On the accuracy of geometric information extracted from SPOT imagery

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Accurate topographic maps are of fundamental importance for economic development and resource management of any country. Third world countries still suffer from shortage in mapping coverage of scale 1:50,000 and 1:100,000. Moreover, the existing maps are considerably out of date. Nowadays, the data available from space imagery are utilized to produce new or update existing topographic maps. This paper handles the aspect of extracting geometric information from System Pour l'Observation de la Terre (SPOT) panchromatic images and focuses mainly on sensor modeling, and secondly on automatic generation of Digital Terrain Models (DTM) and production of orthoimages. The study involves the implementation of two SPOT panchromatic images as a stereo-pair covering an area located on the eastern border of Egypt and extended from Ras Sugary to Ras Dibb along the Red Sea coast. The base-to-height ratio of the stereo-pair is 0.82 and the overlap coverage is approximately 90%. This study was carried out using PCI EASI/PACE image processing software from Geomantic, Ottawa. The results showed that the plan metric accuracy of SPOT images is less than one pixel in east and north directions, which is compatible for producing and updating topographic maps of scale 1:50,000. The obtained accuracy of DTM derived from SPOT stereo-pair is 8.71 m expressed as Root Mean Square Error (RMSE) of elevation residuals.

تعتبر الخرائط الطبوغرافية الدقيقة من أهم مصادر المعلومات اللازمة للتطور الاقتصادي وإدارة الموارد الطبيعية لأي دولة وتشير الإحصائيات إلى وجود عجز شديد في المساحات المغطاة بهذه الخرائط وخصوصاً في دول العالم الثالث، هذا فضلاً عن كون الخرائط الموجودة قديمة ولا تعبر عن الواقع كما أن تحديث هذه الخرائط باستخدام الطرق التقليدية يكون بمعدل بطئ. ومن هنا كان لابد من توجيه النظر إلى استخدام صور الأقمار الصناعية لإنتاج وتحديث الخرائط الطبوغرافية. ويهدف هذا البحث إلى تحديد دقة المعلومات الهندسية المستخرجة من صور القمر الصناعي "سبوت" وتشمل هذه المعلومات دقة إحداثيات النقط و النماذج الرقمية لسطح الأرض وكذلك الصور المعدلة. وقد تم عمل دراسة تطبيقية باستخدام صورتين متداخلتين لمنطقة تقع على الحدود الشرقية لجمهورية مصر العربية بامتداد البحر الأحمر من رأس شقير إلى رأس دب حيث تم بناء النموذج الرياضي باستخدام نقط الربط الأرضية ثم تم استخراج النماذج الرقمية أوتوماتيكيا وإنتاج الصور المعدلة أيضاً. وقد أظهرت النتائج فاعلية صور القمر الصناعي سبوت لإنتاج وتحديث الخرائط الطبوغرافية بمقياس رسم ١: ٥٠,٠٠٠ وكذلك إمكانية استخراج النماذج الرقمية لسطح الأرض بخطأ تربيعي متوسط يساوي ٨,٧١ متر هذا فضلا عن إمكانية إنتاج الصور المعدلة في بيئة رقمية بدقة وسهولة والاستفادة منها بالربط والتكامل مع قواعد البيانات الأرضية الأخرى من خلال نظم المعلومات الجغرافية.

Keywords: Geometric accuracy, SPOT panchromatic images, Digital terrain model, Orthoimages

1. Introduction

Accurate topographic maps are essential for economic development and resource management of any country. Third world countries are arguably the most in need of topographic maps where the deficiency of mapping coverage is acute and even the updating rate of the existing maps is very slow [1]. The developments in computer hardware and software and the availability of digital data from high-resolution Earth observation satellites have enabled the map producers to generate topographic maps in a fully digital environment. Up to now, panchromatic images from SPOT with ground resolution of 10 meters are considerably used for generating various mapping products and updating existing topographic databases.

The purpose of this study is to determine the accuracy of the geometric information extracted from SPOT panchromatic imagery. More specifically, the aim is to assess:

1. The accuracy of three-dimensional coordinates of ground points obtained from SPOT stereomodel.
2. The accuracy of the Digital Terrain Model (DTM) automatically generated from SPOT stereo-pair by digital image matching techniques.
3. The planimetric accuracy of orthoimages derived from SPOT PAN images.

The study involves the implementation of two SPOT panchromatic images comprising a stereo-pair that covers an area located on the eastern border of Egypt along the Red Sea shore. The study area extended from Ras Shuqayr to Ras Dibb. OrthoEngine module of PCI EASI/PACE image processing package is used to perform the complete topographic mapping stages; geometric modelling of SPOT raw data, automatic generation of DTM, interactive editing of DTM, and production of orthoimages.

2. Case Study

2.1. Area of study

The study site covers an area located on the eastern border of Egypt, along the coast of the Red Sea. It extendes from Ras Shuqayr to Ras Dibb. A main road passes from the northwest to the southeast of the study area, parallel to the Red Sea coast. Some secondary roads branch from it but do not extend deeply through the area of high elevations. Few buildings are found as summerhouses. Different terrain slopes are involved in the study area with variations in elevation up to 230 meters.

2.1.1. Images

Two panchromatic SPOT images are used as a stereo-pair. The processing level of both images is 1A. Table 1 summarizes the technical characteristics of the images. These images provide a base to height ratio of 0.82 and the overlap coverage is about 90% between them. A subscene of the left image is shown in fig. 1.

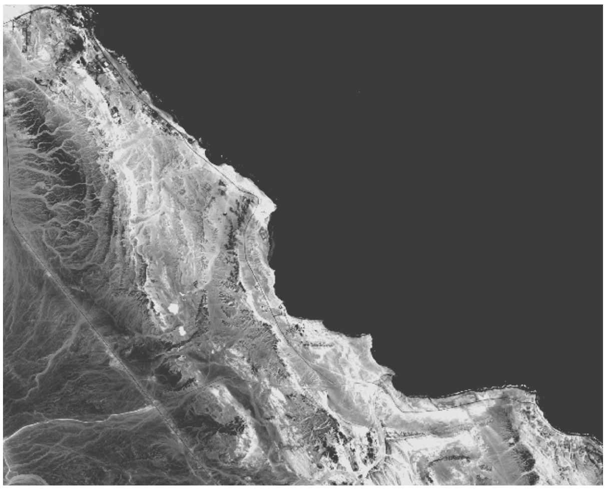

Fig. 1. SPOT subscene of the study area.

2.1.2. Reference data

Two topographic map sheets of scale 1:50,000 were used to determine the three dimensional coordinates of the ground control and check points. These maps were compiled from aerial photographs in 1988 by the Egyptian General Survey Authority (E.G.S.A) in co-operation with Finland. The map sheet numbers are NH36 C1b and NH36 C1a. Contours at 10-m vertical interval are also provided on the topographic maps. The reference ellipsoid is Helmert 1906 and the projection system is Transverse Mercator. The reference DTM was extracted from these map sheets by digitizing the spot heights and the contour lines. Fig. 2 shows the topographic map of the study area.

Fig. 2. SPOT subscene of the study area.

Table 1
Characteristics of the SPOT images

Item	Left image	Right image
Scene ID	S1H1 084937	S1H1 081841
Date of acquisition	13-7-1987	29-6-1987
Viewing angle	22° 02′ 13″	25° 57′ 46″
Sun azimuth	108° 51′	97° 26′
Sun elevation	74° 32′	68° 50′
Satellite height	828.7013 km	828.3628 km
Center latitude	27° 58′ 37″	27° 58′ 37″
Center longitude	33° 06′ 39″	33° 06′ 06″

2.2. Analysis

2.2.1. The mathematical model

The model of SPOT imaging system adopted in EASI/PACE software, OrthoEngine module was developed by the Department of Natural Resources in Canada, and then licensed to PCI through Canada Center for Remote Sensing (CCRS). This model is more complicated than that used for frame photographs because of the dynamic nature of SPOT imaging system rather than the static nature of the aerial or space photos [2]. The implemented model belongs to the physical reality modelling group. It is based on the well-known collinearity equations, which relate image and object coordinates of corresponding points through the perspective center of the imaging sensor. However, the collinearity equations were modified so that each parameter of the model is known by a mathematical formula derived using principles of photogrammetry, orbitography, geodesy, and cartography [3]. The parameters, therefore, are accurate reflection of the physical reality of the complete viewing geometry and represent all distortions generated during the scene acquisition time. These distortions include those due to the platform (position, velocity, and orientation), the sensor (orientation, and field of view), the Earth (rotation, curvature, ellipsoid, and relief), and the cartographic projection system [4].

Actually several unknown parameters were involved in this general model. This large number of unknowns is reduced by combining the correlated parameters resulting in a minimum of eight independent parameters per scene [5]. Therefore, the minimum required number of GCPs to relate the image space and object space coordinate systems is four points for each image.

The three dimensional coordinates of ground points were extracted from 1:50,000 map sheets. Each map was scanned with a resolution of 400 dpi, imported to the image viewer and then geocoded using the coordinates of the grid intersections. The coordinates of GCPs and check points were then digitized from the geocoded scanned maps.

The first input to perform the geometric correction of SPOT stereo-pair is the satellite ephemeris data (satellite position, inertial velocity, and rates of change of attitude) provided in the header file of each scene. The second input is the image space and object space coordinates of GCPs. 22 ground points were identified on both images. 12 of them were used as control points and 10 points were used as check points. The image coordinates were measured monoscopically on each image. Due to the lack of linear features in the study area, 39 tie points were also identified on both images and used along with the GCPs to construct the stereomodel.

The accuracy of the individual images of the SPOT stereo-pair, expressed as Root Mean Square Error (RMSE) of their residuals in term of their fit to the GCPs (modelling accuracy), and check points (restitution accuracy) are shown in table 2.

Table 2
RMSE of GCPs and check points for individual images in meters

		No. of pts	RMS (X)	RMS (Y)	RMS (P)
Left image	GCPs	12	8.45	4.16	9.41
	CKs	10	9.62	7.88	12.43
Right image	GCPs	12	7.55	5.55	9.37
	CKs	10	9.90	6.03	11.59

Table 3
RMS error of residuals of GCPs and check points of SPOT stereo-pair.

	No. of pts	RMS (X)	RMS (Y)	RMS (P)	RMS (Z)
GCPs	24	7.84	4.79	9.18	7.15
CKs	20	9.71	6.83	11.87	9.21

The results indicated that the modelling accuracy of both images is less than one pixel size of 10 m, while the average restitution accuracy is 12.01 m. This accuracy is acceptable for production and revision of topographic maps at scale 1:50,000. The accuracy in Y-direction is higher than that in X-direction which is due to the viewing geometry (push-broom scanner) of SPOT sensor. Table 3 summarizes the RMSE of residuals at X, Y, and Z directions of the stereo-pair. The results show a fairly consistent pattern with that of table 2.

2.2.2. Reference DTM

The Two maps of scale 1:50,000 were used to create the reference DTM. The three dimensional coordinates of spot elevations along with some points on the contour lines were digitized. This led to a random positioning DTM. A grided DTM with post spacing of 10 m was interpolated from random elevations. A wire mesh perspective view of the reference DTM is shown in fig. 3-a.

2.2.3. Automatic generation of stereo DTM

The epipolar images were first generated from the raw images and the orientation parameters. In epipolar geometry, the linearity of scan lines is preserved when pixels in the left image are transformed to their corresponding epipolar positions in the right image. This geometry ensures that the corresponding pixels on the two images are offset only in X-direction (direction of scan lines, perpendicular to the flight direction), and consequently limits the search for correlated matching points along the epiplar lines only [6].

The matching techniques of gray level values on the two images were then applied resulting in the parallax values of corresponding points which are converted to elevation values using the orientation parameters and the coordinates on the two images comprising the stereo-pair [7]. The coordinates of the upper left corner of the automatically created DTM is (128100, 895000), while the lower right corner has the coordinates of (146100, 880000). The post spacing of the stereo DTM is 10 m.

Inspection of the stereo-DTM revealed the necessity for interactive editing especially at the area where poor correlation occurred. To detect the areas where mismatching and blunders occurred, a wire mesh and contour lines for both the reference and stereo DTMs were generated and visually compared. The areas having significant elevation discrepancies were then detected and interactively edited. The elevation posts located in the Red Sea were all set to zero. Some areas, which appeared as sharp peaks or deep wells (concentric contours), were delineated and interpolated from the surrounding posts with correct elevations. The average filter was applied to smooth the terrain surface variations. A wire mesh of the edited stereo-DTM is shown in fig. 3-b.

The stereo-DTM was compared to the reference DTM in a post-by-post manner. The comparison is restricted only to the land area of the study site. This was achieved by creating a bitmap involving land area and discarding water posts located in the Red Sea. The total number of posts involved in the comparison is 1354150 posts. The discrepancies between corresponding post in the stereo and reference DTMs were determined and then the RMS of the elevation residuals was calculated according to the formula:

$$RMS(\Delta) = \left[\sum_{i=1}^{n} (\Delta_i)^2 \Big/ (n-1) \right]^{0.5} ,$$

where

Δ_i is the elevation residual of post (i), and

n is the total number of examined posts.

The obtained RMS of the elevation residuals is 12.57 m and 8.71 m before and after interactive editing, respectively. The maximum positive and negative residuals are found to be (+42.36m) and (–25.76m). A wire mesh of the residuals is also shown in fig. 3-c.

Note that 100 m is added to each elevation residuals of fig. 3-c to explore the negative residuals. In this figure, the elevation residuals range from 74.24m to 142.36m, which actually means from –25.76m to 42.36m. Fig. 3-c shows that the elevation residuals are random in both value and

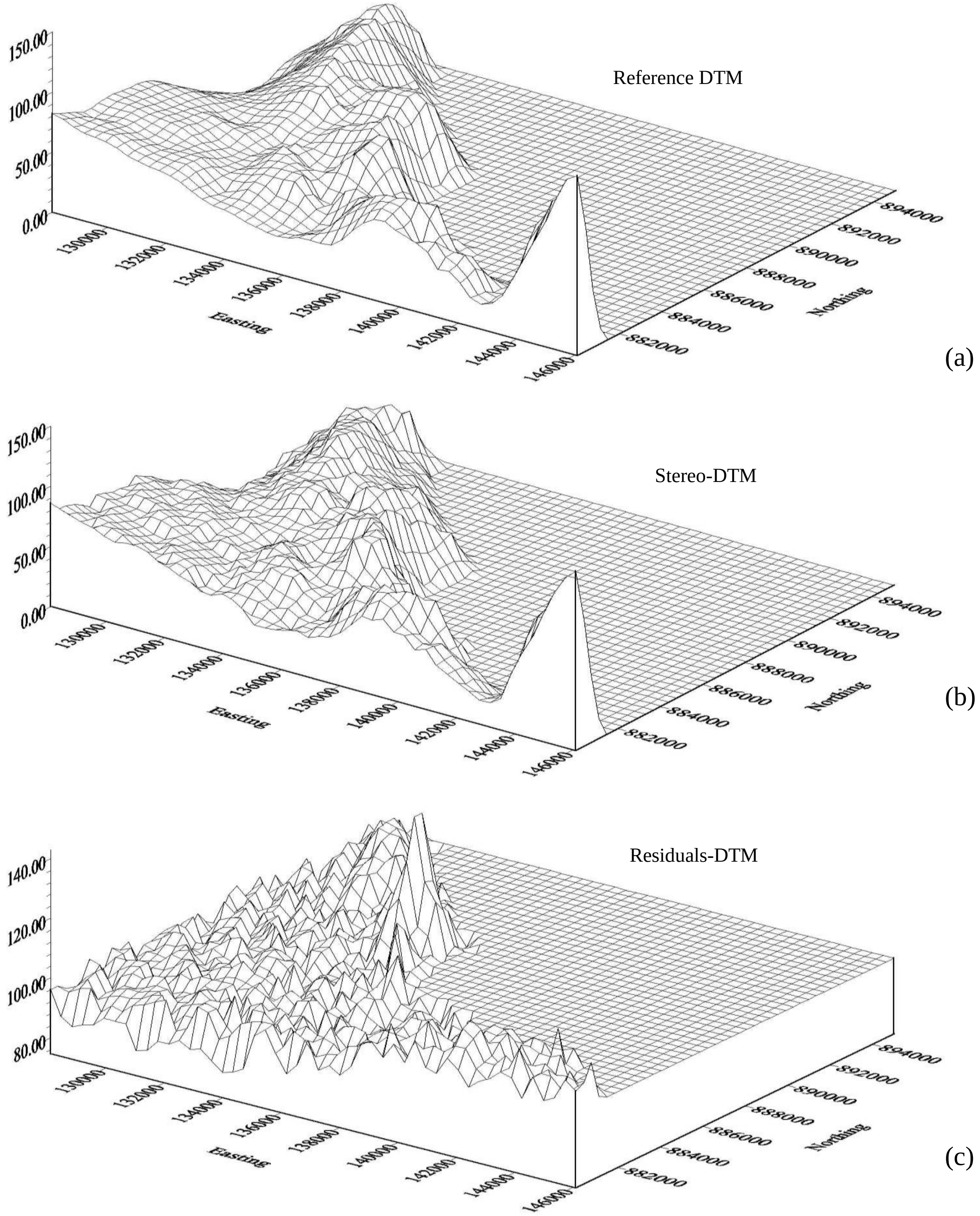

Fig. 3. Wire mesh of (a) reference DTM, (b) stereo DTM, and (c) residuals.

Table 4
RMS error of residuals of created orthoimages (meters)

	Ortho-reference DTM			Ortho-stereo DTM		
	RMS (X)	RMS (Y)	RMS (P)	RMS (X)	RMS (Y)	RMS (P)
Map 1:50,000	8.88	7.49	11.62	10.08	7.98	12.85
Ortho-ref-DTM				4.37	1.63	4.66

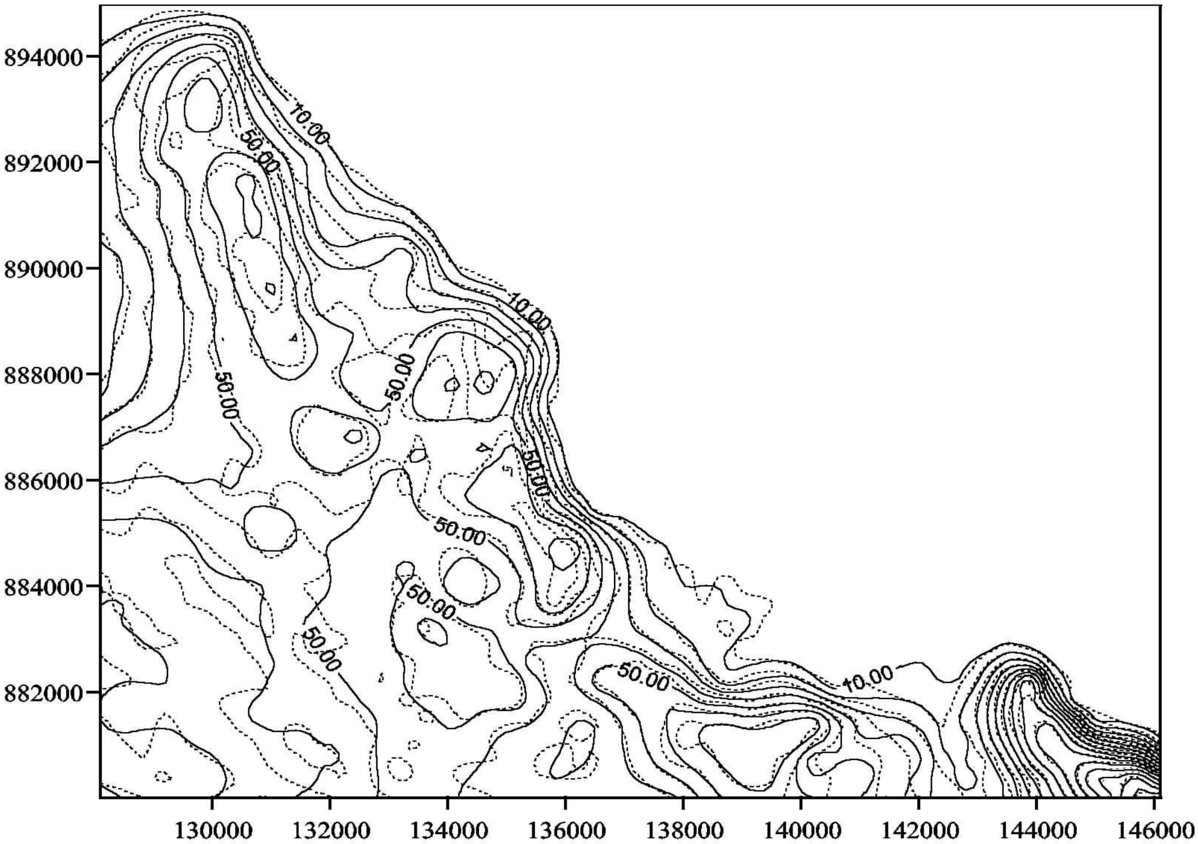

Fig. 4. Superimposed 10-m contours from reference and stereo DTMs.

direction. For comparison purpose, the contours derived from the stereo DTM were superimposed on those derived from the reference DTM as shown in fig. 4. They showed a good consistent agreement.

2.2.4. Production of orthoimage

One of the most important and popular photogrammetric products is orthoimages since they posses the information content of the original image and the geometric fidelity of the map as well. Today, production of orthoimages has become more commonplace due to the development of more powerful computers with sufficient resources, increased generation of digital data, development of many commercial orthoimage production systems, and new application areas, particularly in connection to GIS and digital mapping [8]. In this research two orthoimages have been created using the left-uncorrected image and either the reference DTM or the stereo DTM. To assess the planimetric accuracy, the coordinates of 26 ground points were measured and compared to their counterparts on the scanned maps of scale 1:50,000.

Moreover, the two created orthoimages were compared to each other. RMS of the coordinate residuals in X, and Y directions are summarized in table 4.

From table 4, it can be noted that RMS of easting differences is larger than that of northing differences. However, the planimetric RMS error is compatible for producing and updating topographic maps of scale 1:50,000. Comparison between the two created orthoimages revealed that accuracy of used DTM has more significant effect on the easting direction than that on the northing direction. This is due to the viewing geometry of SPOT sensor, which based on the linear push-broom scanner. Therefore, the relief displacement would be in the direction of scan lines.

3. Conclusions

Various stages of complete topographic mapping from SPOT stereo-pair have been described and implemented to a study site located along the Red Sea coast of Egypt. Different geometric information were extracted and the accuracy of each was assessed. The results proved the potential of SPOT imagery to produce and update topographic maps of scale 1:50,000 and smaller since the positional accuracy obtained is less than one pixel in both Easting and Northing directions. DTM can be automatically generated by area-based correlation matching techniques from SPOT stereo-pair, but the interactive editing is essential. Interactive editing has improved the accuracy of the automatically generated DTM by about 30 % (from 12.57m to 8.71m) expressed as RMS error of the elevation residuals.

SPOT-based orthoimage was created from SPOT raw data and SPOT DTM in a fully digital environment. The planimetric accuracy of the produced orthoimage, expressed as RMS error of residuals is 12.85 m. SPOT-based orthoimages have enabled the photogrammetric community to exploit not only the geometric but also the radiometric information contained in SPOT imagery for various mapping applications and integration with other geocoded databases.

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