Geoinformation for European-wide Integration, Benes (ed.)
© 2003 Millpress, Rotterdam, ISBN 90-77017-71-2

High resolution DEM and ortho-photomap generation from TERRA-ASTER data – Case study of Morocco

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Keywords: high resolution DEM, TERRA-ASTER data

ABSTRACT: Since the successful launching of the TERRA satellite carrying the ASTER sensor more and more parts of the earth become covered with images of ASTER. Moreover these images can be obtained for free. To generate DEMs (Digital Elevation Models) the first three image bands out of 14 are the important ones, since the first bands have the finest resolution of 15 meters. In particular the band 3 (0.76 – 0.86 µm) is recorded twice, once vertically and once viewing backwards. It is possible to order relative and absolute DEMs from these data, but very long waiting lists prohibit their fast and practical use.

This paper proposes a method to generate DEMs from ASTER data in-house based on field-measured GCPs (Ground Control Points) in x, y, z direction and also a method of digital photogrammetry. The study area to test the proposed method is located in the south of Morocco, near the town of Zagora. The photogrammetrical software package, VirtuoZo, was used. As a first step the vertical and the backward taken images were individually enhanced to use images with equal contrast. Those images can be imported into the photogrammetrical software. They have to be re-oriented so that the satellite flight axis becomes the photogrametical x-axis. A relative and absolute orientation, removes the y-parallax, and in this way, the images can be matched.

In this paper, it will be made clear, that the residual errors in x, y, z are in the order of 1-2 pixels. From the matched images, the following products can be derived: DEMs, orthoimages, contour lines, topographical otho-photomaps and 3D presentations. An evaluation of the resulting DEM was based upon a comparison between the validation data set obtained by GPS and the DEM.

1 INTRODUCTION

The lack of 3D information has always been a problem in optical remote sensing. The 3D information was normally added from external information sources like digitised topographical maps, containing contour lines, existing DEM by laser scanning etc. When these data were missing the 3D information simply could not be integrated. This is very often the case in developing countries where these data don't exist, or are not accessible. This 3D information could be extracted from CORONA data (Schmidt M. et al, 2002). The advantage of the Corona data is that they provide stereoscopic images and that DEM's can be generated with a very high resolution (1.8 meter). The disadvantage is that they are very narrow strips of 180 * 14 km. This means that the maximum width of a DEM can be 14 km. (in practice less than that). The ASTER data covers an area of 60 km by 60 km with stereoscopic images in the near infrared bands. Therefore a DEM covering a zone of 60 * 60 km2 can be generated at once with a limited number of ground control points. It must be emphasised that ASTER provides DEM (relative and absolute) on request, and for free. An analysis of a free relative DEM shows many errors and that consequently, the relief structures could not be trusted: e.g. wadi's running up the hills, running over the slopes, etc. This paper submits a method to generate one's own DEMs based on stereoscopic ASTER images.

2 DATA

Aster data have been available since 1999. The ASTER satellite is in orbit at an altitude of 705 km. They are recording images in different band groups. Each group of bands has its own resolution. (table 1)

Table 1. The resolution of the ASTER sensor

VNIR	wavelength [nm]	WSIR	wavelength [nm]	TIR	wavelength [nm]
Band 1	0.52 - 0.60	Band 4	1.60 - 1.70	Band 10	8.125 - 8.475
Band 2	0.63 - 0.69	Band 5	2.145 - 2.185	Band 11	8.475 - 8.825
Band 3N	0.76 - 0.86	Band 6	2.185 - 2.225	Band 12	8.925 - 9.275
Band 3B	0.76 - 0.86	Band 7	2.235 - 2.285	Band 13	10.25 - 10.95
		Band 8	2.295 - 2.365	Band 14	10.95 - 11.65
		Band 9	2.36 - 2.43		
15 meter		30 meter		90 meter	

It is obvious that The VNIR channels of the ASTER data are most important for the generation of DEM and ortho-photomaps, especially the third band, since this one is recorded twice; Once in the nadir viewing mode, and after the passage of the satellite a second time in the backwards viewing mode. The backwards viewing sensor looks with an angle of 27.6° of nadir. It takes the nadir viewing sensor 9 minutes to complete a full scene of 60 km. After 55 seconds the backward viewing sensor starts to record the same area. After 9 seconds the backward scene is completed. This means that the total time needed to record a stereo scene is 64 seconds (see figure. 1). The advantage of the ASTER stereoscopic data compared to the SPOT stereo data is that the ASTER data are recorded the same day by the same overpass with a minimum time interval between the two different scenes, while with SPOT this can take several days or weeks, depending on the cloud cover of the area. (figure 2).

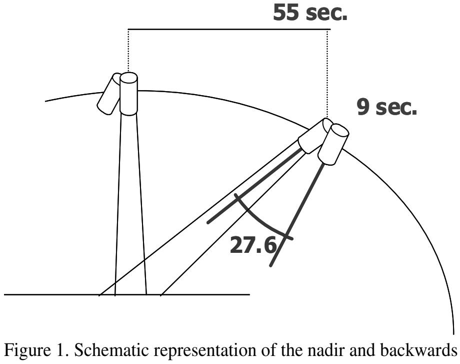

Figure 1. Schematic representation of the nadir and backwards view of the ASTER sensor

With the ASTER data one can see the movement of a cloud between the nadir scene and the backwards-viewing scene. This can give some difficulties for the generation of the DEM at the places where the clouds and their shadows are present.

3 STUDY REGION

The valley of the river Drâa is located on the southern slopes of the Atlas mountains in the south of the Kingdom of Morocco. The river Drâa is a river oasis at the beginning of the Sahara desert, where the hydrological system depends on snow-melt runoff in spring from the High Atlas mountain chain.

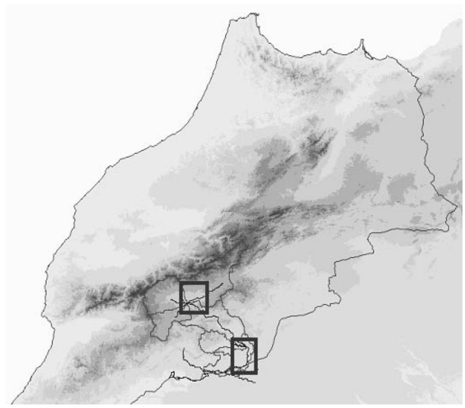

Figure 2. Location of the study regions in the Drâa valley, Morocco.

The GTOPO30 elevation model is in the background of figure 2; the outlined areas are the River Drâa catchment. In this catchment area are two ASTER scenes selected to create two DEM and to evaluate the precision which can be obtained with the proposed methodology. One scene is situated around the town of Ouarzazate, the second one is covers the palm groves of K'taoua and M'hamid.

4 FIELD WORK

During field work, ground control and check points in x,y and z direction were recorded with a TRIMBLE GPS Pathfinder Pro XRS. This type of GPS is receives the correction signal by a geostationary satellite. The points have a relative accuracy of 1m. This field campaign was conducted in the framework of the German IMPETUS project and the Belgian BTC project "Etude d'ensablement dans la vallée du Draa".

5 METHODS

The nadir and backwards-viewing images are characterised by different parallaxes on both images. These parallax differences are a measure of the altitudes of the objects or relief differences. This is illustrated in figure 3.

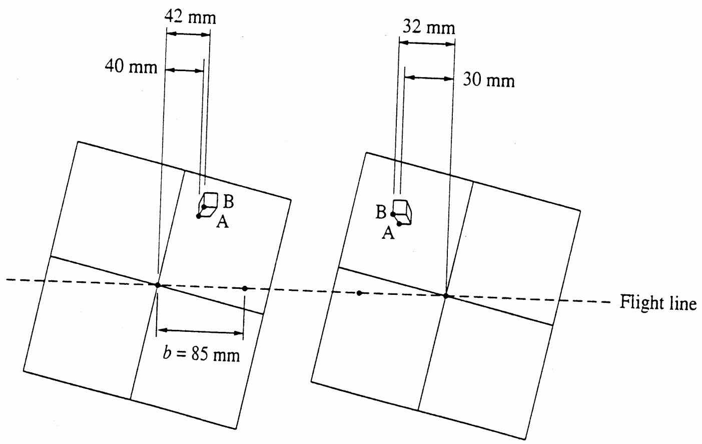

Figure 3. The parallax of an object viewed under different viewing angles (Mikhail et al.. ,2001).

Figure 3 illustrates that the same point viewed on two images has different parallaxes. This is illustrated by the distances o1-a1 and o2-a2. The bigger the topographical differences between points in the field, the bigger the parallaxes will be. Based on the parallax differences, the height differences can be calculated (Mikhail et al.,2001).

Within the software VirtuoZo 3.1 it is possible to work on stereo-image data with a 'non metric' approach with no further input parameters other than ground control points. After inputting the images into the VirtuoZo 3.1, the software through pattern recognition, enables several matching points in both images, and calculate, out of these, a relative orientation including the parameters kappa (κ), phi (ϕ) and omega (ω) of the relatively oriented images. For the calculation of the absolute orientation it was necessary to give at a minimum 6 GCPs to solve the orientation equation system (Chester, 1980). 10 GCPs were used for the exterior information for the Ouarzazate scene and 7 points for the K'taoua scene. It was taken into account that that the GCP were as much as possible homogeneously distributed over the scene. This is not always evident since it is difficult during field work to reach those points which are desirable to be included include in the photogrammetrical restitution. The accuracy of this external orientation for both scenes is given in table 2.

Table 2

Residuals for the K'taoua scene

Residuals

point number	dX	dY	dZ
1	5.718	7.128	1.249
2	4.977	-31.586	-1.833
3	-1.5	43.508	2.25
4	-22.502	7.781	-4.226
5	14.535	-4.645	-1.339
6	-11.556	-19.229	-0.548
7	36.188	1.874	11.352

Root Mean Square Error

mx	=	17.81004
my	=	22.02869
mz	=	4.76316
mxy	=	28.32774

Residuals for the Ouarzazate scene

Residuals

point number	dX	dY	dZ
1	8.629	11.65	16.449
2	7.84	4.845	-5.646
3	-3.356	-17.536	2.99
4	-5.5	9.164	-6.822
5	1.437	12.321	-1.892
6	-11.01	-10.481	-9.421
7	1.342	-8.621	7.582
8	-1.251	-4.782	-2.204
8	9.498	14.881	5.112
9	-0.068	-4.326	-5.308
10	-7.558	-7.117	-0.84

Root Mean Square Error

mx	=	9.05976
my	=	14.77306
mz	=	10.15923
mxy	=	17.32981

Afterwards the y-parallax was removed (Mikhail, et al., 2001) and lines of equal parallax difference and contour-lines were calculated, resulting in a DEM (Maune, 1996). During the processing, it is also possible, within this software, to perform a visual quality check of the quality of the image matching with 3D glasses (Maune, 1996)

6 RESULTS

As table 2 illustrates, the residuals of the photo-grammetric restitution of the both scenes are within acceptable order. All the RMS-errors are within the dimensions of two pixels, and this for x, y and z. It should be noted that the results on the Ouarzazate area are better than the one obtained in the K’taoua area. This is due to the fact that the GCP in the Ouarzazate area are in the first place more homogeneously distributed in comparison to the K’taoua area. Ouarzazate is a central place and much more roads are present which makes the area much more accessible. This also indicates the second reason why the results are better in the Ouarzazate area, compared to the one of K’taoua. In the first area, GCPs could be taken on intersections of the roads, which are undoubtedly certain points. In the second area, less clear points had to serve as GCP: e.g. curves in the road, crossing of the road with wadi’s, and rock outcrops. This explains why the overall accuracy is higher in the Ouarzazate area, but also why the individual residuals are lower in the first area. For the Region of K’taouer 15 additional check points were available which were used for an accuracy assessment of the DEM; the mean height difference was 3.2 m with a standard-deviation of 7.8 m.

The comparison between the generated DEM and the contour lines of the existing topographical maps shows that the generated contour lines are well-fitting with those ones indicated on the topographical map (figure 4). The topographical maps are on a scale of 1/100.000 and indicate a contour interval of 50 meter. The generated contour lines are produced every 20 meter. This explains why both sets of contours do not correspond exactly. The advantage of the proposed method is that one can choose the contour line interval. In this case, contour lines could be produced in much more detail than the existing ones.

The comparison of the generated ortho-photomap with the existing topographical shows anyhow a very good fit. This is illustrated in figure 4 where the topographical map is compared with the generated ortho-photomap. The output ortho-photomap was generated on the input resolution of 15 meter.

These good fittings could be found in the two test areas. Therefore it can be stated that the proposed method is especially suitable for mapping purposes in areas where no topographical maps are exist. This is illustrated in figure 5. This shows an extraction of the southern part of the K’taoua area, close to the Algerian Border. The topographical map in this area is a white spot. The proposed method can serve as an alternative for the topographical map.

	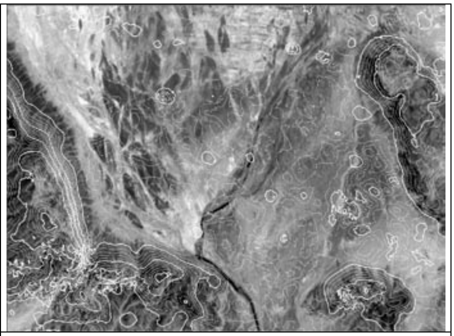
Topographic map Tagounite 1:100.000	Orthophoto-map generated with ASTER data

Figure 4. Comparison of the generated ortho-photomap overlaid with the generated contour lines with the existing topographical map

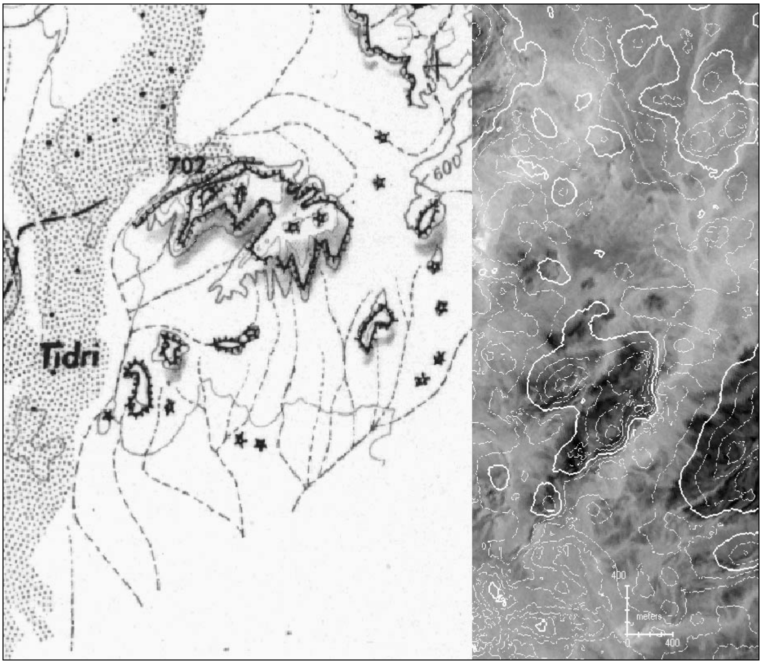

Figure 5.Example where the ortho-photomap is an alternative for the topographical map.

7 CONCLUSIONS

The proposed method can provide DEM's and ortho-photomaps quickly and with a minimum of GCPs. The original 15 meter resolution can be kept, while the free ASTER DEM's have an output resolution of 30 meters. With the same effort, almost automatically ortho-photomaps are produced. The ortho-photomap overlaid with the contour lines can serve perfectly as an alternative topographical map. The digital photogrammetrical restitution of the ASTER data allows the production of much finer contour line intervals, than those normally present on existing topographical maps, especially in developing countries.

ACKNOWLEDGEMENTS

The authors would like to thank the IMPETUS project members. Markus Staudinger and Manfred Finckh for obtaining the GCPs in the field and Marie Drobin for helping to edit this text. The work was funded by the BMBF (Project Number: 07GWK02) and MSWF (Project Number: 514 – 21200200).

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