GMES FAST TRACK LAND SERVICE 2006-2008 ORTHORECTIFICATION OF SPOT 4/5 AND IRS-P6 LISS III DATA

Rupert Müller[1], Thomas Krauß[1], Manfred Lehner[1], Peter Reinartz[1], Manfred Schroeder[1], Bianca Hörsch[2]

[1)] German Aerospace Centre (DLR), Remote Sensing Technology Institute, D-82234 Wessling, Germany-
Rupert.Mueller@dlr.de
[2)] ESA-ESRIN European Space Agency
Via Galileo Galilei, Casella Postale 64, 00044 Frascati (Rome), Italy-
Bianca.Hoersch@esa.int

Special Session SS 7

KEY WORDS: Spaceborne Remote Sensing, Orthorectification, Space Photogrammetry, IRS, SPOT, Land Cover, GMES

ABSTRACT:
The GMES (Global Monitoring for Environment and Security) Fast Track Land monitoring Service (FTLS) is a service to provide on a regular basis land cover and land use change datasets, which can be used by a wide range of downstream services at European, national, regional and local scale. Under ESA contract DLR (German Aerospace Center) produced two multi-temporal datasets of orthorectified images covering the participating EU27 and neighbouring countries (overall 38 countries). An operational and automatic processing chain to process about 3700 satellite images has been established including quality control and creation of a European wide consistent GCP database. The orthorectified products are derived from a mixture of high resolution satellite images from SPOT 4 with 20 m GSD, SPOT 5 with 10 m GSD and IRS-P6 LISS III with 23 m GSD, each with four spectral bands, and geometrically corrected towards European Map Projection with 25 m resolution and national map projection for each country with 20 m resolution using DLR's in-house developed versatile orthorectification S/W package. An overall geometric accuracy of about 10 m RMSE in each direction with respect to the European land cover dataset Image2000 (EU25) and USGS ETM+ land cover dataset (neighbouring countries) has been reached. The paper describes the background of the Image2006 project, the newly developed procedures and methodologies of the automatic and operational orthorectification chain including its limitations in problematic cases, as well as the results in terms of statistical evaluations.

1. INTRODUCTION

The GMES (Global Monitoring for Environment and Security) Fast Track Land monitoring Service (FTLS) is a service to provide on a regular basis land cover and land use change datasets, which can be used by a wide range of downstream services at European, National, regional and local scale. Since the mid 1980's a European Land Cover dataset has been regularly produced with now an increased frequency update from every ten years to every five years, taking 2006 as the current update year. The major products of the GMES land monitoring core service are European wide, high quality orthorectified satellite images for the reference year 2006 (+/- 1 year) (referred to as IMAGE2006) and based on the orthorectified images a European mosaic (referred to as MOSAIC2006), Corine land cover changes 2000-2006 (referred to as CLC2006), Corine land cover map 2006, high resolution core land cover data for built-up areas, including degree of soil sealing and high resolution core land cover data for forest areas, including leaf type [13].

Within the GMES Fast Track Land Service 2006-2008 a new dataset of orthorectified satellite images has been produced by DLR under ESA contract covering the participating EU27 and neighbouring countries (total 38 countries). In order to process about 3700 satellite images (two multi-temporal European coverages at different satellite image acquisition windows for improved discrimination of the vegetation classes) DLR established an automatic and operational processing chain for the orthorectification within a time frame of less than one year including quality control and creation of a European wide consistent GCP database. For countries above 60° latitude – namely Sweden, Finland, Norway and Iceland – the orthorectification of the image scenes are subcontracted by DLR to the Swedish company Metria. The orthorectified products are derived from a mixture of high resolution satellite images from SPOT 4 HRVIR with 20 m GSD, SPOT 5 HRG with 10 m GSD and IRS-P6 LISS III with 23 m GSD, each with four spectral bands, and geometrically corrected towards European map projection with 25 m resolution and national map projection for each country with 20 m resolution. For the final resampling cubic convolution interpolation is applied. The overall geometric accuracy requirement is stated to be better than 20 m RMSE in each direction with respect to the European land cover dataset Image2000 (EU25) and USGS ETM+ land cover dataset (neighboring countries). For SPOT4/5 the line-of-sight vector is derived from continuous measurements of the state vectors and attitude parameters as well as the calibrated camera model provided by SpotImage in DIMAP format. For IRS-P6 LISS III the RPCs (Rational Polynomial Coefficients) serve as orientation input, which are provided by Euromap as a universal sensor model in the OrthoKit format. Further input for the orthorectification is – in case of DLR – the European wide digital elevation model (DEM) from SRTM-C band version 2 of NASA, improved by using inputs from MONAPRO, SRTM-X band DEM and GLOBE within a fusion process using accuracy layers for the different DEM databases. In order to achieve the required geometric accuracy of 20 m RMSE, ground control points (GCPs) are automatically generated via image matching techniques between the reference datasets (Image2000 panchromatic layers for the EU25 countries and USGS land cover dataset for the neighboring countries) and the new satellite scenes and/or manually determined to improve the geometric accuracy of the orthoimages. From these derived GCPs, corrections of the orientation for SPOT4/5 and affine transformation parameters of the RPC for IRS-P6 LISS III are derived. Quality assessment is based on ICPs (Independent Control Points), from which mean RMSE values for each scene and whole countries are derived and from which residual plots are produced.

A further task was to generate a consistent European wide GCP chip database with more than 15 GCPs for an area of 3600 km² and a geolayer for each original pixel in European and National projection shall be generated in order to offer the possibility for (fast) reprocessing.

First the different types of satellite images and databases used to perform the geocoding task are presented including their accuracy specifications. Second the description of the operational and automatic processing chain is given followed by the S/W and H/W infrastructure to handle the huge amount of data. The last chapter deals with the results of the processing and the discussion of problematic cases.

2. DATA BASIS

Sensor	GSD at nadir	Wavelength Green / Red / NIR / SWIR	Image Size at nadir view
SPOT 4 HRVIR	20 m	500 – 590 nm 610 – 680 nm 780 – 890 nm 1580 – 1750 nm	60 x 60 km²
SPOT 5 HRG	10 m	495 – 605 nm 617 – 687 nm 780 – 893 nm 1545 – 1750 nm	60 x 60 km²
IRS-P6 LISS III	23.5 m	520 – 590 nm 620 – 680 nm 770 – 860 nm 1550 – 1700 nm	142 x 141 km²

Table 1: Satellite data products

Table 1 summarizes main features of the high resolution multispectral satellite images used for orthorectification.

SPOT 4 HRVIR and SPOT 5 HRG[1]

The SPOT 5 HRG and SPOT 4 HRVIR Level 1A product consists of the image data in standard GeoTIFF format and the metadata in DIMAP format [8]. The following information was extracted for each image from the XML ancillary file for further processing:

- Satellite ephemeris data containing position and velocity measured by the DORIS system every 30 seconds with respect to the ITRF90 (International Terrestrial Reference Frame 1990) system during the data take and at least four times before and after image data acquisition.
- Attitude data with respect to the local orbit coordinate frame measured by gyros and the star tracker unit with 8 Hz; these data are already corrected for several effects.
- Look direction table for the 3000/6000 CCD elements expressed within the sensor coordinate frame.
- Data used for time synchronization like line sampling period and scene center time.

According to the „SPOT Satellite Geometry Handbook" [8], Lagrange interpolation of the ephemeris data (satellite position and velocity w.r.t. ITRF90 datum) and linear interpolation of the attitude data (Euler angles w.r.t. orbit coordinate frame) are recommended to calculate the exterior orientation for each scan line using scene center time and sampling period for synchronization.

IRS P6 LISS III[2]

The IRS products consist of OrthoKits, including GeoTIFFs and RPC files, and as Super Structure BSQ products, generated from System Corrected full scenes. OrthoKit products are path oriented system corrected products, in UTM projection with WGS84 geodetic datum, using cubic convolution resampling. The OrthoKit consists of band separated GeoTIFF files, which are directly converted from the Super Structure image files without any geometric or radiometric processing, and text files holding the Rational Polynomial Coefficients (RPC) of the camera model. The system correction includes the radiometric and geometric correction of the data [9].

Digital Elevation Model

A European wide digital elevation model (DEM) serves as input for the processing chain. The DEM database is derived from SRTM-C band Version 2 of NASA and improved by using inputs from MONAPRO, GLOBE and SRTM-X band DEM within a fusion process. Parts of the DEM dataset are manually edited to remove blunder areas. The DEM is given in geographic projection (geodetic datum WGS84) with 1 arcsec planar resolution (~30 m) with ellipsoid heights. The DEM serves as input in order to perform terrain correction within the orthorectification process and to extract interpolated heights for the GCP chip database. According to the "Statement of Work" the DEM database developed and implemented at DLR is used for this purpose. The height accuracy (1σ) of the DEM is about 6m in flat areas and up to 30 m in mountainous areas. In the Alps greater parts of MONAPRO and in east Turkey greater parts of GLOBE has to be used [7].

Reference Data Sets

For the countries, which took part in the IMAGE2000 project [3], the absolute references are the orthorectified panchromatic images derived from Landsat 7 Enhanced Thematic Mapper ETM+ imagery given in geographic projection with a resolution of 0.000115° and an accuracy of about 9-15 m $RMSE_x$ and 7-

[1] © CNES 2007 Distribution Spot Image S.A., France, all rights reserved; produced by DLR/Metria – data provided under an ESA contract for FTS LM IMAGE2006

[2] © ANTRIX Corporation Limited 2007, Distribution by Euromap GmbH, Germany, all rights reserved; produced by DLR/Metria - data provided under an ESA contract for FTS LM IMAGE2006

[3] © European Communities, Source: Joint Research Centre IMAGE2000, *based on Landsat 7 ETM+ © ESA, distributed by Eurimage; ortho-correction EU15 © Metria, ortho-correction other countries GISAT; mosaic production GISAT*

18 m $RMSE_y$ (except for Austria with 52 m $RMSE_x$ and 27 m $RMSE_y$) [12]. For all other countries the USGS ETM+ Land Cover dataset given in UTM projection with a resolution of 28.5 m and a global accuracy of about 50 m $RMSE_{xy}$ serves as absolute reference. Additionally the accuracy of both reference data has been investigated using ground control information from superior quality in the region of southern Bavaria. Table 2 summarizes the quality assessment derived from 12 GCPs.

	$RMSE_{x/y}$ [m]	$Mean_{x/y}$ [m]	$Sigma_{x/y}$ [m]
Image2000	15.6 / 13.2	2.9 / -6.2	15.4 / 11.7
USGS	30.6 / 21.2	28.9 / 17.6	10.1 / 11.8

Table 2: Absolute geolocation accuracy of reference images derived from 12 GCPs of superior quality in southern Bavaria

These results confirm the official accuracy specifications with slightly better values for the USGS land cover dataset in this region. A systematic error for the USGS land cover dataset can be obtained, but with similar standard deviations as for the IMAGE2000 dataset.

3. METHODOLOGY

Figure 1 illustrates the overall operational processing chain, which is fully automatic, except for the manual process of the internal quality control. The automatic processing steps are:

1. **Transcription:** The transcription system reformats the original images to an internal image format and extracts from the metadata the information needed for further processing (internal level 1 product). For SPOT 4/5 images the ephemeris data (position and velocity) and the attitude measurements are interpolated for each image line based on synchronisation information. The interior orientation given by look direction angles is evaluated for each pixel in the scan line. For IRS-P6 images the Rational Polynomial Coefficients (RPCs) are extracted from the OrthoKit product, which contains human readable dumps of the Super Structure files.
2. **DEM & reference tile generation:** Using the provided coarse image corner coordinates congruent tiles from the DEM database and from the reference image database are extracted and mosaicked with a margin of about 2 km due to the pointing knowledge of the sensor.
3. **Coarse image registration:** Also based on the four image corner coordinates a coarse image registration using simple affine transformation is performed. The coarse registered images are the starting point for the hierarchical image matching with the reference image tiles.
4. **Automatic tie point generation by matching:** In order to automatically extract GCPs/ICPs (Ground Control Points / Independent Control Points) from the reference image a hierarchical intensity based matching is performed [10] [11]. The matching process uses a resolution pyramid to cope with large image differences between the reference and the coarse orthorectified image. Based on the Foerstner interest operator pattern windows are selected in one of the images and located with an accuracy of about one pixel in the other image via the maximum of the normalized correlation coefficients computed by sliding the pattern area all over the search area. The search areas in the matching partner image are determined by estimation of local affine transformations based on already available tie points in the neighborhood (normally from a coarser level of the image pyramid). The approximate tie point coordinates are then refined to sub-pixel accuracy by local least squares matching. The number of points found and their final (sub-pixel) accuracy achieved depend mainly on image similarity and decrease with time gaps between imaging. Only points with high correlation and quality figure are selected as tie points including cross checking by backward matching of all found points.
5. **GCP/ICP Generation:** The tie points or manual measured points belonging to the reference image are supplemented to 3D object points by interpolated DEM values. Finally the set of tie points is divided into GCPs for an improvement of the orthorectification and ICPs for quality assessment. The selection of GCPs is based on the requirement of equally distributed points over the scene with high quality figure.
6. **Parameter estimation:** Within the next processing step improved parameters for the orthorectification are estimated using GCP information. For SPOT 4/5, which utilizes the DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) system to achieve high accuracy orbit determination (position accuracy < 1m), attitude restitution remains the main task. For SPOT 4 especially the initial attitude values and for SPOT 5 the thermally affected misalignment between sensor and body coordinate frame are the major causes of pointing errors. For IRS-P6 LISS III a RPC correction via affine transformation is performed. Within the Least Squares Adjustment simple, iterative blunder detection is integrated, which eliminates step by step GCPs with a residual greater than 2 pixels starting with the bottom quality GCP.
7. **Geocoding:** For SPOT 4/5 scenes the physical model of Direct Georeferencing (DG) [4] and for IRS-P6 scenes the rational polynomial camera model (RPC) [2] is applied to produce orthoimages with 25 m resolution in European projection LAEA ETRS89 (Lambert Azimuthal Equal Area with European Terrestrial Reference System 1989 as geodetic datum) [3] and with 20 m resolution in national map projection different for each country. For the resampling process bi-cubic spline interpolation (a-factor = -0.66) is applied to achieve best image quality for thematic interpretation.

Quality control can be separated into examination of correctness of the orthorectified images and completeness of the coverage and is partly based on the “Guidelines for Best Practice and Quality Checking of Ortho Imagery” [1].

The correctness check includes the following tasks:

- Checking for equal distributed GCPs over the scenes
- Checking of residual plots derived from the ICPs (residual vectors should not show systematic behaviour)
- Checking if RMS errors fulfil the requirement to be better than 20 m in each direction
- Visual checking of orthorectified image overlaid with re-projected reference image.
- Visual checking of orthorectified image overlaid with neighbour scenes.
- Visual checking of radiometric quality and cloud coverage of the orthorectified images
- Visual checking of DEM tiles used (holes, artefacts) and reference tiles used (cloud coverage, radiometric quality, artefacts, geometric errors)

The results of the quality check are summarized in a Quality Assurance Record (QAR) and stored in a database. In case the

geolocation accuracy requirement is not fulfilled or inconsistencies are detected GCPs are measured manually and the scenes are "checked in" for re-processing.
For the completeness check image mosaics of whole countries are generated (images with broad cloud coverage are stacked to the background). Using country frontier polygons the image mosaic is proved for a complete coverage of the country without any holes.

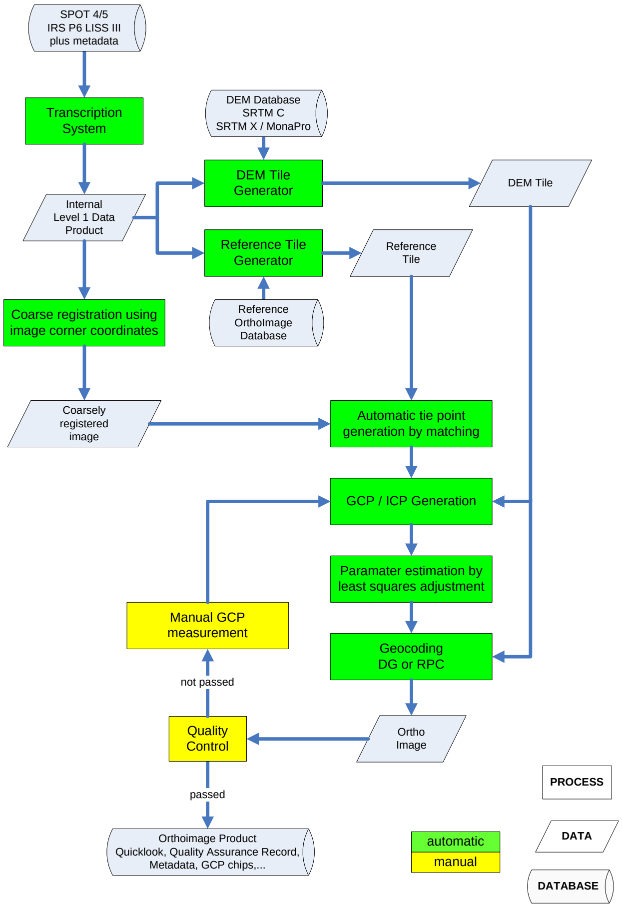


Figure 1 Operational automatic processing chain for orthoimage production.

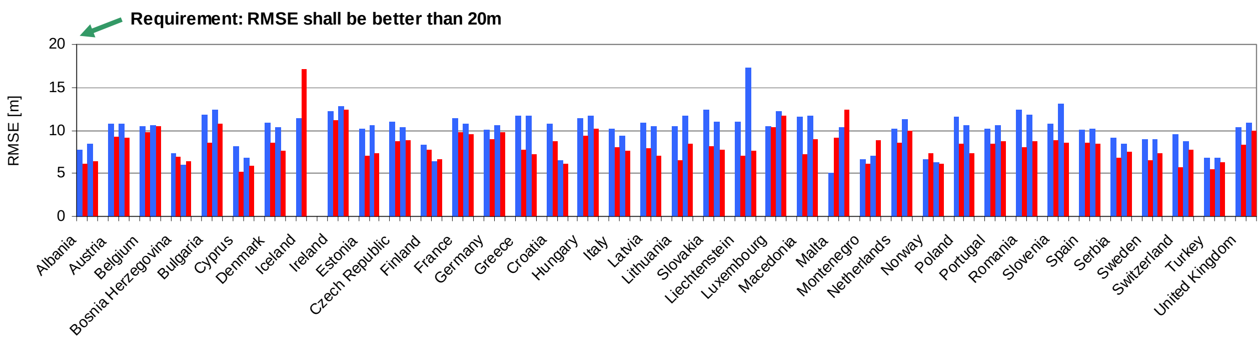


Figure 2 Geometric accuracy (RMSE) of Image2006 products w.r.t. reference images (relative accuracy). $RMSE_x$ (blue) and $RMSE_y$ (red) for European coverage 1 (first two columns of country) and European coverage 2 (last two columns of country)

4. PROCESSING ENVIRONMENT

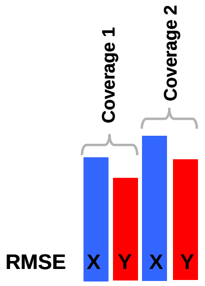
For the huge amount of scenes to be processed in a very short time interval the S/W and the H/W must be suitable for parallel processing with the capability of reliable data storage.

The H/W consists of a passive and active cluster node - file servers replicated and synchronized via heartbeat - with two dual core Intel 5050 processors each, which are connected to a direct attached storage (RAID 5) of 7.2 TByte (excluding backup storage) via fibre channel. For parallel processing 10 workstations are attached to the file server via 1 Gbit Ethernet. The Linux 64bit CentOS 4.4 x86 serves as operating system. A permanent external monitoring process watches the condition of system resources – namely network connectivity, RAID status,

CPU, memory, fan, power, storage resources and system processes and reports fail functions and storage overflows via SMS and e-mail.
The S/W front end consists of a web based interface for the administration of the image data and the different processing levels – namely imported, GCP/ICP generated, geocoded, quality controlled, completed, delivered - with a mySQL database in the background. The parallel processing is realized by an autonomous process queue distributing the jobs among the workstations. The different processing modules are assembled to S/W processors using higher level script languages. The whole processing chain is a DLR in-house development and therefore allows flexible reactions to fulfil the requirements.

5. RESULTS

5.1 Relative geometric accuracy



Two complete European coverages consisting of about 3700 scenes have been processed. Figure 2 shows the results broken down into the processed countries and the two coverages. The first two columns of each country show the RMS errors in x (east) and y (north) direction for the first coverage. The last two columns are valid for the second coverage. For SPOT4/5 and IRS-P6 orthorectified scenes an overall geometric accuracy with respect to the reference images (relative error) of about 10 m RMSE in each direction is reached (for Spot4/5: $RMSE_x$=10.4 m , $RMSE_y$=8.6 m and for IRSP6: $RMSE_x$=9.7 m , $RMSE_y$=8.0 m)

which corresponds to half a pixel size. It has to be considered that for Spot, unlike for IRSP6, an oblique view up to 30° is possible, so that DEM errors influence the geometric accuracy of the orthoimages generated from Spot. The mean number of ICPs used for quality assessment is 5496 points per scene for IRS-P6 and 1360 points per scene for SPOT 4/5.

5.2 Absolute geometric accuracy (first results)

The assessment of the absolute geometric accuracy started with the comparison of aerial orthoimages of superior geometric quality from the Bavarian land surveying office and the Image2006 products. The first results are listed in table 3.

Test sites Germany	$RMSE_x$ [m]	$RMSE_y$ [m]	$RMSE_{xy}$ [m]	Number of points
Chiemsee	6.3	5.6	8.5	34
Oberpfaffenhofen	4.2	6.1	7.4	87

Table 3: Absolute geometric accuracy

For these two examples the absolute geometric accuracy is slightly better than the relative geometric accuracy. More investigations including other countries will be performed to confirm the (promising) results.

5.3 GCP Image Chip Database

A GCP (Ground Control Point) is a geographical object (e.g. center of a road crossing) for which the position in an image and the location on Earth is known with a certain accuracy. A GCP image chip database can be used to automatically locate GCP in a sensor's imagery for tasks like automatic orthorectification or quality assessments. Elements of the database have been established through automatic correlation processes and manual selection of suitable GCPs out from the set of automatically found points afterwards. The criteria for manually GCP selection were

- Time invariance (e.g. road crossings)
- Equally distributed
- High quality figure (e.g. correlation coefficient)
- High texture of the GCP image chips

Figure 3 shows an example of a GCP image chip. The center of the chip center pixel defines the 3D object coordinate given in meter units using the European map projection system LAEA-ETRS89.

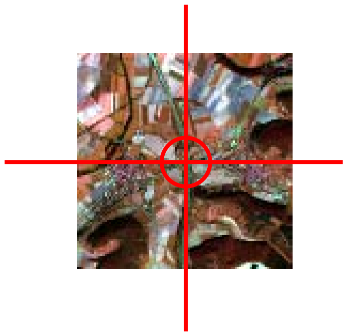


Figure 3: Example of a GCP image chip

The main features of the European wide GCP chip database are

GCP chip naming convention:
<Easting>_<Northing>_<EllipsoidHeight>.png
Example: *4179645_2766680_385.png*
Projection: LAEA-ETRS89
Resolution: 25 m
Chip size: 101 x 101 pixels
Channels: Green, Red, NIR
Origin: Image2006 data set of first coverage and interpolated heights from "best of" DEM
Accuracy: ~10m w.r.t. reference data (as Image2006)
Density: ~5 GCP chips @ 1000 km²
Total amount of GCP image chips EU38: 61053

5.4 Experiences

The number of automatically derived ICPs and GCPs strongly depends on the similarity of the images having a time gap of 5-6 years. Especially agriculture areas show greater changes over the years, which reduce dramatically the amount of tie points. In the case of Romania with heavy flooding between the years 2000 and 2006 for some affected scenes less tie points can be found. Good candidates for tie point generation by image matching are arid areas like in Spain or mountainous areas with time constant sharp ridges.

For scenes containing only land areas of small extend (like scenes with only islands) the image matching sometimes fails due to a image pyramid used up to level 32. At this high pyramid levels small land areas vanish. In these cases manual GCP measurements have to be performed.
As stated before IMAGE2000 and USGS land cover datasets should be considered as absolute reference. These datasets contain systematic and local geometric distortions. The models and the parameter estimations used for the orthorectification process (DG and RPC) are not designed to handle unrealistic errors in a rigorous manner. For example figure 4 shows an ideal distribution of the residuals at the ICPs (and GCPs) over a SPOT scene with no systematic behaviour. In figure 5, which represents a mountainous area in Austria, larger deviations can be obtained in the bottom-left part. This results, for example, from the mosaicking of orthorectified reference images with insufficient geometric accuracy.

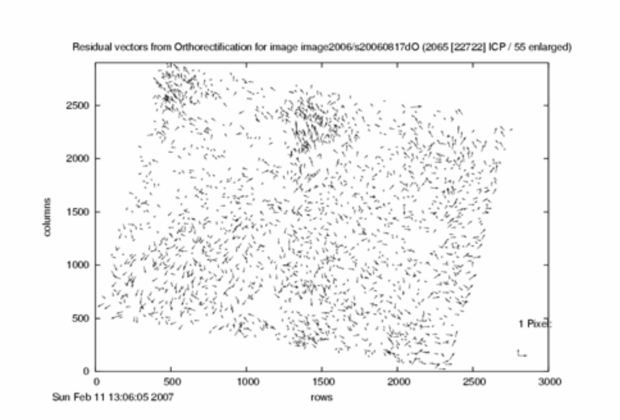


Figure 4: Deviations in pixel - factor 55 enlarged - of automatically determined ICPs from the reference image versus image coordinates of the orthorectified scene (SPOT 4) after correction with GCPs (RMSEx=12.4 m, RMSEy=8.0 m)

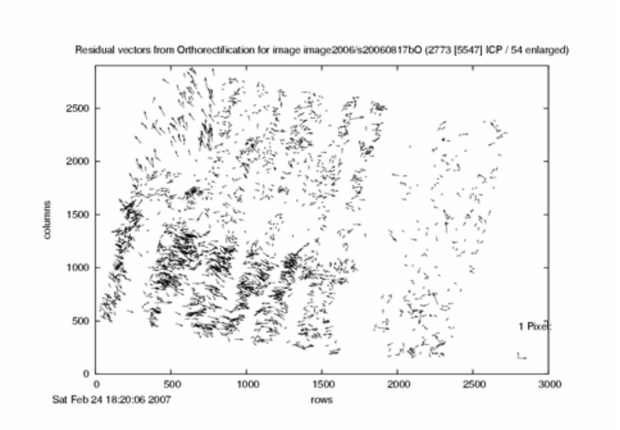


Figure 5: Deviations in pixel - factor 54 enlarged - of automatically determined ICPs from the reference image versus image coordinates of the orthorectified scene (SPOT 4) after correction with GCPs (RMSEx=12.6m, RMSEy=12.3m)

A further experience made - or better: lesson learned - is the difficult task to produce orthoimages in the manifold National map projection systems. Especially the description of the geodetic datum with the different definition possibilities can lead to wrong processing results. A database of currently used map projection parameters for the 38 countries has been established.

The demanding task to process about 3700 scenes in a very short project life cycle requires fast and parallel processing. Table 4 shows the processing times for the different subtasks:

Sub-task	IRS-P6 [hours]	SPOT 4/5 [hours]
Transcription, DEM & Reference tile generation, coarse rectification	0.1	0.1
Matching, GCP/ICP generation	2.2	0.3
Geocoding (national and European product) plus parameter estimation and reprojection of reference image for quality control and geolayer generation	1.5	0.5
Quality control (manual)	~1.5	~1.0

Table 4: Throughput values in hours for one workstation

For a network of 10 workstations the throughput of the whole system is therefore for one IRS-P6 scene about 0.5 h and for one SPOT scene about 0.2 h.

6. CONCLUSION

A new operational and automatic processing chain to orthorectify satellite images from SPOT 4 HRVIR, SPOT 5 HRG and IRS-P6 LISS III covering European and neighbouring countries was developed and successfully applied for the IMAGE2006 GMES Fast Track Land Service project.
The relative geometric accuracy of the about 3700 orthorectified scenes is better than 10 m RMSE in each direction with respect to the IMAGE2000 and USGS Land Cover reference datasets, which corresponds to half a pixel size. The accuracy assessment is based on ~450 automatically extracted ICPs per 1000 km². The absolute geometric accuracy assessment is still in progress with first results of about 6 m RMSE in each direction.

A European wide consistent GCP image chip database has been established with about 5 GCPs per 1000 km².

Less than 5 % of the images have to be processed manually (additional GCP measurements) in cases the product does not pass the internal quality control.

REFERENCES

"Guidelines for Best Practice and Quality Checking of Ortho Imagery", Issue 2.5; 2003; EUROPEAN COMMISSION DIRECTORATE GENERAL, JRC JOINT RESEARCH CENTRE – ISPRA Institute for the Protection and Security of the Citizen, Monitoring Agriculture with Remote Sensing Unit; http://mars.jrc.it/

Lehner, M.; Müller, Ru.; Reinartz, P.; 2005:
"DSM and Orthoimages from QuickBird and Ikonos Data Using Rational Polynomial Functions", Proceedings of "High Resolution Earth Imaging for Geospatial Information", May 17-20, Hannover, Germany
http://www.ipi.uni-hannover.de/fileadmin/institut/pdf/062-lehner.pdf

"Map Projections for Europe": Edited by A. Annoni, C. Luzet, E. Gubler, J. Ihde; 2003; Institute for Environment and Sustainability; http://europa.eu.int

Müller, Ru.; Lehner, M.; Reinartz, P.; Schroeder, M.; 2005: "Evaluation of Spaceborne and Airborne Line Scanner Images using a generic Ortho Image Processor", Proc. of High Resolution Earth Imaging for Geospatial Information, ISPRS Hannover Workshop, Commision I WG 5 http://www.ipi.uni-hannover.de/fileadmin/institut/pdf/046-mueller.pdf

Reinartz, P.; Müller, Ru.; Lehner, M., Schroeder, M.; 2006: "Accuracy Analysis for DSM and orthoimages derived from SPOT HRS stereo data using direct georeferencing", ISPRS Journal of Photogrammetry & Remote Sensing 60, pp. 160-169

Roth, A.; Knöpfle, W.; Strunz, G.; Lehner, M.; Reinartz, P.; 2002: "Towards a Global Elevation Product: Combination of Multi-Source Digital Elevation Models", Symposium on Geospatial Theory, Processing and Applications, Ottawa, 2002

SPOT IMAGE, 2002:"SPOT Satellite Geometry Handbook" S-NT-73-12-SI, Edition 1, Rev. 0, Toulouse, France. http://www.spotimage.fr/dimap/spec/dimap.htm

IRS-P6 LGSOWG (Super Structure)
DIGITAL DATA PRODUCTS FORMAT
DPSD/SIPG/SIIPASpace Applications Centre, ISRO, Ahmedabad, INDIA; May 2003
http://www.Euromap.de/download/p6super_20050222.pdf

Lehner M., Gill, R.S., 1992: "Semi-Automatic Derivation of Digital Elevation Models from Stereoscopic 3-Line Scanner Data", *IAPRS*, Vol. 29, part B4, Commission IV, pp. 68-75, Washington, USA

Kornus W., Lehner M., Schroeder, M., 2000, "Geometric inflight calibration by block adjustment using MOMS-2P 3-line-imagery of three intersecting stereo-strips", SFPT (Société Francaise de Photogrammétrie et Télédétection), Bulletin Nr. 159, pp. 42-54

"IMAGE2000 and CLC2000 Products and Methods"
EUR21757 EN ISBN 92-894-9862-5

GMES Fast Track Service on Land Monitoring, EEA Project Implementation Plan GMES Land FTS 2006-2008, AMP 2006 – 1.2.4 CST / AMP 2007 – 1.2.6 ASO, 2006

ACKNOWLEDGEMENTS

The authors like to thank D. Hoja for supporting work, M. Schneider for the acquisition and verification of national map projection parameters and C. Alberter, J. Huth, C. König, A. Otto, S. Platzer, A. Reuschl, I. Riesinger, for the internal quality control.