GEOMATICS APPLICATIONS FOR MAP PRODUCTION AND WATER MANAGEMENT IN DEVELOPING COUNTRIES

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Abstract – Effective actions in water management in developing countries are limited by lack of adequate maps. In this work, we will show a possible approach for low cost map production, based on satellite remote sensing and GPS survey techniques. ASTER and QuickBird images have been acquired to generate respectively a Digital Surface Model (DSM) and a 1:10.000 orthoimage of a watershed in a rural area in Burkina Faso. A GPS survey was conducted to collect the ground control points needed for images exterior orientation. The created orthoimage can be exploited for hydrologic planning and generally for land management by local technicians.

Keywords: ASTER, Developing Countries, Environmental, Floods, Mapping, QUICKBIRD, DSM, Orthoprojection

1. INTRODUCTION

Water management in developing countries is a critical issue to deal with in order to guarantee a good distribution of water resources for population and to mitigate soil erosion for agricultural purposes.
This work refer to some technical solutions in map production studied for a cooperation project by the student association Engineering Without Borders (ISF) and the NGO CISV in Turin (Italy).
CISV have worked for many years with hydrologic and agronomic actions in the Sahel to increase the alimentary security in areas where the main problems are erosion and desertification. In that context has grown up the need to have a correct frame planning of the actions set to manage the soil erosion: indeed that is limited by lack of adequate maps, as in some countries the only available ones refers to 1:50.000 scale and they are often dated '50s – '60s.
Map production with hydrologic management purposes in developing countries has specific requirements: it needs a cheap product, simple for updating, in a medium scale (1:25.000 – 1:10.000). Traditional production methods however don't fulfill all of them. Aerial images usually are not available or inappropriate because of the age or of the scale, and it is not possible to plan a express acquisition especially for lack of companies or really high costs. Traditional topographic method instead is suitable to update existing maps, but it is not due for new production, as limited to punctual information of the area.
Nowadays, with high resolution remote sensing, it is possible to use satellite images for cartographic purposes with good results, that fit the demand of developing countries.
The advantage of satellite remote sensing for cartographic production and updating in respect to the traditional photogrammetric techniques consist in short acquisition time joined to the great frequency of acquisition due to the short revisiting time, that make possible to map expressly even areas where is it difficult to access and transit; moreover, satellite images provide radiometric information in addition to the geometric ones, to integrate the panchromatic metric precision and the thematic informative multispectral contribution.

The aim of this work is to show a possible approach for low cost map production, based on satellite remote sensing and GPS survey techniques. The method studied has been successfully applied in a watershed in a rural area in the north of Burkina Faso, with the results presented in this paper.

ASTER and QuickBird images have been acquired to generate respectively a Digital Surface Model (DSM) and a 1:10.000 orthoimage. A GPS survey was conducted to collect the ground control points (GCP) needed for images exterior orientation. DSM generation has been carried out both through PCI Geomatics OrthoEngine and AsterDTM ENVI module software.
DSM has been moreover used to build up an approximate flood model based on terrain slope criteria.

1.1 Case study

Test area is Ninigui watershed, sited in the north of Burkina Faso (Yatenga region). This area offers the chance of a real application of the method, for the presence of a important hydrologic work, a soil dam, who need management of the entire watershed in order to avoid erosion an to improve the dam performance. The area is nearly plane, with some low hills, between 300 and 550 meters over sea level.

Fig. 1. Case study area.

2. IMAGE DATA

2.1 QUICKBIRD image

The test image is a QUICKBIRD Ortho Ready Standard, expressly recorded on demand. The choose of a Standard product (geocoded) instead of a Basic one is due to the possibility to acquire not the entire scene but a specific area (in our case, corresponding to the watershed, approximatively of 10x10 km, described with a shape file), at a very lower cost. Ortho Ready Standard Imagery is geocorrected but it has no topographic corrections, making it suitable for orthorectification: it is projected to a constant base elevation, which is calculated on the average terrain elevation per QUICKBIRD scene. Ortho Ready Standard images have a delivered absolute geolocation accuracy of 23-meter CE90%, excluding any topographic displacement and off-nadir viewing angle. QUICKBIRD images has as a geometric resolution of 0.60 m for the panchromatic band and 2.40 m for the multispectral ones (4).

2.2 Aster image

As test data to extract a DSM (Digital Surface Model) an ASTER Level 1B image (AsterDTM software can equally manage both L1A and L1B ASTER images) has been adopted. That image has been chosen between three of them because of the best performances due to lack of clouds in the test area. ASTER sensor produces stereoscopic and multispectral images characterized by a varying geometrical resolution and covering a spectral range from 0.556 to 11.32 µm. Moreover, ASTER can record along track stereo images (bands 3N and 3B, mean geometric resolution of 15 m and central wavelength of 0.804-0.807 µm).

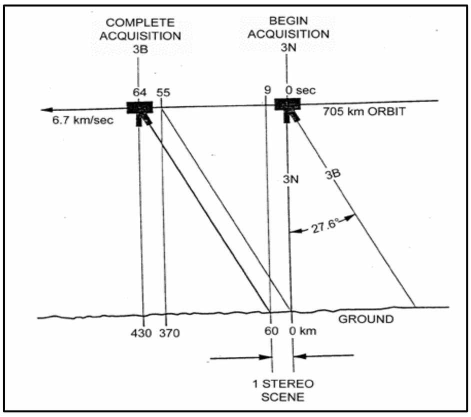

Fig. 2. ASTER stereo pairs recording sheme (HAROLD R. LANG, ATBD- AST-08 document).

3. GPS SURVEY

Because of the particular test area, adequate reference data (GCP, Ground Control Points) to calibrate QUICKBIRD image orthoprojection were not available. A GPS survey, aimed to collect GCPs, has been therefore carried out. The GCPs were previously identified over the image. To facilitate scene interpretation a Pan-sharpening operation was carried out to transfer the spectral content of the multispectral lower resolution bands to the higher resolution panchromatic one. GCPs was chosen according to some natural and man-made details (building edges, wall corners, some anti-erosion rock stringcourses, small trees, crossroads and points that in general could guarantee univocal and easy identification both over the image and at the ground).

In order to overcome any inconvenience due to the point accessibility and the quality level of the GPS signal problems, it was decided to identify more points than the strictly necessary for the orthoprojection operations; a choice that proved to be wise.

A relative GPS positioning with post-processing was performed. According to this technique, the positions of the individual points are determined, starting from the known coordinates of some vertices on the network, to determine some joined base-line vectors. There are two main conditions for this method: two or more receivers must be available to measure simultaneously, and the coordinates of some vertices in the network must be known precisely.

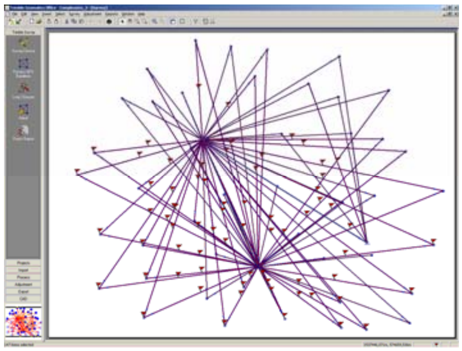

Fig. 3. Plot of the GPS Survey

Three GPS receivers were used:

- 1 double frequency Trimble 4000Ssi model, endowed with a Compact L1/L2 antenna with Ground Plane.
- 2 single frequency Trimble 4600 models.

The geometry of the network (base-lines with a maximum length of 8.37 Km) made it possible to use the single and double receivers together, though some shrewdness was necessary.

Fig. 4. GPS Survey example

On the ground, the first operation was the identification of the three vertices of the network to be considered fixed during the compensation procedures. These were materialized over the ground by a steel pillar.

The adopted procedure used two GPS instruments placed simultaneously on two of the three vertices and a Rover instrument to measure in kinematical mode (time periods of about 20 minutes) the network points. The double frequency receiver was always placed alternatively on one of the three materialized vertices of the network and it performed measuring sessions of 24 hours or more, which permitted the Precise Point Positioning (PPP), using Bernese software developed at the University of Berna, to be carried out. Past experiences demonstrate that at least 24 hours of consecutive and uninterrupted measurements, with acquisition intervals of 30 seconds, are necessary for a positioning with an accuracy of 10^{-2} m. By extending these results to the network under examination, the coordinates obtained with the PPP compensation were assumed as coordinates of the fixed network vertices. The compensation operations of the base-lines were carried out using Trimble Geomatics Office software while the differential approach was used for the treatment of data with combinations of Wide Lane phases to obtain a better fixing of the phase ambiguity.

4. DSM EXTRACTION

To extract a DSM from ASTER stereo images, AsterDTM, an optional ENVI (Research System-Kodak) add-on module was used. It allows to extract digital elevation data from ASTER 1A and/or 1B images.
As reported in the FAQ section of the AsterDTM website, "the basic principle behind the DTM extraction with AsterDTM is the well known parallax effect - you look at an object from two different angles and thus can obtain it's third dimension. Each ASTER image contains it's own stereo pair - looking at the same terrain from two different angles, provided in the form of a 3N (nadir) and a 3B (backwards) pair of images with 15 m spatial resolution. AsterDTM converts these two bands into a pair of quasi-epipolar images which have a pixel displacement in the satellite flight direction proportional to the pixel elevation. A cross-correlation method is used to evaluate this displacement , and transform it into elevation values. This method has it's limitation where the correlation between the two images is ambiguous (typically large areas of water, sand, ice or snow) or not accessible (e.g. cloud cover and associated shadows). Clouds are a major problem because they occur in both images but at different locations (time between the acquisition of nadir and backward images is approximately 6 seconds during which the cloud may have already traveled a few hundred meters). Cloud shadows also affect the correlation analysis, as there may be no cloud or shadow at a certain location in your 3N image, but in the 3B image , which destroys the correlation, yielding an area of low confiability DSM values. AsterDTM tries to fill these holes by interpolating from surrounding "good" elevation values. One can always access the quality of the elevation data by evaluating the confiability map, which shows the score (from 0 [no correlation] to 1 [best]) for the normalized cross-correlation for each pixel (i.e. the "score map")". AsterDTM software does not produce a report showing residuals and RMS errors for the GCPs used during the orientation operation (in this test 20 GCPs have been used). Then no direct on-the-fly check is possible to the user. Otherwise it is possible to vary the extraction process settings to obtain the best performance from the starting image. The processing parameters that can be defined are:

- DSM Minimum and Maximum value;
- DSM output pixel size;
- Output DSM north oriented;
- DSM nodata value;
- Interpolation method;
- Correlation matrix size;
- Use water detection;
- Use GCPs.

In the test case, we fixed some of them and tested the results obtained by changing the correlation matrix size (between 7x7 and 13x13 pixel) and the DSM output pixel size (15 or 30 meters).
In order to appreciate the accuracy of the generated DSM some tests have been done, calculating and comparing the height differences between the elevation values of 20 GCPs and 27 Check Points (CHKs). As accuracy parameter it has been considered the:

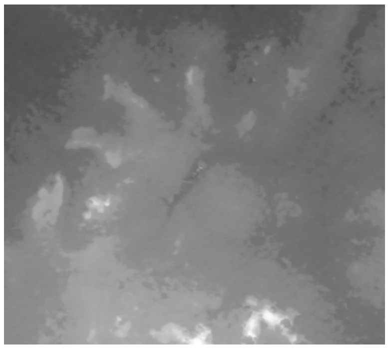

Figure 5. Generated DSM.

Table 1. DSM generation parameters.

	DSM_0210_finale
DSM Minimum value	100
DSM Maximum value	800
DSM output pixel size	15 m
Output DSM north oriented	no
DSM no-data value	-9999
Interpolation method	2-D cubic
Correlation matrix size	13x13
use water detection	no
use GCP's	yes

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (h_i^{\ R} - h_i^{\ C})^2}{N-1}}$$

where:
h_i^R = *observed elevation value of GCPs/CHKs*
h_i^C = *calculated elevation value of GCPs/CHKs*

In table 2 and figure 6 are shown obtained result:

Table 2. RMSE of the obtained DSM (GCPs and CHKs).

N. CHKs	27	**N. GCPs**	20
RMSE (m)	4.11	RMSE (m)	3.50
Mean Error (m)	-1.37	Mean Error (m)	-0.57

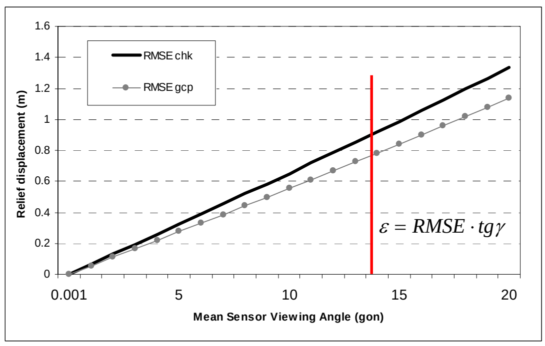

Figure 6. Dependency of the planimetric errors in orthoimage (relief displacement) from DSM RMSE.

Considering these RMSE values in elevation differences it is possible to define the potential planimetric error (relief displacement, ε) that will affect the final orthoimage due to the accuracy of the DSM used in the process. This can be done paying attention to the mean viewing angle (γ) of the sensor, as shown in Figure 6.

5. ORTHOPROJECTION

Past experiences demonstrate that best results for planimetric accuracy of orthoimages derived from high resolution satellite data could be obtained through a n orientation based on rigorous sensor model. QUICKBIRD sensor model exists and it is available within commercial software. For this case study we used PCI Geomatics 9.1.
Rigorous sensor models are based upon collinearity equations; each line of the image can be considered a central perspective. Collinearity equations have then to be modified in order to take into consideration the dependence of the sensor attitude and position on the time. Starting values of the exterior orientation parameters necessary for their estimation, based on GCPs, can be got from the ancillary data provided with the image by the reseller company: generally position vectors, attitude values and/or time dependent attitude coefficients and starting/end time of acquisition are provided. Otherwise initial values have to be calculated in other ways (i.e. time dependent DLT equation).
QUICKBIRD image orthoprojection has been calibrated with 45 GCPs (high resolution QUICKBIRD image has permitted to recognize more surveyed GCPs than during DSM generation) and the elevation information has been derived from the previously generated DSM. Results are shown in table 3.

Table 3. RMS errors and mean errors resulting after image orientation with PCI Geomatics Quickbird sensor model (calculated only over GCPs).

N GCP	45
RMSx (m)	0.56
RMSy(m)	0.40
Mean X Error (m)	4E-05
Mean Y Error (m)	-6E-05
RMSE (m)	0.69

As can be noted, mean errors are very close to zero. This encourages us to assume that no systematic error is present during the operation. X,Y and total RMS error indicate that orthoimage can be suitable for 1:5000 scale mapping, if compared to Italian technical specification for map production. Comparing these results with the expected planimetric accuracy related to the adopted DSM (as previously described) it is possible to verify how they are very similar. This proves that orthocorrection process has gone on well and results are consistent.

6. DSM ANALYSIS FOR FLOOD RISKS

DSMs can be successfully used for terrain analysis related to water resources management and flood risks. At the moment, for the study area, has been simply conducted a flood analysis, considering the presence, in this area, of a dam generating a lake. A flood scenario has been derived from the ASTER DSM considering the dam as the water flow starting point, an the contained lake as an infinitive capacity reservoir. The scenario has been generated with the MicroDEM/TBII free software. Figure 5 shows vectorial map of the potential flooded area overlaying the QUICKBIRD orthoimage.

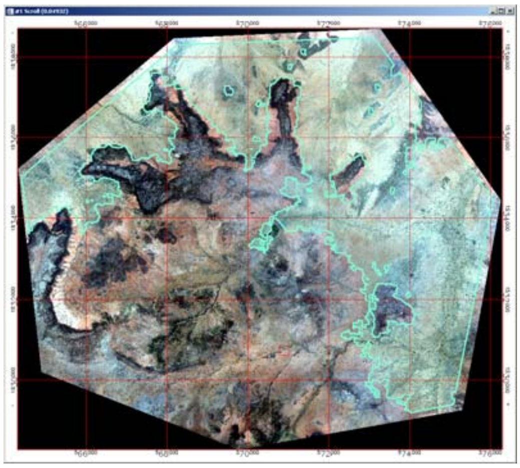

Figure 7. QUICKBIRD orthoimage and potential flooded area overlaid.

7. CONCLUSIONS

According to the preliminary remarks and the results achieved, it is possible to consider satellite images as good instruments for map production in developing countries. Planimetric accuracy obtained is comparable with 1:5000 map obtained from aerial images, although without the same information contents. DSM extracted from ASTER images is a valid and cheap product useful in QUICKBIRD images orthoprojection and, on the whole, for hydrological simple analysis. In the future, the development of high resolution stereo images and GPS survey techniques will supply more effective tools to this application field. Cooperation projects about rural development will take a lot of advantages from the correct land representation available with this kind of instruments.

8. REFERENCES

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8.3 Acknowledgements

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