(Article begins on next page)

ORTHORECTIFICATION OF HR SATELLITE IMAGES WITH SPACE DERIVED DSM

R. Cavallini[a], F. Mancini[a], M. Zanni[a]

[a]DISTART, University of Bologna, V.le Risorgimento 2, 40136 Bologna, Italy
roberto74@libero.it , fmancini@racine.ra.it , michela.zanni@mail.ing.unibo.it

KEY WORDS: Remote Sensing, Orthorectification, EROS, DEM/DTM, High Resolution, Accuracy

ABSTRACT:

The paper addresses the item of orthorectification of high resolution satellite images and the assessment of the final accuracy achieved when Digital Surface Models (DSM) provided by other remotely sensed data are used. By using a photogrammetric processing, a DSM was obtained from an EROS (Earth Resources Observation System) high resolution stereo pair acquired over a portion of the city of Bologna (Italy). After the accuracy assessment of the terrain model trough the comparison with external Digital Elevation Model (DEM), a broad range of orthorectification procedures with high resolution satellite images (Ikonos, QuickBird and EROS) have been therefore investigated by the authors. The accuracy in final positioning provided by the orthorectification of a QuickBird imagery with the EROS-derived elevation dataset was evaluated using a evenly spaced set of Ground Control Points from GPS survey. The achieved accuracy could meet the requirements needed in technical cartography specifications (to scale as large as 1:10000) updating of well recognizable features or entities and generic mapping procedures.

1. INTRODUCTION

In this paper the use of high resolution optical satellite data for both DSM generation and subsequently image orthorectification have been addressed in the area of the city of Bologna (Italy) and its surroundings. The EROS A1 satellite, successfully launched on December 2000 by ImageSat International and operating in an asynchronous mode, on Feb. 24, 2002 recorded an along track stereo-pair over the study area under favourable weather conditions. Using the new photogrammetric processing utilities available in Geomatica v9.1 package and GCPs, a 2-pixel post spacing Digital Surface Model was generated from the stereo-pair. The DSM was therefore validated by means of an available terrain model obtained from digitizing the contour lines of 1:5000-scale topographic maps covering the area. After the validation, in order to achieve a procedure for geospatial data analysis entirely based on satellite data, an orthorectification procedure of a QuickBird image using the EROS DSM was tested. The final result is represented by a satellite map that could be useful for updating the existing cartography (see published papers from the authors reported in the references section).

2. MATERIALS AND METHODS

Hereafter the EROS stereo-pair for DSM generation, the high resolution QuickBird satellite data and ground GPS survey methodologies will be briefly discussed after a description of the study area.

2.1 Site location

The area surrounding the city of Bologna is characterized by a predominantly flat topography (northern area) and a slightly hilly portion (southern area) with peaks that do not exceed 400 m above sea level. The most built-up area is almost entirely extended in the flat portion. Figure 1 shows a perspective view of the area: the high resolution multispectral QuickBird image has been draped over the terrain model.

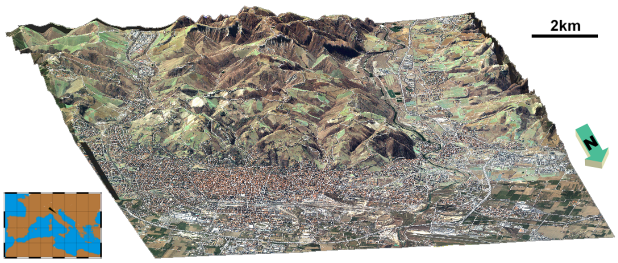

Figure 1. Site location and main topographic features of the investigated area

2.2 The EROS stereo images

The EROS images were purchased in the 1A raw format. They have been initially corrected for sensor geometrical distorsion using the camera model, provided by the vendor, into the 1B format with its characteristic trapezoidal shape. After the resampling the GSD (Ground Sample Distance) of the 1A images, equal to 2.4 m, is transformed into an average pixel spacing (2.268 m 2.290 m respectively).
In Table 1 some technical specification of the EROS 1A stereo-pair are summarized.

Image name	ITA1-e1123941	ITA1-e1123943
Date of acquisition (hour)	Feb. 24, 2003 (9:34:16)	Feb. 24, 2003 (9:35:36)
Along-track angle	30.2°	30.6°
Across-track angle	8.0°	198.0°
Scene size (km)	12.9 x 17.9 km	12.8 x 17.9 km
Scene size (pixel)	7560 x 5980 pixel	7640 x 5900 pixel
GSD	2.4 m	2.4 m

Table 1. Basic properties of the EROS 1A format stereo pair used in the DSM generation

In figure 2a and 2b the stereo images in the 1B version are shown.

Figure 2a. Image ITA1-e1123941.1B
(©2000-2004 IPT Informatica Per il Territorio srl.
©2000-2004 ISI Imagesat International Ltd)

Figure 2b. Image ITA1-e1123943.1B
(©2000-2004 IPT Informatica Per il Territorio srl.
©2000-2004 ISI Imagesat International Ltd)

2.3 The QuickBird imagery

The orthorectification of a panchromatic QuickBird (Basic product) image using the terrain data provided by the EROS stereo-pair will be discussed in the next sections. The dataset, corrected by the internal calibration, was acquired on Sept. 29, 2002 (10:16 a.m) with a significant off-nadir angle (20.8 degree). The image swath is 16.5x16.5 km, the nominal spatial resolution 0,61m and a significant cloud coverage (16%) partially compromises its quality.

2.4 Ground Control Points (GCPs) and CheckPoints (CPs) collection

A large set of points (57) have been surveyed through a differential GPS survey (see figure 3). A subset of the whole dataset will be used for geocoding the QuickBird image (GroundControlPoints), the remaining for validating the final accuracy achieved (Indipendent CheckPoints).
For the DSM extraction from the stereo pair the control points for geocoding each image have been derived from 1:5000 maps.
In Figure 3 the red dots represent the distribution of GPS surveyed points, while the white rectangle illustrates approximately the limits of the EROS scenes.

3. DSM EXTRACTION

For both processes of DSM extraction and QuickBird image orthorectification PCI Geomatica Orthoengine v9.1 software has been used. It implements a rigorous model for EROS and QuickBird images and a Rational Function Model for orthorectification of QuickBird images.
In order to correct geometrical distorsions of the EROS images and produce a DSM, the software uses a 3D physical (rigorous) model based on collinearity equations and complanarity equations for the stereo-model computation. Though the EROS model is designed for 1A images, we imported 1B images as generic files with average parameters derived from metadata.
The DSM extraction procedure allows the generation of relative or absolute DSM. The first does not require ground control points (surveyed or collected from maps), but tie-pointing between the pair allows to obtain a model of elevation not tied to a cartographic reference system. Conversely, when an absolute (geocoded) elevation model had to be sought, a certain number of GCPs are needed.

As the results of the present work have to be related to a national grid, the National Gauss-Boaga Reference System, the DSM has to be geocoded through ground true.

First step of the DSM generation is the collection of GCPs over the two images. In this work 16 GCPs (collected from 1:5000 maps) for each image have been used.

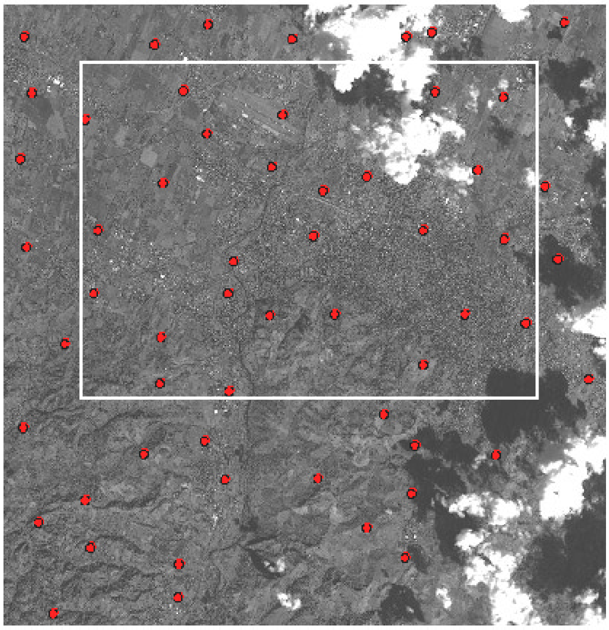

Figure 3. QuickBird image illustrating the point dataset acquired with the DGPS survey and, in the white rectangle, the EROS image limits

They are evenly distributed over the scene and cover all of the elevation range of the relieves. The availability of tie points recognizable over both images is also useful for the DSM extraction procedure because they improve the matching (stereo-correlation) between the two images.
Through GCPs the geometric model is computed for both images separately with a rigorous and specific model and the stereo model geometry is refined with a least square adjustment process.
As soon as the matching is performed, a quasi-epipolar geometry for the stereo-pair has to be created. Using epipolar

images, in fact, increases the speed of the correlation process. Once the images have been registered to the same ground area, positional differences are assumed to be due to parallax, which results due to relief. Measured parallax differences are converted to absolute elevations using trigonometric functions and the orbital data (orbital position, altitude, attitude and the scene center).

The automated image matching procedure used to derive the elevation from the parallax and produce the DSM is carried out through a comparison of the grey values of the two images. This procedure is based on a mean normalized cross-correlation matching method with a multi-scale strategy to match the image using the statistics collected in the defined windows. The multi-scale strategy is based on a hierarchical approach using a pyramid of reduced resolution images. The first attempt at correlation is performed on very coarse version of the images. This enables the software to match the features more accurately and, subsequently, improves the correlation success. The next correlation attempts are performed using finer features and on higher resolution versions of the image. The full resolution is then used in the last correlation.

The result of matching procedure is represented by correlation coefficients, varying between 0 and 1 for each pixel, with 0 representing a total failure of the matching and 1 a perfect match. A refinement of the matching procedure could be performed in order to improve the accuracy to sub-pixel level. Elevation points are extracted at every pixel for the complete stereo pair. As previously said the advantage of using this procedure is that the search for the matching pixels is limited to the epipolar line, allowing a significant improving of the algorithm efficiency and accuracy.

The percentage of the correlation successfully performed was around the 99%. The figure 4 represents the correlation index computed over the whole image using a grey level scale.

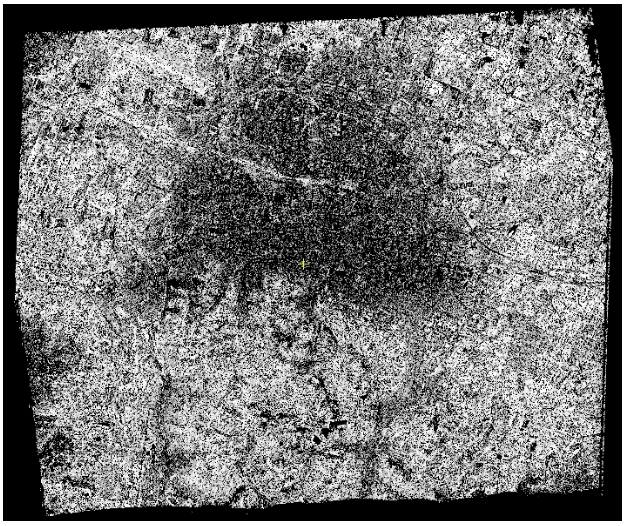

Figure 4. Correlation index plotted as grey levels; white pixels indicate the full correlation whereas black pixels indicate a low correlation or correlation failure

The grid spacing of the extracted DSM has been selected to 2 pixels, corresponding for the EROS images processed, to approximately 4.6 m. The resulting file is composed of more than 8 million of points with an elevation ranging between 15 and 490 m a.s.l. In figure 5 a perspective view of the geocoded DSM.

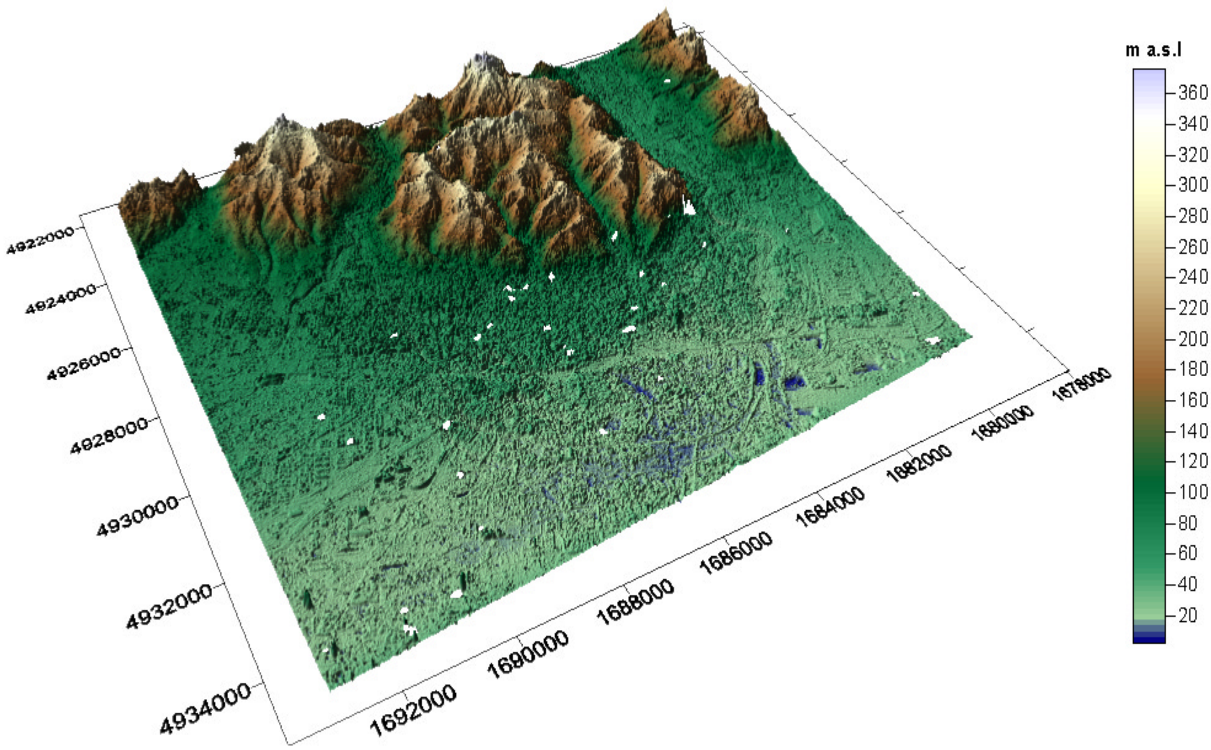

Figure 5. Geocoded Digital Surface Model. Elevation. Coordinates are expressed in the National - Gauss-Boaga grid. Holes, depending on the failure of the correlation phase, are visible in figure as white area.

3.1 DSM editing

On the whole, and at first look, the DSM appears to be satisfactory over the areas where the correlation has been successful. The use of a large number of tie points helps in getting better oriented epipolar images and improves the possibility of a good image matching and, hence, allows to obtain a good DSM with few failure areas. Notwithstanding, a little lack of data where the matching has failed, particularly in the urban area corresponding to buildings with high reflectivity and bare soil facing the sun, is present.
Moreover, a border effect is also affecting the DSM. Elevation in some cases are considerably out of range. For these reasons it has been necessary the editing of data in order to cut-off the outliers and fill the area where the matching fails.
A noise removal filter and a smoothing have been applied

3.2 DSM accuracy assessment

Once edited the DSM, its accuracy has been evaluated by comparing elevation with an available and accurate DTM derived from the digitalisation of 1:5000 maps with a gridding space equal to 10 meters. For the comparison, both models must have the same gridding space. For this reason, the extracted DSM has been interpolated with a kriging algorithm and resampled to the lower spacing. Differences in elevations between the new and the available terrain model can be then evaluated at each node.

It's worth to notice that while DTM represents the real morphology of the terrain, the satellite derived DSM represents the surfaces of features in the scene, as the bare soil in non-vegetated areas, the tree canopies in wooden areas and the building obstructions in urban environment. In figure 6 a series of transects are reported in order to show discrepancies between the cartographic DEM and the DSM under evaluation. Plots in the following figure 7 shows the differences along the transects between the terrain models.

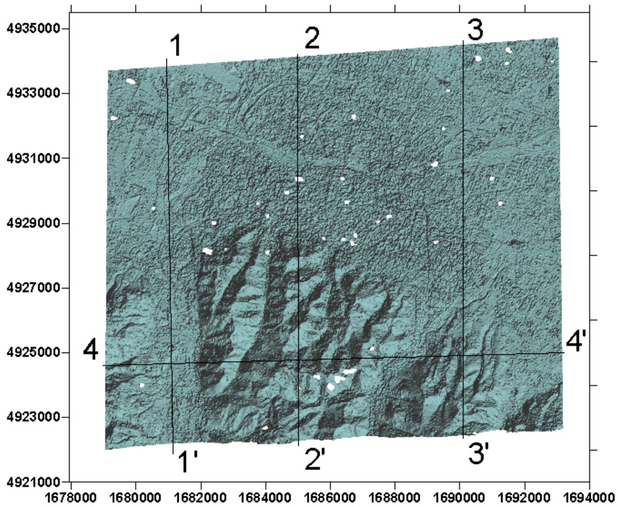

Figure 6. Transects for comparison between terrain models shown on the DSM

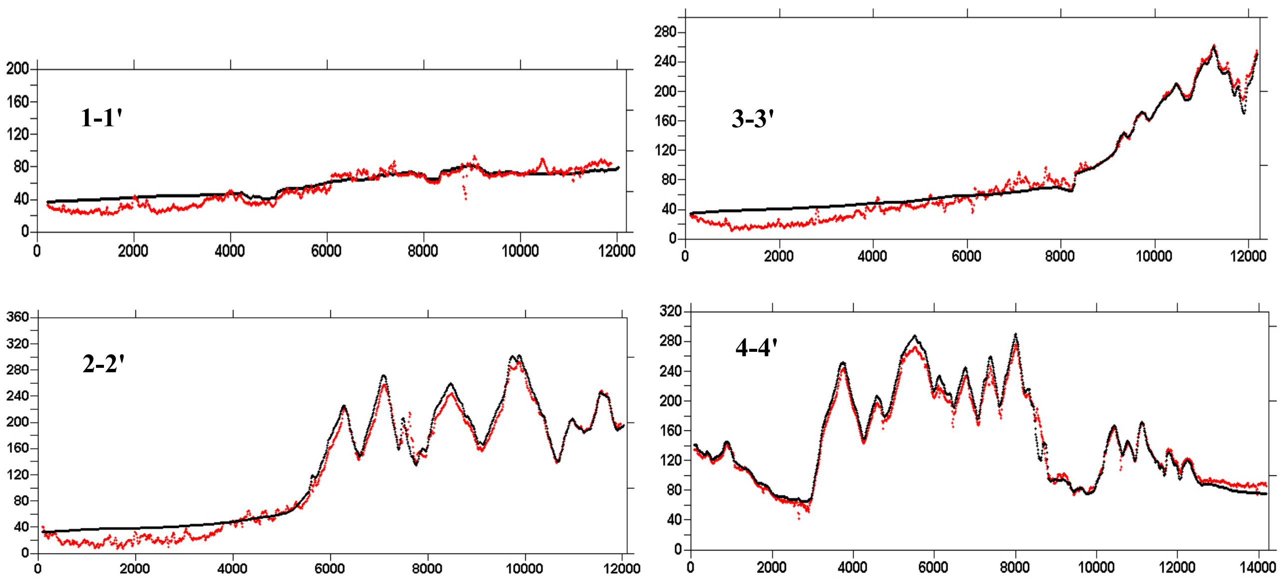

Figure 7. Comparison between the elevations (m) of the Digital Elevation Model obtained from vectorialization of maps (black solid lines) and elevations as provided by the satellite Digital Elevation Model (red lines). Numbers on the left-above have to be related to the previous Figure 6. In the x-axis the progressive distances (m) along the transects

After resampling the DSM to a pixel spacing of 10 m, the comparison with the DEM was evaluated in order to emphasize possible systematic or gross errors. As shown in the frequency histogram of figure 8 the distribution of differences shows a distribution with the 90% of pixel exhibiting a difference with the reference elevation of ± 20m.

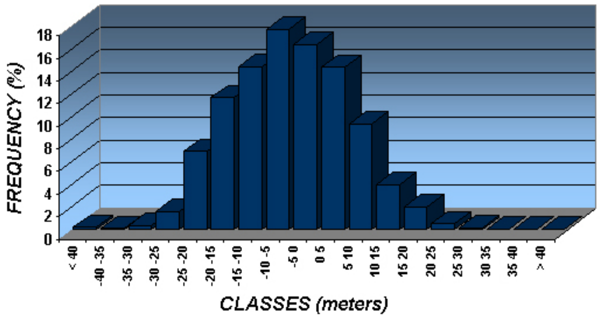

Figure 8. Frequency histogram showing differences in the comparison between the satellite-derived DSM and the DEM used as reference

4. ORTHOIMAGE GENERATION

The orthorectification of the QuickBird image, based upon the discussed DSM, has been performed using PCI Geomatica software. The software adopts different geometric correction models, among them the parametric rigorous model and the rational polynomial model are the most accurate.

The rigorous model can be applied through the knowledge of a certain number (around 20) of ground control points well and evenly distributed over the whole scene.

The Rational Polynomial Model can be theoretically applied without knowing ground control points, but just using the coefficients (RPC, Rational Polinomial Coefficient) delivered with metadata. In this work the transformation between UTM-WGS84, that is the reference system in which RPC are computed, to the National Gauss_Boaga grid system, that is the final required system, has been applied using a set of GCP in the latter system.

It has to be noticed that the extension of the QuickBird scene is wider than the EROS one, so the orthorectification could be carried out only for the overlapping area.

4.1 Orthoimage accuracy assessment

Results of the orthorectification tests are generally expressed in terms of Root Mean Square Error (RMSE) along the East and North grid axis computed using a series of known and independent checkpoints which are clearly recognizable on the orthoimage. Several test have been experienced in the past by the authors (Barbarella, 2003). On the other hand, it is well known from literature that the accuracy achieved in the orthorectification may be fixed in 1 or 2 pixels.

The overall quality of the final orthoimage map could be also checked by the comparison with cartography at the higher scale than possible. The "first look" comparison between the raster orthoimage and the vector map available, with its related and scale-dependent accuracy, would be useful in the identification of critical area where the procedure fails. In figure 9 the overlapping of raster orthoimages and vector layer is shown.

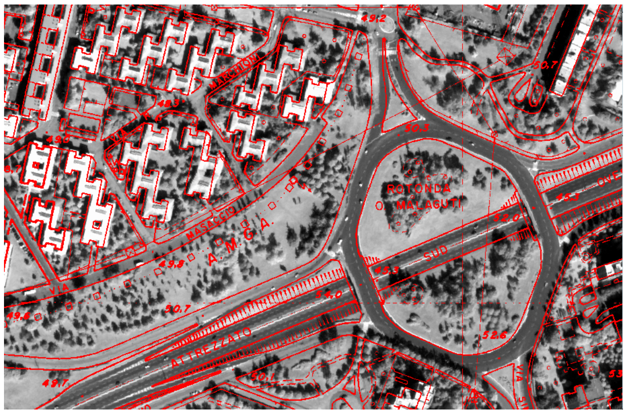

Figure 9. Overlay of portion of the raster orthoimage and the map layer. Comparison of the main features highlights differences between products

5. CONCLUSIONS

The generation of Digital Surface Models from satellite high resolution optical images and its use in the ortho-reprojection of external HR satellite images (we discussed the case of a QuickBird image) should be considered as a productive methodology when the accuracy requested in map production has to meet the requirements of cartography at scale as large as 1:10000. In particular, within the spatial methodology for terrain modelling, the use of stereo-pairs acquired by the EROS constellation may be considered one the possible choice, considering the low cost of the raw data. Problems may arise in the correlation procedure (low data quality, cloud coverage, atmospheric effects or shadowing in densely urbanized area), producing lack of data in the DSM or erroneous elevations.

REFERENCES

Barbarella, M., Mancini, F., Zanni, M., 2003. Rectification of high resolution satellite data: evaluating accuracy for map updating. *Proceedings of the ASPRS/MAPPS conference* "Terrain data: application and visualization, making the connection", Charleston, SC, USA, Oct. 2003.

Barbarella, M., Mancini, F., Zanni, M., 2003. Processing of high resolution satellite data for map updating. *Proceedings of 30th International Symposium on Remote Sensing of Environment*, Honolulu, Hawaii, USA, Nov. 2003.

Hirano, A., Welch, R., Harold, L., 2002. Mapping from ASTER stereo image data: DEM validation and accuracy assessment. *ISPRS Journal of Photogrammetry and Remote Sensing,* 57, pp. 356-370.

Jacobsen, K., 2003. Orthoimages and DEMs by QuickBird and Ikonos. *Proceedings of EARSeL*: "Remote Sensing in Transition", Ghent, 2003, pp.513 – 525

Siva Subramanian, K.S., Amitabh, S., Manda, S., 2003. Evaluation of Digital Elevation Models created from different satellite images. *Proceedings of Map India Conference 2003,* New Delhi, India, Jan 2003 *http://www.gisdevelopment.net/proceedings/mapindia/2003/tt.htm* (accessed 27 Apr. 2004)

Toutin, T., 2003. DTM generation from Ikonos in-track stereo images using 3D physical model. Submitted to *Photogrammetric Engineering & Remote Sensing*, 2004

PCI Geomatics Enterprises Inc., 2003. Geomatica OrthoEngine. User Guide v9.1

AKNOWLEDGMENTS

Our thanks to Regione Emilia Romagna (Dr. Gavaruzzi) for providing the DTM data.