

ACCURACY EVALUATION OF DEM GENERATED FROM SPOT5 HRS IMAGERIES

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ABSTRACT:

The present paper deals with the accuracy potential of SPOT-5 HRS satellite imageries for DEM generation. The goal is to derive a DEM from the along-track stereo data of the SPOT HRS sensor and to assess the accuracy by comparison with DEM data of superior quality. Following a brief description of the instrumentation and the data set used, the quality of the DEM generated from these imageries is assessed in several steps. For georeferencing of the stereo pair of images, some ground control points (GCPs), extracted from digital vector maps of the study area. A DEM of 10 meter grid size was generated from those images. And finally, the resultant DEM was compared with an existing and sufficiently accurate reference DEM of the study area. As can be seen below, the findings and results are very promising.

1. INTRODUCTION

DEM generation from satellite imageries scores over conventional methods of DEM generation, using topographic maps or aerial photographs. The global availability of satellite images allows for more quickly data processing for an equivalent area. In other words DEM generation using satellite images, draws continuous efforts mainly because of frequent imaging, global coverage and low cost. Though still lacking the accuracy and the amount of extracted information in comparison to the traditional aerial photogrammetry, the advent of ever higher resolution satellite images attempts to diminish the deficiency (Kim et al, 2001). In this regard, the present paper focuses on accuracy evaluation of DEM generated from SPOT-5 HRS satellite images. The derivation of terrain models from along track stereo data from space has up to now only been possible with the German MOMS-2P and the American ASTER sensor on TERRA (Reinartz, 2003). These sensors have lower resolution equal to 15-18 meter pixel size, but the new HRS sensor on SPOT-5 produces along track image stereo pairs with 5 meters ground sampling distance. This resolution is more suitable for obtaining higher accuracy in DEM generation process. In this study, an automatically generated DEM from a stereo pair of HRS images is compared with another reference DEM, generated from digital vector maps. In this way, the suitability of these images for DEM generation is investigated.

2. INSTRUMENTATION

SPOT-5 belongs to the latest generation of SPOT missions with significant improvements in terms of on-board instruments and autonomous system of positioning and attitude control that will enable high absolute location accuracy. HRS produces images with two optics looking forward and backward with 20 degrees with respect to the nadir direction. It has a spatial resolution of 10 meter across track and a ground sampling distance of 5m along track. The swath of the HRS is 120 km with 12000 CCD elements. Forward and backward acquisitions cannot be performed at the same time. As a consequence, the maximum stereo segment that can be acquired is a little bit more than 60 km. The size of pixels on the ground is 10m x 10m. However, HRS instrument has been designed for a ground sampling distance of 5 meters along the track. In a direction close to the

epipolar planes, this along-track over-sampling allows higher altimetry accuracy of the DEM to be obtained.

3. DATA USED

The study area (Rasht region) located in the northern part of Iran. It includes both mountainous and flat terrain, fully covered with vegetations in the non-urban parts. It is essential to test the performance over diverse terrains and different conditions for scene acquisition. In particular, the terrain slope may affect the performance of automatic DEM generation. The terrain slope causes the layover effect and distorts an image. Such a varying relief terrain, allows for a more realistic evaluation of the results. The following data were used for this study:

- 8 bit image data (size 12000 lines x 12000 pixels = 120 km x 60 km) of the study area from two viewing directions in TIFF format. The data have been acquired on 2002-07-13 with a sun elevation of 69 degrees and nearly no clouds.
- 1:25000 scale 3D map of the study area in digital format (Coordinate system: UTM; datum: WGS84).
- DEM of 10 meters resolution produced from 1:25000 scale topographic maps of the study area. These topographic maps were by Photogrammetric method using 1:40000 photographs in 1993 (Coordinate system: UTM; datum: WGS84). For the generated DEM, the RMSE of errors within 90% confidence level was found equal to 1.6 meters. This data is used as reference data for this accuracy assessment study.

4. PROCESSING STEPS

PCI Geomatica ver 8.2 was the main software package used for processing the data. In georeferencing step a total number of 99 ground control points (GCPs) were used for each image of the stereo pair. They were extracted from 1:25000 scale digital vector maps of the area. Also, to improve matching between stereo images, a total number of 100 tie points (TPs) were collected. Table 1 shows the accuracy results on these GCPs for each image. The distribution of GCPs and TPs in the two images has been shown in Figure 1.

		IMAGE 1	IMAGE 2
RMSE _x	Pixel	0.67	0.58
	Meter	6.6	5.69
RMSE _y	Pixel	0.63	0.57
	Meter	3.38	3.06
RMSE _{xy}	Pixel	0.94	0.81
	Meter	7.42	6.46

Table 1. The accuracy of GCPs for the two images

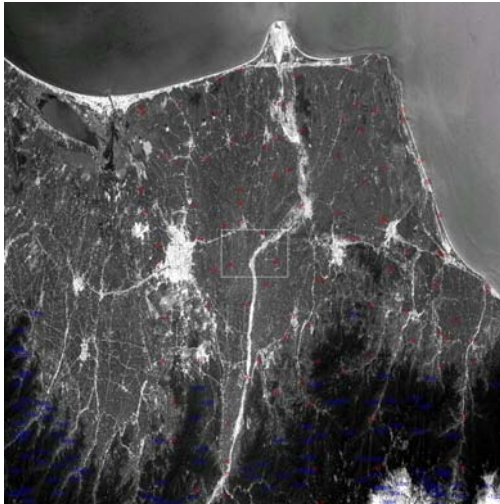


Figure 1. Distribution of GCPs and TPs in the image, the red point numbers are GCPs and the blue point numbers are TPs.

In the next step these two images were converted to epipolar projections. Epipolar projected images are required by the DEM generation routine, since it reduces the error between the stereo images in the y-direction, so that the stereo matching can be performed. Measured parallax differences on a pixel-by-pixel basis are converted to absolute elevations using trigonometric functions and the orbital data (orbital position, altitude, attitude and the scene center). The computation relies on the inherent parallax between stereo images (Siva Subramanian, 2003). An automated image correlation algorithm (Toutin, 1995) is used to derive elevations from the parallax, by a set of well located GCPs and tie points (TPs). The image matching technique operates on a reference and a search window. For each position in the search window, a match value is computed from gray level values in the reference window. The match value is computed with the mean normalized cross-correlation coefficient and the sum of mean normalized absolute difference (Marra, 2001). Elevation points are extracted at every pixel. The 3-D intersection is performed using the computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to the three dimensional data. The output elevations are not computed for the pixels where the image matching fails to find the corresponding pixel in the reference image, resulting into some failure areas. In case of small and scattered failures the software does interpolate and compute most probable values for them. The generated DEM is in raw format and does not contain georeferencing information. So, the DEM needs to be georeferenced by using GCPs. The workflow of these steps for generating DEM from HRS stereo images has been shown in Figure 2.

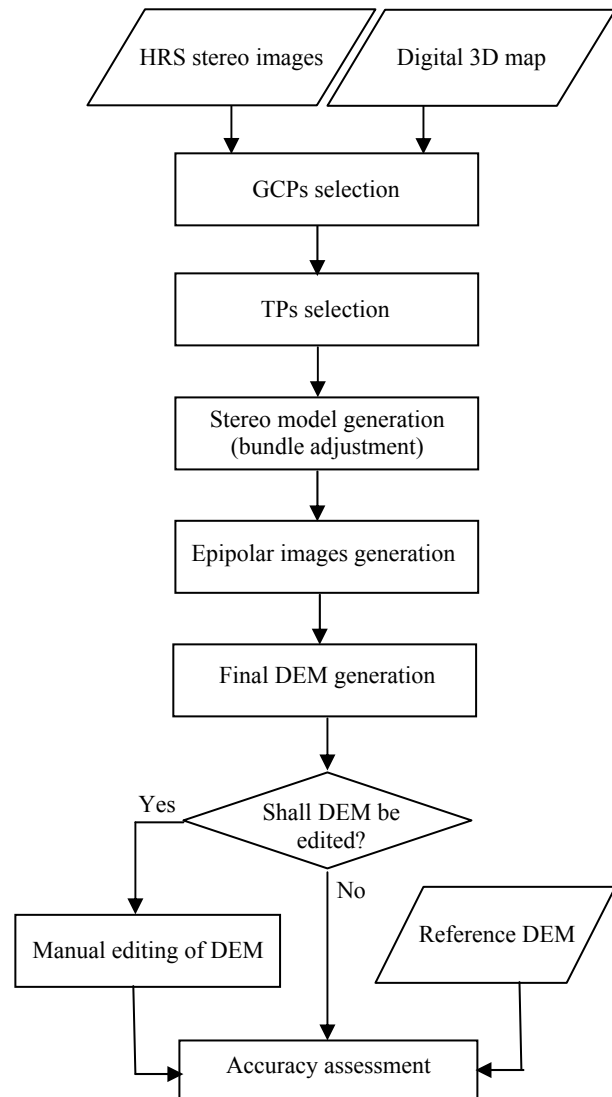


Figure 2. The work flow of DEM generation

In this study, a DEM of 10 meter grid size for the whole area was generated using OrthoEngine module of Geomatica software. Lots of empty patches were found in the generated DEM, especially in forest areas, due to matching failures. Some 100 tie points were collected but it could not significantly improve the quality of generated DEM. Because there are lots of forest regions in these images, lots of empty patches exist in the extracted DEM. Then, a 60Km by 25Km subset of the whole area was selected for quality assessment of the generated DEM. This subset contained fewer empty patches and covered a rather hilly terrain with height difference of about 350 meter. This subset is shown in the Figure 3.



Figure 3. The subset of extracted DEM with less failing areas

5. ACCURACY ASSESSMENT

As reference data, an existing 10 meter resolution DEM of the study area, which was produced from 1:25000 scale digital vector maps, was used. The heights of some 97 points were extracted from the generated DEM and compared with their correspondings in the reference DEM. Number of test points (n) selected for this assessment was determined by Equation 1.

$$n = \frac{NZ^2 pq}{Nd^2 + Z^2 pq} \quad (1)$$

where N = total number of population elements
Z = confidence level
d = needed accuracy

In this equation n is number of test points and N is total number of population elements that in this case is infinite. Z is the value corresponding to confidence level and d is the needed accuracy. The value of p is proportion of elements that have especial characteristic and q is the other elements without this characteristic (p = 1- q). In the case of infinite number of population elements, number of samples for accuracy assessment is determined with Equation 2.

$$n = \frac{pqZ^2}{d^2} \quad (2)$$

For example by assuming p = 0.50 and d = 0.10 and confidence level equal to 95%, n would be equal to 97. These points have been generated from production of some random numbers with uniform distribution as x and y coordinates. Since the chance of selection of each number must be equal to the others, the uniform distribution was applied. For computing the accuracy of extracted DEM from stereo images, first the subset of generated DEM without any editing with interpolation was evaluated. Some points that posed in failing area were eliminated from points list. The preliminary statistics of this test are as Table 2.

Number of check points (CPs)	97
Mean of errors (absolute values)	3.87 m
Mean of errors	1.31 m
Maximum error (absolute value)	21.00 m
Standard deviation of errors	5.32 m
Frequency of errors	dz >1m n=89 91.8% dz >2m n=67 69.1% dz >3m n=48 49.5% dz >4m n=39 40.2% dz >5m n=33 34.0% dz >6m n=20 20.6% dz >7m n=17 17.5% dz >8m n=14 14.4% dz >9m n=11 11.3% dz >10m n=08 08.2%

Table 2. The statistics of DEM test without editing

Also, the subset of extracted DEM with editing of failing area with interpolation was assessed with 97 points. Then some

points that posed in failing area were assessed with height produced from interpolation. The statistics of this test are as Table 3.

Number of check points (CPs)	97
Mean of errors (absolute values)	3.94 m
Mean of errors	0.85 m
Maximum error (absolute value)	13.00 m
Standard deviation of errors	4.89 m
Frequency of errors	dz >1m n=87 89.7% dz >2m n=73 75.3% dz >3m n=62 63.9% dz >4m n=48 49.5% dz >5m n=36 37.1% dz >6m n=27 27.8% dz >7m n=18 18.6% dz >8m n=12 12.4% dz >9m n=06 06.2% dz >10m n=04 04.1%

Table 3. The statistics of DEM test with editing

For better investigation of this product, the whole of the region without any editing was also evaluated with some random points. Some points that posed in failing area were eliminated from points list. The results of this test were shown in table 4.

Number of check points (CPs)	97
Mean of errors (absolute values)	2.67 m
Mean of errors	0.53 m
Maximum error (absolute value)	16.00 m
Standard deviation of errors	3.99 m
Frequency of errors	dz >1m n=76 78.4% dz >2m n=53 54.6% dz >3m n=38 39.2% dz >4m n=28 28.9% dz >5m n=17 17.5% dz >6m n=12 12.4% dz >7m n=08 08.2% dz >8m n=07 07.2% dz >9m n=04 04.1% dz >10m n=04 04.1%

Table 4. The statistics of DEM test without editing

Finally, the whole extracted DEM with editing of failure area with interpolation was assessed with 97 points. Some points that posed in failure area were assessed with height produced from interpolation. The statistics of this test are as Table 5.

Comparing table 2 and table 3 shows that the standard deviation of the subset of extracted DEM with editing of failing areas is better than the standard deviation of the subset of extracted DEM without any editing. That is because of production of more suitable heights using interpolation of neighboring heights in failing areas. In the subset of extracted DEM, some small and

scattered failing area exist that can be interpolated well with close pixels.

Number of check points (CPs)	97
Mean of errors (absolute values)	26.08 m
Mean of errors	17.98 m
Maximum error (absolute value)	108.00 m
Standard deviation of errors	37.31 m
Frequency of errors	dz >1m n=92 94.8% dz >2m n=81 83.5% dz >3m n=75 77.3% dz >4m n=69 71.1% dz >5m n=60 61.9% dz >6m n=58 59.8% dz >7m n=52 53.6% dz >8m n=50 51.5% dz >9m n=44 45.4% dz >10m n=43 44.3%

Table 5. The statistics of DEM test with editing

But comparing table 4 and table 5 doesn't show this improvement because in the case of the whole extracted DEM the failing areas are very wide and numerous. Extraction of true heights for these areas from neighboring pixels is very hard and then some false heights are produced in these areas. Existence of these heights in edited DEM and thereby in selected points is the reason of large standard deviation in the whole edited DEM. In general above experiments show that for generated DEM, the RMSE of errors within 95% confidence level was found nearly equal to 4.89 meters. Naturally this value for RMSE is produced in areas that image matching is executed well and forest areas have a little extent. In images with large forest areas where the image matching fails to find the corresponding pixels in large areas, interpolation is not a good way for DEM editing and RMSE is not a satisfied result.

5. CONCLUSION

Creating Digital Elevation Model by digitizing contour lines from topographic maps or through stereoscopic semi automated methods from aerial photographs are proven methods. However, DEM generation from satellite stereo images is still not a common practice. The DEM generated from satellite stereo pairs have some significant advantages over other sources, viz:

1. World wide availability of satellite data without any restriction (often available as archived data) as against restricted and non availability of topographical maps and aerial photographs
2. Large area coverage per scene
3. Moderately high resolution
4. Faster processing through sophisticated software and little manual effort
5. Low processing cost

Comparing some other studies reveal that of the different image pairs processed, this SPOT HRS images yield the better results. Kim and Kang produced a DEM from SPOT panchromatic stereo images with RMSE equal to 12.4 to 14.4 m (Kim, 2001). Also with KOMPSAT images with 6.6 m resolution the DEM extracted was produced with RMSE equal to 8-13 m (Kim, 2001). In the same area using SPOT images with 10 m

resolution one DEM with 32 m RMSE was extracted (Kim, 2001). Comparing the ability of DEM extraction from some images showed that using ASTER, Radarsat, IRS-1c and SPOT images with 15, 12.5, 6 and 10 m resolution RMSE equal to 30, 65, 35 and 32 m were produced (Siva Subramanian, 2003). There are some reasons for these results. The results of SPOT-5 are better because the temporal difference between the stereo pair is only a few seconds, whereas some pairs acquired through other satellites require a larger time cycle. Results also show that matching is good in case of the images with this condition due to short temporal differences. On the other hand the proper b/h ratio yields more consistent and better results over various terrains. The other reason is better resolution of these images in comparing with the others.

This study shows that SPOT-5 HRS stereo images have a good potential for DEM generation.

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