frame	A unit of image acquisition with a single set of orientation parameters	
Interpolation	Method used to estimate a pixel value for a corrected image grid, when re-sampling from pixel values in the original grid. Common methods are nearest neighbour, bilinear interpolation and cubic convolution.	
Maximum Tolerable Discrepancy	Defined as three times the RMSE of the check point sample: is used to help determine if a point can be considered as a blunder error.	
Model	Abbreviation of *Stereoscopic Model*	
Orientation	Orientation can have two or three stages. Interior orientation establishes precise relationships between a real *image* and the focal plane of a perfect imaging system. Relative orientation establishes precise relationships between the focal planes of a perfect stereopair to establish a precise *stereomodel* Absolute orientation establishes a precise relationship between the *stereomodel* and a geographic reference system (map projection). Absolute orientation follows relative orientation. Exterior orientation establishes precise relationships between the focal plane co-ordinates and a geographic reference system (map projection). It can be achieved by relative and absolute orientation or can be carried out in a single step.	
Orthorectification (orthocorrection)	*Rectification* of an image (or image stereo pair) using 3D *ground reference* and a DEM to position all image features in their true orthographic locations. The process eliminates displacements due to image geometry (especially tilt) and topographic relief, and results in an image having the same geometric properties as a map projection.	Wolf 1983
Pass point	A synonym for *tie point*.	

Pixel size	Distance represented by each pixel in an *image* or *DEM* in x and y components. Pixel size can be expressed as a distance on the ground or a distance on scanned hardcopy (e.g. microns). It is not a measure of *resolution*.	
Polynomial rectification (also called Warping)	*Rectification* of an image to a *ground reference* using horizontal *ground control points*. It assumes that the local distortion of the image is uniform and continuous since it ignores effects of terrain.	
Precision	The precision of a *GCP* or *check point* is the standard deviation of its position (in x, y and z) as determined from repeated trials under identical conditions. Precision indicates the internal consistency of a set of data and is expressed as the *standard deviation*. Note: Data can be precise yet inaccurate; precision is not used when comparing a set of data to an external reference, *RMSE* is used to express this.	
PRESS	The cross validation estimate, also referred to as the Prediction Sum of Squares (PRESS) statistic. In this statistic the best-fit model is refitted 'n' times. Each time it is fitted to a subset of the GCPs from which one point has been removed. By using the best fit to all the other points, the predicted location of the omitted point is computed and the difference from its actual location is then obtained. The average of these squared differences computed on the complete set of 'n' differences is the PRESS value and the square root provides a figure in the measurement units of the residuals.	
Rectification	The process of resampling pixels of an image into a new grid which is referenced to a specific geographic projection, using a spatial transformation (matrix). The resampling is achieved through *interpolation*.	
Registration	*Rectification* of an *image* to conform to another *image*.	
Residual	A residual is the linear distance between a fixed reference point [ground control point] and the position determined by the transformation applied to the observed data to give a best fit to the reference points. Note: This is not the same as a *discrepancy* because the computed error of a residual is based only on the internal (statistical) consistency of a set of points and not on comparison to independent locations known to higher accuracy.	
Resolution (resolving power)	The smallest visible separation between similar objects that can be clearly reproduced by a remote sensing system – usually expressed as the maximum number of line pairs per unit length.	Light 1993
RMS Error	The square root of the average of the squared *discrepancies* or *residuals*: $\sqrt{\frac{1}{n}\sum_{1}^{n} d_n^2}$ where d is the measured discrepancy or residual in x, y or z. For small samples (n < 30) or if systematic error is present this is not the same as the *standard deviation* of the discrepancy.	ASPRS 1989
RMSE (Absolute)	*RMSE* based on *check points* obtained from a *ground reference* of recognised higher *accuracy*.	Adapted from EC 1997
RMSE (Relative)	*RMSE* based on *check points* extracted from another *geocoded image*. In practice the RMSE of the GCP *residuals* is also used as a measure of relative error.	Adapted from EC 1997
Standard Deviation	The square root of the variance of n observations, where the variance is the average of the squared deviations about the estimate of the true mean value. $\sqrt{\sum_{i=1}^{n}\frac{(x_i - \bar{x})^2}{n-1}}$ For small samples (n < 30) this is not the same as the *rms error*. If there is no *systematic error*, standard deviation is equal to the *RMSE* for large samples.	
Stereoscopic Model	Three-dimensional model created by viewing or analysing the overlapping area of	

(or Stereomodel)	two *images* obtained from different positions.	
Tie points	Points that appear on the overlap area of adjacent images. They are used for *orientation* and *aerotriangulationor block processing*. In general are not measured on the ground and only image coordinates are used	
Tolerance	The tolerance is the permissible degree of *error* in a geometrically corrected *image* or mosaic as determined using a well distributed set of *check points*. Tolerance is specified with one value: the maximum allowable *RMS error* of all check points	
Warping	Synonym for *Polynomial Rectification*	
Well-defined point	A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself.	FGDC, 1998

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