ORTHORECTIFICATION AND GEOMETRIC QUALITY ASSESSMENT OF CARTOSAT-1 FOR COMMON AGRICULTURAL POLICY MONITORING

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ABSTRACT:

The European Union uses remotely sensed data in a large operational programme to monitor subsidies given to farmers and to identify irregularities in claims. The trend over the last few years has been a sharp increase in the use of very high resolution sensors, with a number of different sensors being used in a complementary manner. For instance, whilst instruments able to provide imagery with a ground sampling distance (GSD) of <1m make up the primary use (with acquisition in 2005 of around 150,000 km2), sensors acquiring data with around a 2m GSD are in general used as a back-up in case of primary instrument acquisition failure. Cartosat-1 falls into this 2nd category and potentially could provide useful data in the main programme.

A study site located near to Mausanne-les-Alpilles (France), used since 1997 with a time series of reference data series for the checking of farmers' aid applications, was imaged in the framework of the Cartosat-1 Scientific Assessment Programme (C-SAP). The determination of the performance of image orthorectification and geometric quality assessment of the results in relation to the different factors, were the principle goals of the programme. To this end, the availability of high quality reference data is essential. The assessment will be achieved through the quantitative and qualitative evaluations of orthorectified imagery using independent check points, according to a standardized protocol, helping to identify the influence of different factors (e.g. acquisition parameters, methods of orthorectification, site conditions, ancillary data quality) on the geometric accuracy level of orthoimage products.

Two secondary objectives of the study will cover:

- The testing of agricultural field area measurement performance
- An assessment of the instruments ability to assist in the detection of typical crop types, in particular olive trees, vineyards and the main crops targeted under the EU subsidy programme.

A positive outcome of this assessment would serve as a demonstration of the validity of the use of the CARTOSAT-1 instrument for control purposes, as well as serving to validate the instrument's use in a particular agricultural monitoring application.

1. INTRODUCTION

1.1 Study aim

The European Union (EU) uses remotely sensed data in a large operational programme to monitor subsidies given to farmers and to identify irregularities in claims. In 2005, 24 EU member states were involved, checking around 163,000 farms on 210 sites (Chmiel et al., 2004). The so-called "Control with Remote Sensing" operation utilises a mixture of high resolution (i.e. ground sampling distance [GSD] of 5-30m, such as SPOT, IRS, DMC) and very high resolution (GSD <1m, such as QuickBird, IKONOS). Details of the technical specifications and methodology can be found at the project web site (European Commission, 2006a).

A number of other instruments – EROS 1A, SPOT 5 supermode, Formosat – fall in between these two generalised classifications, with GSD being around the 2m to 3m range. Such instruments are used in the control operation as back-up instruments, in case of non-acquisition for the site due to technical or meteorological problems. CARTOSAT-1 was tested here with the prospect of performing in such a role.

The study objectives were:

1. to determine a reliable, operational, approach for orthorectification of the CARTOSAT-1 scenes provided for testing;
2. to assess the performance of the instrument for production of orthoimagery;
3. to assess the suitability of the stereoimagery for DEM generation.

1.2 Study site

The study site located near to Mausanne-les-Alpilles (France) has been used by the European Commisison Joint Research Centre since 1997 (Spruyt and Kay, 2004). It therefore comprises a time series of reference data (DEMs, imagery, ground control) and presents a variety of agricultural conditions typical for the EU. The study site presents a low mountain massif (elevation up to around 650m above sea level), mostly covered by forest, surrounded by low lying agricultural plains. A number of small urban settlements of low density and limited vertical extent exist, with a few limited water bodies.

1.3 Instrument, imagery acquired

CARTOSAT-1 (NRSA, 2006) carries two state-of-the-art Panchromatic (PAN) cameras that take panchromatic stereoscopic pictures of the earth in the visible region of the electromagnetic spectrum. The swath covered by these high resolution PAN cameras is 30 km and their nominal instantaneous geometric field of view is 2.5 metres.

The images acquired for this study consist of two sets of stereo pairs, provided as Orthokit GeoTiff format, referenced to the WGS84 ellipsoid and datum. Other specific data are given in Table 1 below.

Instrument	Fore	Aft
Acquisition date	31 Jan 2006	
Image ID	065103300601	065103300602
Scene Centre Roll	-13.6degs	-13.6degs
Acquisition date	06 Feb 2006	
Image ID	065103300501	065103300502
Scene Centre Roll	+4degs	+4degs

Table 1. General characteristics of imagery acquired for the Mausanne-les-Alpilles site

The location and overlap of the two datasets is given in Figure 1 below. Due however to time constraints, analysis so far has been completed only on the 31Jan2006 image pair, which covers better the main study site.

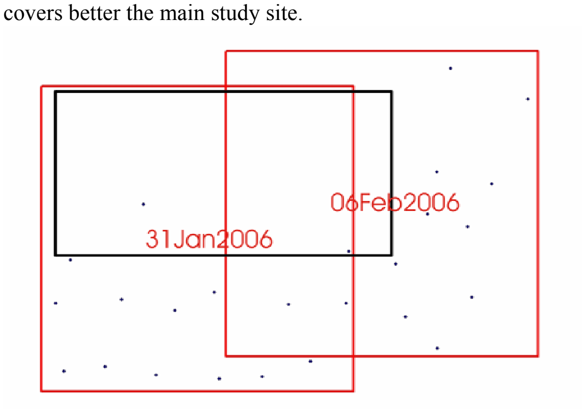

Figure 1. Location of imagery acquired for the Mausanne-les-Alpilles site. The black rectangle defines the nominal study area of interest. New ground control points collected specifically for the study are shown.

2. METHODS

2.1 Software

Since the main objective of the study was to determine the operational use of CARTOSAT-1 imagery, only off-the-shelf software was applied in the test. Specifically, for this study, Geomatica 10.02 and the Leica Photogrammetric Suite (LPS v9.0) were tested for orthorectification performance.

Geomatica 10 permitted the testing of both physical and RPC approaches to orthorectification; LPS by contrast allowed only the RPC method. Since both approaches are mainstream in the operational programme, all three methods were tested.

DEM creation was made using the LPS software. All assessment of the results was made in a separate GIS environment, to ensure compatibility of results.

2.2 Reference data

Some 60 high quality (centimetre precision) GPS points were available for the test site; in addition, it was possible to use previous, higher quality imagery (Spruyt and Kay, 2004) to photointerpret new points.

Nevertheless, due to the specific characteristics of the instrument in question, it was considered necessary to undertake further field work and acquire (using dual frequency GPS) a new series of 25 points at specific locations, chosen on the CARTOSAT-1 imagery (Figure 1).

The study site comprises a number of digital elevation models, the best of which was acquired in 2003 using an airborne digital instrument (Spruyt and Kay, 2004). This DEM presents a verified quality (linear Root Mean Square Error [RMSE] in the vertical axis, Z) of better than 0.60m on well defined points. The data have a grid spacing of 2m, and are stored in the study standard projection (UTM 31N, WGS84 ellipsoid and datum).

2.3 Orthorectification and DEM assessment

Our chosen approach was to:

- Determine the best method for image rectification and model adjustment; this was verified by undertaking a series of orthorectifications and comparing results with independent check points;
- Upon selecting the chosen model creation, undertake the extraction of the DEM using the stereo pair, and proceed with the DEM quality assessment.

The orthorectification approaches applied are the mainstream RPC bias method and physical model (Toutin, 2004). In all cases, the image pairs were (where possible with the software) corrected together using tie points. All ground control points used, check points and tie points were identically chosen for each test, to ensure that comparisons were not complicated by different selection. Furthermore, the transfer of image coordinates was achieved via file import, to ensure interpretation errors were constant between tests.

Note that we specifically opted to use the best available DEM for the orthorectification process in order that any influence of the DEM would be eliminated at this stage.

The basic approach applied for geometric assessment is the standard method developed by the JRC (European Commission, 2006b). This method applies the strict use of independent check points in the evaluation of image correction performance, permitting the comparative benchmarking between different instruments and different processing methods.

The assessment of the DEM generation was made using a complex method developed during the testing of SRTM and Reference3D products (Kay et al., 2005). In brief, the full DEM covering the study site is compared with a reference DEM (of higher quality), and assessed according to the land cover and slope categories. This approach – carried out in GIS – permits the assessment by three broad land cover categories (derived from the EU's CORINE land cover classification) and four slope categories (derived from the reference DEM), thus enabling application specific assessment of the DEM generation and potential for image use.

Using the above methodology, the area of interest was divided into the land cover and slope stratification (Figure 2 and Figure 3). The importance of each stratification category is given in Table 2 below.

Land cover classes				
Contribution of the class [%]	Arable	Forest	Urban	Water
	64	30	5	1
Slope classes				
Contribution of the class [%]	0–10%	10–20%	20-40%	> 40%
	71	7	9	13

Table 2. Importance of the land cover and slope strata for the study site. Note that the water class were excluded from the analysis.

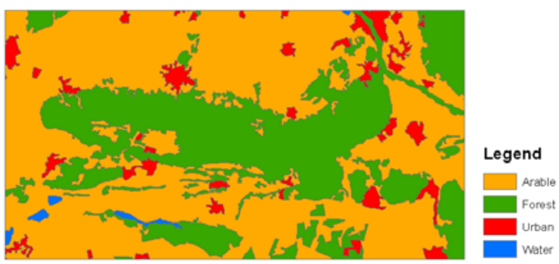

Figure 2. Land cover category distribution throughout the study site

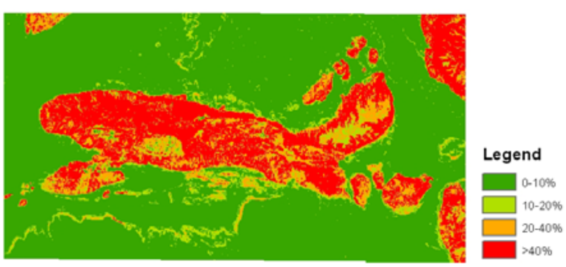

Figure 3. Slope category distribution through the study site.

3. ORTHORECTIFICATION RESULTS

3.1 Geomatica software

3.1.1 Physical model rectification

A series of rectifications were carried out, using identical ground control points and the highly accurate reference DEM. In accordance with the software documentation (PCI, 2006), the minimum number of ground control points (GCPs) required for the use of this model is only 6. We therefore started tests using six well distributed ground control points; extra GCPs were progressively added. However, the regular distribution was maintained.

The results (Figure 4) show the performance of this test series for each image (fore, aft) for the image pair 31 Jan 2006. The results are presented for each image, with the check point linear RMSE value presented for the Easting (X) and Northing (Y) value separately.

The results clearly show that best performance is achieved for the two images tested only when a minimum of 11 GCPs are used.

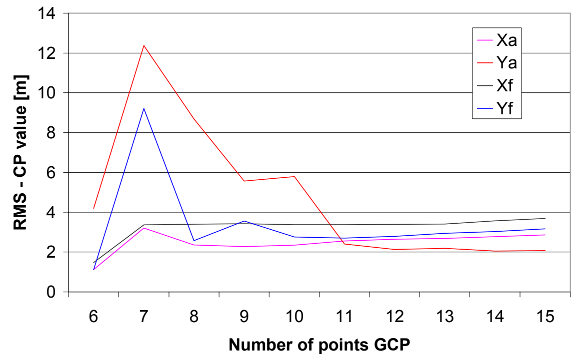

Figure 4. Number of GCPs required to orthorectify using the Geomatica physical model. It can be seen that whilst the minimum number of points required was six, the model stability was only achieved when at least eleven points were used.

3.1.2 RPC rectification

The RPC approach in Geomatica 10 applied was the bias method, applying the coefficients supplied with the imagery. Again, the testing began with the use of the same six GCPs, identical to the physical model test. The identification of the points was done via a file import of image coordinates, thus ensuring that no interpretation differences exist between the two tests.

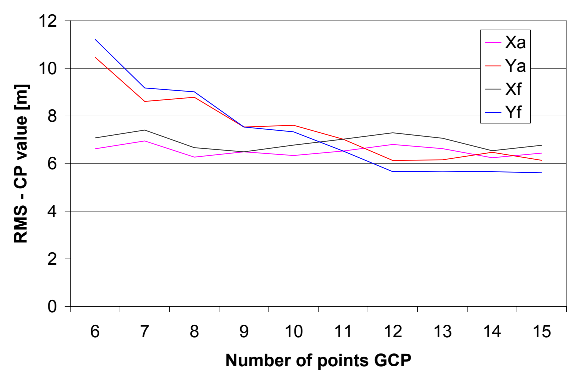

Figure 5. Number of GCPs used for the RPC bias method, using Geomatica 10. A stable condition was reached around 11 GCPs.

The results (Figure 5) show a weaker performance of the RPC method in this software compared to the physical model. Whilst the results are relatively stable, they do not pass below the 6m RMSE value (either X or Y). Indeed, at the most stable level, the resulting errors are twice as high as those obtained using a physical model.

We subsequently repeated the test using a 1st order and 2nd order adjustment. However, whilst performance in the Easting direction was improved, the errors in the Northing (Y) direction were considerably worsened. The trend visible for the 1st order adjustment results (Figure 6) was even more noticeable in the 2nd order result (not presented here).

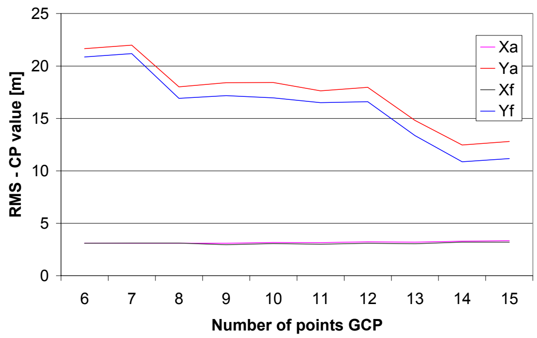

Figure 6. Number of GCPs required to orthorectify using the Geomatica RPC model. No stable condition was reached and errors in the Y (northing) direction were very high.

3.2 LPS Software: RPC

No physical model for the CARTOSAT -1 was available in the LPS software used for testing. We therefore applied exclusively the RPC approach, again undertaking a series of rectifications, using identical ground control points and the highly accurate reference DEM.

Figure 7 (below) shows that the rectification performance was considerably improved with respect to the previous tests. Linear RMSE (that is, either X or Y directions) was reduced to around 1 pixel, even when only 6 GCPs were used for the rectification.

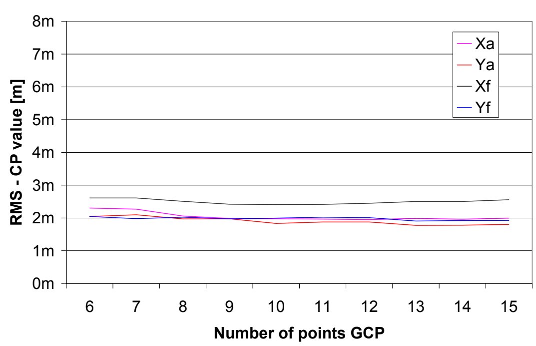

Figure 7 Number of GCPs required to orthorectify using the LPS RPC model. Stable condition was reached using six points.

3.3 Orthorectification, summary

It was demonstrated, therefore, that it was already possible to perform good orthorectification using standard off the shelf software packages. It should be recalled that in both cases, the CARTOSAT-1 specific satellite models used were relatively new and therefore it is likely that they will improve.

With both packages it was feasible to correct the imagery to within the specifications required for the operation of the EU Control with Remote Sensing program.
At this stage, we chose to proceed using the LPS software package, applied with the RPC model block solution and just 6 ground control points.

4. DEM PROCESSING

4.1 DEM Extraction

The DEM was extracted from the 31 Jan 2006 stereo pair, using the model built from the RPC approach using 6 GCPs, in the LPS software. The grid size for the DEM generation was 10m, and was generated for the full overlap of the image pairs. However, the assessment presented here is only for the area for which a reference DEM was available (Figure 1), i.e. approximately 50% of the acquired imagery.

During the creation of the DEM, all six GCPs and tie points were used as seed vertices. This input enhances the relative position of the DEM generated and improved results. However, we did not apply any filtering or post-processing of the DEM to change the result of the automatic extraction.

According to the internal software quality reporting (General Mass Point Quality) 58% of the generated vertices were considered "Excellent" matches, 23.5% were considered "Good", and with some 18.4% considered "Suspicious". Rather than filter the DEM to eliminate peaks and spurious vertices, we used this information as a mask and the results relate only to 81.5% of vertices classed as "Excellent" or "Good".

4.2 DEM assessment

Table 3 below presents the overall results of the comparison with the higher-grade reference DEM. This assessment was applied using the "raster to vector" approach (Kay et al., 2005), using bilinear interpolation to determine the elevation for each CARTOSAT-1 DEM 10x10m cell position in the reference data set, by interpolating from the nearest 4 vertices from the 2x2m grid.

The standard deviation and mean values of the elevation differences (between the CARTSAT-1 DEM point and the corresponding interpolated vertex) are calculated and stored for analysis.

We then continued by analysing the performance of the DEM generation first by land cover category, and then by slope category, separately. Note that in the results presented, the values for the land category include all slope categories, and vice versa.

As can be seen in Table 3 and Figure 8, the DEM gives good performance (Standard Deviation [SD] 3.80m) for the Arable category, well inside the required quality for the Control with Remote Sensing program (established as 5m $RMSE_Z$). Whilst the Urban category also presents a similar result (SD 3.77m), the forest areas – as expected for an instrument that effectively picks up the canopy top – is more variable at 5.12m. The mean values for all three categories are not significantly different from zero with respect to the Standard Deviation results recorded, although the Forest category shows a bigger shift than the Urban or Arable categories.

Land cover mask	Land cover	Std. Dev.	MEAN
	Arable	3.80m	-0.32m
	Forest	5.12m	-0.92m
	Urban	3.77m	-0.11m

Slope mask	Slope class	Std. Dev.	MEAN
	0 - 10%	3.85m	-0.17m
	10 - 20%	4.78m	-0.80m
	20 - 40%	4.27m	-1.94m
	> 40%	5.81m	-0.95m

Table 3. Overall results of the DEM comparison

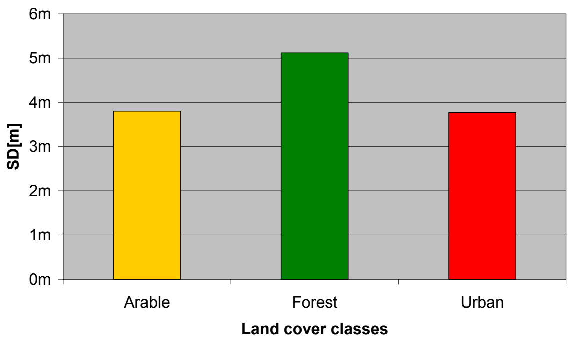

Figure 8. Overall results of the DEM comparison, by Land Cover category

Most noticeable for the breakdown by slope category (Table 3 and Figure 9) is the stability of the Standard Deviation result, which exceeds 5m only for the steepest category (>40%, covering 13% of the study vertices). Again it should be recalled that these results mix all land cover categories for each slope category. For this reason we further detailed (Table 4) the analysis by splitting each land cover category by slope category.

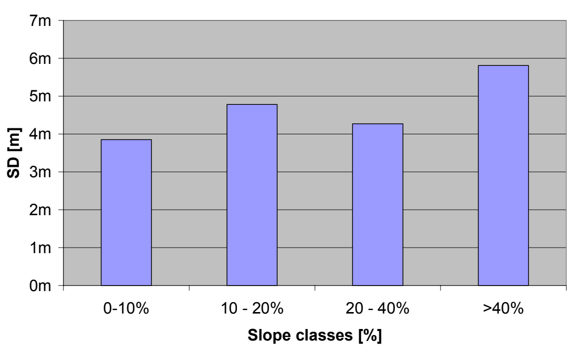

Figure 9. Overall results of the DEM comparison, by Slope category

Arable	Slope Class	Std. Dev.	MEAN
	0 - 10%	3.76m	-0.21m
	10 - 20%	4.09m	-0.88m
	20 - 40%	3.76m	-2.28m
	> 40%	3.39m	-3.26m
Forest		**Std. Dev.**	**MEAN**
	0 - 10%	4.63m	0.18m
	10 - 20%	5.00m	-0.82m
	20 - 40%	4.25m	-1.93m
	> 40%	5.88m	-0.82m
Urban		**Std. Dev.**	**MEAN**
	0 - 10%	2.88m	-0.16m
	10 - 20%	6.75m	0.59m
	20 - 40%	9.09m	0.88m
	> 40%	6.97m	-1.00m

Table 4. Detailed results of the DEM comparison

In Table 4, which details the split of each land cover category by slope category, we can see that the results degrade with increased slope, for all types of land cover category. However, this is the expected situation in DEM generation. For all but the steepest of categories, the DEM created is inside the requirements of the Control with Remote Sensing program.

Figure 10 represents these results graphically. Here we can see that for normal agricultural and forest area applications, performance is in general compatible with the stated performance of the instrument (NRSA, 2006) and inside the required performance for the Control with Remote Sensing program.

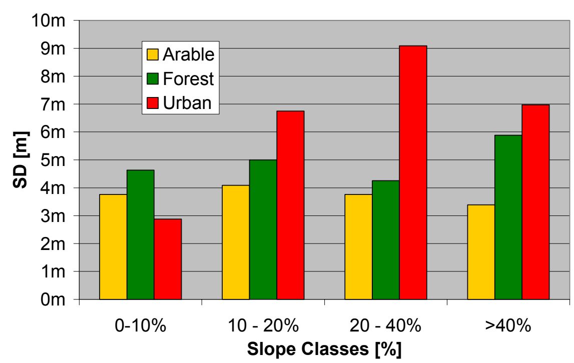

Figure 10. Results of the DEM comparison, by Land Cover and Slope category

It is worthwhile to observe that, whilst these results appear promising, they also seem comparable or slightly worse than the publicly available SRTM data set (Kay, 2005, Rodriguez et al., 2006) with a reported Standard Deviation result well under 5m. However, we have not yet been able to complete the direct comparison for Mausanne-les-Alpilles site.

5. CONCLUSIONS

A series of orthorectification tests were completed to evaluate the operational performance of the CARTOSAT-1 sensor in the production of orthoimages. Our tests show that it was comparatively straightforward to produce reliable products, well inside the expected performance of a modern satellite instrument, from 2 to 3m $RMSE_{1-D}$ (i.e. in either Northing or Easting directions). This was achieved using either a physical model approach (in Geomatica 10, with a minimum of 11 GCPs) or using the RPC bias method (in LPS v9, with just 6 GCPs).

Some difficulties were encountered when using the RPC method in Geomatica 10, but these are not thought to be directly related to the RPC coefficients provided with the imagery. Instead, it is probable that the weaker implementation of the block bundle adjustment may be the cause of the problem observed.

After choosing the LPS method for sensor geometry modelling, the extraction of the corresponding DEM produced good results that again are suitable for the operational purposes of the EU Control with Remote Sensing program, i.e. better than 5m $RMSE_Z$ for typical agricultural areas.

Furthermore, the image quality – given the sub-optimal acquisition date of January for this test site – was very suitable for use as a back-up instrument, compatible with the requirements of the EU control program and commensurate with the technical characteristics (spatial and spectral resolution) of the sensor.

Further results will be elaborated, specifically focusing on the second image pair provided for this test site and other aspects of the DEM and orthoimage generation.

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