# A METHOD FOR THE IMPROVEMENT ELEVATION DATA GENERATED FROM AUTOMATED PHOTOGRAMMETRIC METHODS INTO SIS

A.M. Felicísimo [a], A. Cuartero [a], F.J. Ariza [b]

[a] Dept. of Graphic Expression, Extremadura University, 10071 Cáceres , Spain. acuartero@unex.es amfeli@unex.es
[b] Dept. of Cartography, Geodesy and Photogrammetry Engineering, University of Jaén, 23071, Jaén. Spain
fjariza@ujaen.es

**Commission VI, WG VI/4**

**KEY WORDS:** DEM, Stereoscopic, Matching, Correlation, Accuracy

**ABSTRACT:**

DPW generates DEMs with very large storage volumes may require quite large computation loads. Then its integration into a SIS may lead to conflict between these huge data sizes and the operations of analysis, mapping algebra, simulation, etc. It would clearly be advisable therefore to avoid a blind inclusion of all of the data derived from the photogrammetric process, and only to take those which are both, of good quality and significant in representing the relief. By eliminating poor quality data, one will improve the model's accuracy, and by eliminating unnecessary data one will reduce the redundancy, the data volume and the computational loads. Those effects will improve the efficacy of the SIS or GIS, in which the DEM is just been integrated.

We propose, and analyze, a method based on a single and objective criterion designed to generalize DEMs by the way of data redundancy removal with no appreciable loss of accuracy. The criterion is to state a correlation threshold for the correlation values that the DPW assigns to each point of the DEM, so that points which correlation values are below the threshold will be rejected. For several DEMs we checked the resulting accuracy against a set of more than 7000 ground control points measured using differential GPS techniques obtaining satisfactory results

## 1. INTRODUCTION

The digital photogrammetric workstation (DPW) introduced major changes into the flow of tasks in analytical photogrammetry. One of these changes was the possibility of automating part of the steps of the photogrammetric process itself. For instance, automation allows one to construct DEMs with an almost arbitrarily large density of points. In the manual process, however, it had been necessary to make a preliminary selection of only those points that the operator interpreted as significant in describing the relief (these were called VIPs, very important points).

Due to this very high density of points, DPW-generated DEMs may attain quite massive computational sizes. Then their integration into a geographic information system (GIS) may lead to conflict between these huge data sizes and the operations of analysis, mapping algebra, and simulation. It would clearly be advisable therefore to avoid a blind inclusion of all of the data deriving from the photogrammetric process, and only take those which are both of good quality and significant in representing the relief. By eliminating poor quality data, one will improve the model's accuracy, and by eliminating unnecessary data one will reduce the redundancy. Both effects will improve the efficacy of the characteristic operations of the GIS, in which the DEM is just one more of the variables to be considered.

To carry out such a cleaning up process, one needs an objective criterion for the selection of which data to keep and which to discard. DPWs generate a correlation value for each point of the DEM. This value depends on the success of the stereo-matching operations used to estimate the parallax from which the elevation is calculated. It is to be expected a priori that high correlations correspond to more reliable points, whereas keeping points with low correlations could introduce errors.

We here analyse the efficacy of a method of selecting reliable points on the basis of their correlation values. We evaluate the error of the DEM as points are eliminated and determine the threshold separating reliable points from those of high uncertainty. This process of simplification allows one to "lighten" the data structure, making it better adapted to integration in a GIS.

## 2. BACKGROUND

Constructing a DEM on the basis of correlation methods usually gives better results than using conventional analytical techniques. Ackerman (1994) studied the case of aerial photograms, finding that the precision of the parallax depends on the stereo-correlation technique: 0.1-0.2 pixels with least squares matching (LSM) and 0.3-0.4 pixels with feature based matching (FBM).

Dependence on analogue aerial images was formally broken in 1980 when the American Society of Photogrammetry and Remote Sensing (ASPRS) included the possibility of using digital data from remote sensing in its definition of photogrammetry (Slama, 1980). The techniques of photogrammetric restitution have been known for decades, but the possibility of using satellite images did not arise until 1986 with the launch of the first of the SPOT series satellites. The work of Priebbenow & Clerici (1988) dealt with the cartographic utility of panchromatic SPOT images, whose 10 m pixel size was compatible with a 1:50 000 scale. Mukai et al. (1989) studied the generation of DEMs from the overlap zones of contiguous Landsat-TM images. The estimated RMSE with 60 ground control points was 92 m, approximately thrice the pixel size. An identical study performed with panchromatic SPOT images of Japan's Central Alps (Mukai et al., 1990) gave RMSE values of 26 m with 40 ground control points taken from pre-existing 1:25 000 maps. Sasowski & Petersen (1992) carried out the same test for a zone of Alaska. They obtained a

RMSE of 19 m and a non-zero mean error, indicative of a systematic bias in the DEM. They did not use ground control points to control the error, but constructed another DEM from conventional maps with 5 m contour intervals.

The more recent literature reports similar findings, so that there seems to have been no influence of the steady improvement of the stereo-matching algorithms or the development of specific SPOT-image modules designed to take into account the information of orbital parameters, image capture angles, etc. Hae-Yeoun et al. (2000) obtained RMSE values of 25.5 m and 33.6 m according to the study area: their controls were made by comparison with other DEMs of 100 m (DTED, USA) and 60 m (Korean National Geographic Institute) resolution.

The best results are those reported by Al-Rousan & Petrie (1998). They generated DEMs in a single desert zone of north-eastern Jordan with different commercial program suites, and obtained variable error values depending on the accuracy of the images and on the programs used. The RMSE ranged in value from 3.3 to 6.7 m. The number of ground control points was also variable, ranging from 10 to 47. It was not possible in their work to deduce the type of relief of the terrain, possibly because of the size of the error.

Table I shows a set of significant examples about accuracy in SPOT-DEM. We can see that RMSE values are not comparable, varying from 3.2 m (Toutin, 2002) to 33 m (Hae-Yeoun, 2000). The number of declared check points is also very different, from 6 to 40, but many authors do not provide information about this issue. Also, other aspects that may be crucial, such as the terrain topography, remain unknown.

There are some common problems in using digital stereoscopic pairs, e.g., the difficulty of identifying the ground control points, and the frequent radiometric differences between the two images. These differences arise because the left and right components are usually taken on different days, and the light conditions may change (Baltsavias & Stallmann, 1993). Nonetheless, there are many works which lend support to the quality of the results of using this type of data, due to their wide coverage and good temporal resolution.

| Date | First Author | RMSE[a] (m) | Method [b] |
|---|---|---|---|
| 1988 | Priebbenow | 5.4 | |
| 1990 | Mukai | 26 | 40 CPs extracted from cartography 1/25000 |
| 1992 | Sasowki | 19 | Comparison with DEM generated from cartography 1/5000 |
| 1998 | Al-Rousan | 3.3 and 6.7 | |
| 2000 | Hae-Yeoun | 25.5 and 33.6 | Comparison with DEM of 100 m and 60 m of resolution |
| 2002 | Toutin | 3.2 | 6 CPs from DGPS |

[a] Root Mean Square Error.
[b] Method which has been calculated the root mean square error (RMSE) in elevation of DEM. When method is hole paper no specify it.

Table 1. Some works about SPOT-DEM accuracy determination

Once these problems that are inherent to the photogrammetric process have been overcome, the resulting DEMs have to integrated into a GIS. In a literature search, we could find no references to possible optimization strategies for this phase of the process, in which one would like to guarantee the elimination of redundant and, in so far as possible, erroneous data. In earlier work, we have studied this latter part in some detail (Felicísimo, 1994; López, 2000), so that the present study will focus on the selection and control of the points which are to be kept in the data structure that will be integrated into the GIS.

## 3. OBJECTIVES

This paper aims to:

- To analyse the DEM accuracy genereted by automatic stereomatching techniques from SPOT-HRV images by different photogrammetric softwares (OrthoBase PRO, Socet Set) and to compare results each other and whith a DEM generated from cartographic data. It is emphasized that, to guarantee reliable error control, it is necessary to have sufficient well distributed, and highly accurate, ground control points available.
- Propose a method of improvement for the structure of DEM without a loss in accuracy. This process of simplification enables the data structure to be better adapted for integration in a GIS.

The working hypothesis is that the correlation coefficient associated with each elevation datum may be used to determine whether that datum should be kept or discarded, thereby simplifying the TIN structure without significant degradation of its quality. The actual loss of quality of the DEM will be checked against a large number of ground control points measured with high-precision GPS techniques.

## 4. MATERIAL AND METHODS

### 4.1 Area under study

Work area is a 23 km x 28 km rectangle in the province of Granada (Southern Spain) (Fig. 1). It is an area with a complex topography: Steep slopes in the South and flat surfaces in the North. Elevations are in the range 300-2800 m with an average of 1060 m.

### 4.2 Data

We have used two panchromatic SPOT-HRV images with 10 m pixel size. The images were taken on the days 2-11-1991 and 2-01-1992, and cover a total area of 60 km x 60 km.
Error estimation was performed using 315 check points to calculate all SPOT-DEM errors and 7071 check points to stydy the method of improvement. These check points have taken with differential GPS techniques.

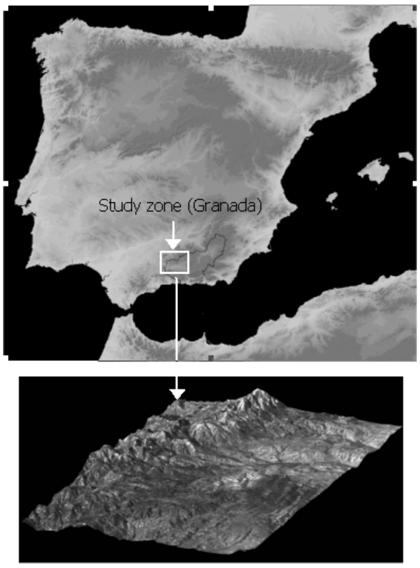


Figure 1. Study area
(SPOT image dropped over DEM).

### 4.3 Sofware

SPOT-HRV data were processed two photogrammetric aplications: Socet Set (Bae Systems) and OrthoBase Pro (Erdas Imagine). The rest of the procedures were carried out using the GIS, ArcView 3.2, with the modules 3D Analyst and Spatial Analyst (ESRI, 1998).
The photogrammetric applications only variying characteristics are commented below.

- **Socet Set (Leica Geosystems)**
  Socet Set allows work with a specific module for SPOT data. The DEM may be generated as either a TIN or as a raster Uniform Regular Grid, or URG.

- **Erdas Imagine 8.5 with OrthoBASE Pro**
  OrthoBASE Pro has a specific module to work with SPOT data, but ASTER is only supported by means a generic module introducing the values for angles, B/H ratio, etc. The DEM may be generated only as a vector structure, a Triangulated Irregular Network or TIN.

### 4.4 DEM generation: extraction of elevations

In the photogrammetric process, the stereo-matching consists basically of locating homologous points in the images. In the fit to the SPOT images, RMSE values of 0.5 pixels may be attained from a small number of ground control points as long they are appropriately distributed spatially. The process has a relatively high precision since the collinearity equations allow one to obtain a direct relationship between the coordinates of the image and the object. One thus obtains the relative orientation and the model coordinates, and the calibration parameters may be included in the reduction of systematic errors. The Socet Set application used performs the orientation of a stereoscopic SPOT pair with the module MST (Multisensor Triangulation), and the identification of homologous points can be performed by area based matching.

The elevation was calculated using an iterative algorithm which begins with the top level of the image pyramid (that of poorest resolution), and advances to the highest image resolution. The DEM may be generated as either a vector structure - a triangulated irregular network, TIN (Peucker et al., 1978) - or as a raster structure - a uniform regular grid, URG. The latter does not require the position to be stored since it is implicit in the structure itself. The TIN structure may be adapted to the type of relief, i.e., to changes in the topography of the surface. We constructed a URG-DEM and chose a pixel size of 20 m. The automatic extraction of DEM is facilitated if the specific sensor model information is available.

In order to guarantee the best possible DEM that can provide SPOT-HRV images, we have analyzed the influence of some aspects, such as number and spatial distribution of GCP, the data structure (TIN or URG), and the sample interval; depending on the software used, the algorithms and correlation coefficient threshold can also be tested.

We have conducted several experiments to determine the optimal value of influential aspects (Table 2). We constructed ninety SPOT derived DEM (see the results section, Table 4) .

| Test | Variable analyzed | Range of values | Nº of DEM by SocetSet | Nº of DEM by OrthoBase |
|---|---|---|---|---|
| 1 | number of CP [a] | 5…20 | 16 | 16 |
| 2 | distribution of CP [a] | 4 distributions | 4 | 4 |
| 3 | data structure | TIN [b] / URG [c] | 2 | 2 |
| 4 | size of grid | 100, 80, 60, 40, 20, 15, 10 m | 7 | 7 |
| 5 | algorithm of matching | several | 2 | 12 |
| 6 | coefficient of correlation | SocetSet: 0.5…1 OrthoBase: 0.6…0.95 | 11 | 8 |
| | | | **42** | **49** |
| | | DEMs generated: | **91** | |

[a] Control Points.
[b] Triangulated Irregular Network.
[c] Uniform Regular Grid.

Table 2. DEM generated from SPOT-HRV images.

### 4.5 Accuracy and realibility

DEM accuracy is estimated by a comparison with DEM Z-values, and by contrasting many check points with “true” elevations. The pairwise comparisons allow the calculation of the Mean Error (ME), Root Mean Squere Error (RMSE), Standard Deviation (SD) or similar statistics.
It’s obvious that reliability in the process is not a constant but depends on several factors. The number of chek points is an important factor in reliability because it conditions the range of stochastic variations on the SD values (Li, 1991). Another factor is obvious: The accuracy of check points must be sufficient for the control objectives.
The estimate of errors in DEM is usually made by following the USGS recommendation of a minimum of 28 check points. Li showed, however, that many more points are needed to achieve a reliability closer to what is accepted in most statistical tests. The expression that relates reliability to number of check points is:

$$R(e) = \frac{1}{\sqrt{2(n-1)}} \times 100\% \quad (1)$$

where R(e) represents the confidence value in % and n is the number of check points used in the accuracy test. Figure 2 shows realiability evolution versus the number of check points used according the equation 1. As an inverse example, if we wish to obtain a SD confidence value of 5%, we need about one hundred check points. If we used 28 check points, we would reach a 20% confidence value.

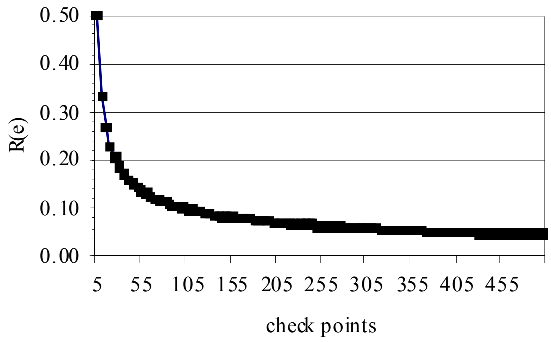


Figure 2. *R(e)* values versus the number of check points according the Equation 1.

Therefore, the number of check points must guarantee stability in error estimates. Revised research is rather heterogeneous regarding number and accuracy of check points, and no author has verified reliability in of these results.

Most research used a number of check points that proved clearly insufficient for guaranteeing the validity of error results. One article explained the use if check points from pre-existing cartography; this procedure is not recommended, as there tends to be no knowledge about the control map quality itself. Methods based on GPS constitute the ideal source to obtain these points, since they yield the coordinates with great accuracy, and also allow to plan a spatially well-distributed sample covering the whole area under analysis.

### 4.6 The DEM depuration procedure

As was indicated above, the DPW adds to each estimated elevation datum a value for the correlation coefficient. These values can be regarded as metadata, being estimators of the reliability of the elevation calculated at each point. The elevation and correlation data were exported as text files, and then integrated into ArcView, since this GIS is not able to read the TIN generated in Socet Set directly. The TIN was then generated in ArcView using the points as the vertices of triangles in a massive triangulation procedure.

This huge DEM (with no points yet eliminated) was denoted MDE00. The other DEMs were generated by previously eliminating those points whose correlation coefficient was less than one of a set of threshold values. For example, MDE50 was the result of the threshold 0.50 for the correlation coefficient (Table 3).

For the calculation of the accuracy, we used a set of 7071 randomly distributed ground check points whose coordinates were determined by differential GPS techniques. We then determined the difference between these points and the elevation values of the DEMs, and estimated the mean error (ME), standard deviation (SD), and root mean square error (RMSE).

| DEM name | Threshold value | No. points | % points |
|---|---|---|---|
| MDE00 | none | 2 204 906 (all) | 100 |
| MDE50 | 0.50 | 1 946 805 | 88 |
| MDE75 | 0.75 | 1 634 059 | 74 |
| MDE80 | 0.80 | 1 457 043 | 66 |
| MDE85 | 0.85 | 1 194 227 | 54 |
| MDE90 | 0.90 | 810 394 | 36 |
| MDE91 | 0.91 | 716 759 | 32 |
| MDE92 | 0.92 | 617 733 | 28 |
| MDE93 | 0.93 | 514 095 | 23 |
| MDE94 | 0.94 | 407 005 | 18 |
| MDE95 | 0.95 | 199 745 | 9 |

Table 3. Depuration of DEM-SPOT by change in threshold correlation values.

To ensure error reliability, we used a set of 7071 randomly distributed check points whose coordinates were determined by DGPS techniques. The transformation between the WGS84 and the UTM local system was achieved by a Helmert transformation with parameters derived from observation measurements. These involved between 60 and 90 minutes at five geodetic vertices around the area, with errors inferior to 0.01 m. After the geodetic frame was determined, and the GPS processing of the check points adjusted, we were able to calculate the difference between these points and the elevation values of the DEM, and estimate the mean error, standard deviation, and RMSE.

## 5. RESULTS

### 5.1 DEM-SPOT accuracy and reliability

We constructed 91 from SPOT images. Tables 2 outline the different experimental tests. Optimal findings include:

- Erdas Imagine generates the most accurate SPOT-DEM (7.7 m RMSE) as a TIN structure, using 14 ground control points, a 9x9 correlation window, and using a threshold correlation value of 0.65.
- Socet Set obtains the best SPOT-DEM (8.6 m RMSE) as a URG structure (20 m cell size), and using 13 ground control points. Socet Set allows selection from several matching algorithms, and the result was more positive by using an 'adaptive' algorithm instead of the specific algorithm included for SPOT data.

A synthesis of the results is given in Table 4, which lists the values of the mean error (ME), standard deviation (SD), its confidence interval (CI=95%, $\alpha$=0.05), and RMSE.

In our case, the availability of 315 check points enabled the error control to have a reliability of 96%. This value allows the RMSE confidence limits to be calculated for each DEM. Furthermore, for a comparative analysis, we calculate error statistics for a DEM generated from conventional cartographic 1:25.000 data.

Based on the results obtained in this study, the generation of DEM from SPOT-HRV stereo-images can be done with methods of digital restitution, leading to RMSE values less than the pixel size. The sampling interval is one of the factors that influences the quality of the DEM: The best results are obtained for a cell size twice the pixel size (i.e., 20 m from SPOT-HRV). Increasing of this distance among sampled points is not a good strategy because it is equivalent to a progressive generalization of the DEM structure.
The influence of software is not obvious from the experiments carried out. The accuracy of SPOT-DEM is similar for both Erdas and Socet Set.
Finally, SPOT-DEM have been compared with the DEM generated from a topographic map at a 1:25.000 scale. This process implies the comparison of 2.200.000 points.
Comparing DEM was done by means a simple difference map algebra operator. Table 4 shows the basic statistics. The accuracy statistics of the cartographic DEM are similar to those of SPOT-DEM. Comparing DEM was done by means a simple difference map algebra operator. We can observe the small differences in SPOT-DEM and cartografic DEM.

| Source data | Software | Error (m) | | | |
|---|---|---|---|---|---|
| | | ME [a] | RMSE [b] | SD [c] | CI [d] |
| SPOT-HRV | Ortho Base | 1,5 | 7,7 | 7,4 | ±0,6 |
| | Socet Set | -4,6 | 8,6 | 7,3 | ±0,6 |
| Cartographic | | -1,1 | 7,9 | 7,8 | ±0,6 |

[a] Mean Error
[b] Root Mean Square Error
[c] Standard Deviation
[d] Confidence Interval for SD (95%)

Table 4. Error statistics for DEMs

### 5.2 DEM depuration results

We have conducted the depuration process based on the hypothesis of a certain correspondence between correlation and data reliability: The presence of a low correlation value is not a definitive proof of poor quality, but is a valid warning signal and has statistical significance. If this hypothesis is true, we can carry out a cleaning procedure of the potential inaccurate points without a significant loss of quality.

Figure 3 shows the errors of the depuration of the DEMs as a function of the chosen correlation coefficient threshold. The huge DEM (with no points yet removed) was denoted as MDE00. Other DEM were generated by previously deleting those points whose correlation coefficient was less than a threshold value (Table 3). For example, MDE50 was the result of taking a threshold value 0.50 for the correlation coefficient.
It can be noted that error did not rise significantly when the number of eliminated points is increased, at least until a correlation threshold of 0.93 (standard deviation, SD=7.9) or 0.94 (SD=8.0) is reached. On moving to 0.95, the quality of the DEM significantly dropps (SD=12.2). MDE94 contains only 18.5% of the points of the massive original DEM (MDE00), while the MDE93 contains 23%.

We emphasize that the depuration process does not imply an improvement in accuracy statistics, but it contributes to making the structure much more manageable in a GIS environment.

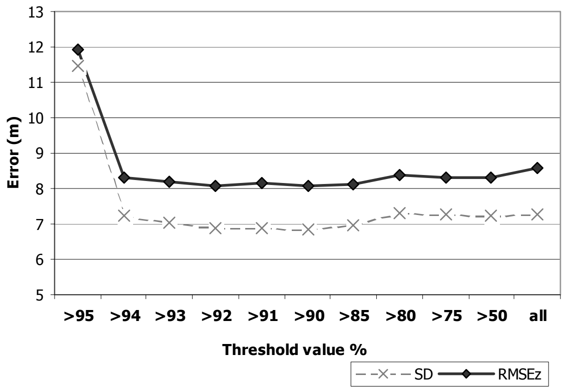


Figure 3. Errors in the DEMs according to the threshold value of the minimum acceptable correlation coefficient (test of 315 CPs). It's possible to reduce the initial TIN to only 19% of the points without any statistically distinguishable loss of quality.

## 6. CONCLUSIONS

Automated DEM extraction using cross-track SPOT satellite, has been known for 17 years. We concluded that SPOT images will provide the opportunity for the generation of DEM with RMSE Z-values less than the pixel size. We cannot conclude that the accuracy results are affected by other factors.

Digital photogrammetric procedures generate points which, in certain conflictive zones, may not be very reliable. These zones are characterized by low correlation values due to the radiometric differences between images or because they are in the shade where the stereo-matching algorithms do not work correctly. The presence of a low value of the correlation is not a definitive proof of poor quality, but it is a warning signal. Occasionally the converse may be the case: the existence of a high value for the correlation may be accidental. The usual case, however, is for a certain correspondence between correlation and quality of the data.

Hence, the depuration of a DEM by means of threshold values of the correlation coefficients seems to be a simple but effective way of reducing the size of the data structure without significant loss of quality. The tests that we performed supported this hypothesis, and in our working zone we were able to reduce the initial TIN to only 19% of the points without any statistically distinguishable loss of quality.

It is to be expected that the optimal correlation threshold will depend on such factors as the radiometric quality of the images, the geometrical resolution, and even on the stereo-matching algorithms used in the DPW. Since quality control procedures are always required, however, it is not any great extra burden to carry out the type of tests described in the present work in order to "lighten" the DEM before it can be regarded as a finished product.

One of the problems that can arise is the deficient localization of the ground control points. While these points should be spread out over all types of relief, the usual case is to take them in the more readily accessible zones. Such deficient sampling can interfere with the results of the tests. It is also important to have a sufficiently large number of ground control points available so as to obtain adequate reliability values. The more than 7000 ground control points used in the present work represent a sufficient gurantee in this sense.

We emphasize the obligatory use of many accurate check points. The use of a very limited number of points implies a very unreliable error control that can make the results useless. We suggest a minimum of 100 points which corresponds to a confidence value of about 0.10.

## 7. ACKNOWLEDGEMENTS

This paper is part of the Project 2PR03A105 co-funded by the Junta de Extremadura (Consejería de Educación, Ciencia y Tecnología — II Plan Regional de Investigación, Desarrollo Tecnológico e Innovación de Extremadura) and FEDER (Fondo Europeo de Desarrollo Regional).

JUNTA DE EXTREMADURA FEDER

## REFERENCES

**References from Journals**:

Ackermann F., 1994. Digital Elevation Models - Tecniques and Application, Quality Standards, Development,. *International Archives of Photogrammetry and Remote Sensing*, 30 , pp. 421-432.

Al-Rousan N. and Petrie G., 1998. Sistem calibration, geometric accuracy testing and validation of DEM & ortoimages data extracted from SPOT stereopairs using commercially available image processing systems. International Archives of Photogrammetry and Remote Sensing, vol. 32, pp. 8-15.

Baltsavias P. and Stallmann D., 1993. SPOT Stereo matching for Digital Terrain Model generation. *2nd Swiss Symposium on Pattern Recognition and Computer Vision*, Zürich, Switzerland.

Felicísimo A. M., 1994. Parametric statistical method for error detection in digital elevatiom models. ISPRS Jornal of Photogrammetry and Remote Sensing, 49, pp. 29-33.

Hae-Yeoun L., Wonkyu P., Taejung K., Seungbum K., Heung K.L, and Tag-gon K., 2000. The Development of an Accurate DEM Extraction Strategy For Satellite Image Pairs Using Epipolarity of Linear Pushbroom Sensor and Intelligent Interpolation Scheme. *International Archives of Photogrammetry and Remote Sensing*, 33, pp. 705-712.

Hae-Yeoun L., Wonkyu P.,.Taejung K, Seungbum K., Heung K.L, and Tag-gon K., 2000. The Development of an Accurate DEM Extraction Strategy For Satellite Image Pairs Using Epipolarity of Linear Pushbroom Sensor and Intelligent Interpolation Scheme. *International Archives of Photogrammetry and Remote Sensing,* 33, pp. 705-712.

Li Z., 1991. Effects of Check Point on the Reliability of DTM Accuracy Estimates Obtained from experimental test. *Photogrammetric Engineering & Remote Sensing*, 57, pp. 1333-1340.

Li Z., 1991. Effects of Check Point on the Reliability of DTM Accuracy Estimates Obtained from experimental test. *Photogrammetric Engineering & Remote Sensing*, 57, pp. 1333-1340.

López C., 2000. On the improving of the elevation accuracy of Digital Elevation Models: a comparison of some error detection procedures. *Transaction on GIS*, 4, pp. 43-64.

Mukai Y., Sugimura T., and Arai K., 1990. Automated generation of digital elevation model using system corrected SPOT data. *Proceedings 23th International Symposium on Remote Sensing of Environment*, Bangkok.

Mukai Y., Sugimura T., Iijima T., Ayabe K, Tachi K., 1989. Automatic computation of elevation data of side-lap area using system corrected Landsat TM data. *Remote Sensing Technology Center of Japan*. Tokyo, pp.8.

Peucker T. K., Fowler R. J., Little J. J., and Mark D. M., 1978. The triangulated irregular network. *ASP Digital Terrain Models (DTM) Symposium*, Falls Church, Virginia.

Peucker T. K., Fowler R. J., Little J. J., and. Mark D. M, 1978. The triangulated irregular network. *ASP Digital Terrain Models (DTM) Symposium*, Falls Church, Virginia.

Priebbenow R. and Clerici E., 1988. Cartographic applications of SPOT imagery. *International Archives of Photogrammetry*, 37, pp. 289-297.

Sasowsky K. C. and Petersen G. W., 1992. Accuracy of SPOT digital elevation model and derivatives: utility for Alaska's North slope. *Photogrammetric Engineering and Remote* Sensing, 58., pp. 815-824.

Toutin T., 2002. 3D Topographic Mapping with ASTER Stereo Data in Rugged Topography. *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, pp. 2241-2247.

**References from Books**:

Slama C. C., Theurer C., and Henriksen S. W., 1980. Manual of Photogrammetry, 4th edition ed. Falls Church, VA, USA.