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Improving the Accuracy of the SRTM Global DEM Using GPS data fusion and regression Model

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Abstract

Digital Elevation Models (DEMs) are commonly produced through different surveying approaches that varied in processing techniques, time, and cost. During the last decade, the Global DEMs of the Shuttle Radar Topography Mission (SRTM) with a horizontal resolution of 90 m is representing the freely available DEMs worldwide with relevant quality.

The main objective of this research is to improve the accuracy of the DEM generated by SRTM using GPS data fusion and a developed regression model. Ground control points (GCP) were observed using GPS with centimetre-level accuracy. Herein, the GCP are divided into two main groups. The first group is the solution dataset that define the coefficients of the polynomial, while the behaviour of the polynomial has been investigated against the number of used common points and the average spacing between these points. The second group is a check dataset which is used to assess the accuracy of the new developed DEM using statistical methods. Moreover, the potential of using visual analysis technique has been proved by the evaluation of the validity of the visual techniques in doing such analysis.

The final analysis results has shown that the applied polynomial of the first order using control points with average spacing 250 m has improved the SRTM DEM to be more close to the GPS DEM. Also, the statistical analysis has supported these results where the value of the root mean square error (RMSE) of the check points is ranging between ±0.42 m and ±1.21 m for flat terrain.

Keywords

Regression model, polynomial, digital elevation model, quality assessment, visual analysis, Shuttle Radar Topography Mission (SRTM).

I. Introduction

The digital elevation model is a statistical representation of a part of the continuous earth's surface by a large number of selected points with known X, Y, and Z coordinates in numerical form. Nowadays, DEM have been widely used in a vast range of applications such as civil engineering, military applications, and visibility analysis ….etc. (R.J. Peckham, and Gyozo Jordan, 2007).

Many techniques are developed to extract the DEMs that varied in time, cost, and production techniques, where they can be mainly classified as field surveying, Photogrammetry and remote sensing, cartographic digitization, Radargrammetry and synthetic Aperture Radar (SAR), and Airborne Laser Scanning (LIDAR). (Zhilin Li et al. 2005):

Nowadays, using satellite images to produce DEM has a remarkable advantage because it is relatively cheaper and it takes less time to generate the DEM. However, the disadvantages of using the optical spectral range are that it requires high resolution, good light conditions, and cloudless view for better accuracy of DEM.

Recently, Interferometric Synthetic Aperture Radar (InSAR) has become popular in extracting elevation data due to the independency of natural illumination as an active system, and the low atmospheric absorption at typical radar wavelengths (Gerald Forkuor and Ben Maathuis, 2012).

One of the products that followed the SAR methodology is Shuttle Radar Topographic Mission (SRTM). This Global DEMs covers more than 80% of the Earth's land surface during an 11-day Space Shuttle mission. It became publicly available at 3 arc-second sampling (90 m) for the area outside of the U.S. (Odutola Christian Amans et al., 2013).

The accuracy of the SRTM in flat area is ranged from 2.9-3.4 m and from 5.4-6.29 m for semi-flat region (A. K. Karwel and I. Ewiak, 2008; Bridget Smith and David Sandwell, 2003).

Many approaches have been applied to improve the accuracy of the SRTM, for example Manoj Karkee, et al. (2008) improved the accuracy up to 44% to have RMSE of 8.3m by the data fusion of Aster and SRTM DEM. Additional approach that used 90m SRTM DEMs as a source to generate DEMs of the 30m resolution using the resampling improved the accuracy (RMSE) by about 20% to have RMSE of 2.33m (Chaiyapon Keeratikasikorn and Itthi Trisirisatayawong, 2008; Endan Suwandana et al., 2012).

Therefore, the study presented in this paper is to refine the accuracy of the SRTM using the cubic convention resampling of the SRTM then the fusion with GPS data through a developed polynomial model based on two datasets collected by GPS in both Qena and Al-Menia governorates in southern Egypt that define the flat terrain. Both datasets were observed using GPS technique, while statistical analysis that include mean, Root Mean Square Error, standard deviation and median of the absolute errors value are applied. Different degrees of polynomial model along with different spacing distances of GPS points were examined for each site separately. Finally, visual inspection has been performed for the assessment and the validity of the results of the statistical analysis.

II. Methodology

In this paper, a multiple orders of 1^{st}, 2^{nd} and third degree of the polynomial mathematical models are applied in order to enhance the accuracy of the SRTM DEM. The equation of the polynomial is described as follows:

$$\begin{aligned} Z_{GPS} = {} & a_o + a_1E' + a_2N' + a_3Z' + \quad \ldots(1^{st}\text{ order}) \\ & + a_4E'^2 + a_5N'^2 + a_6Z'^2 + a_7E'N' + a_8E'Z' + a_9N'Z' \quad \ldots(2^{nd}\text{ order}) \qquad (1) \\ & + a_{10}E'^3 + a_{11}E'^2N' + a_{12}E'N'^2 + a_{13}E'^2Z' + a_{14}E'Z'^2 \\ & + a_{15}N'^3 + a_{16}N'^2Z' + a_{17}N'Z'^2 + a_{18}Z'^3 \quad \ldots(3^{rd}\text{ order}) \end{aligned}$$

Where Z_{GPS} is the elevation value of the GPS observed points, while N', E' and Z' are the corresponding SRTM DEM values of northing, easting, and elevation respectively. These represent the coordinates of the common points, in order to generate the polynomial coefficients (a_0, a_1, $a_{2...}$) (Manuel A. Aguilar et al. 2007). Within the research, and for each study area, two sets of testing are applied, the first set is using the original SRTM DEM of 90 m resolution and the second one is using the resampled SRTM DEM of 30 m resolution. Herein, two case studies are applied and will be described at section (3), where the applied data are composed of two main groups of data points for each case study. These groups are defined as follows:

- The first group represents common points between GPS and SRTM and is used as common data. Four solutions for each case study are applied, with average spacing 500 m, 375 m, 250 m, and 125 m respectively.
- The second group of points is used as check points to estimate the quality of the results. The number of check points in the two case studies is 235 and 1000 points respectively.
- Two sets of testing are applied for each study area, the first set is using the original SRTM DEM of 90m resolution and the second one is using the resampled SRTM DEM of 30m resolution. For each set four solutions are applied using the different average spacing among the common points.

The proposed methodology is implemented for each case study through three main stages, data preparation, data processing, and accuracy assessment.

A. Data Preparation

After downloading the SRTM DEMs of the study areas, the data was transformed into the same projection system which is Universal Transverse Mercator (UTM) zone 36 north - WGS 1984. The original 90 m resolution of the SRTM DEM is resampled into 30 m resolution using cubic technique. Figure (1) shows this technique for resampling DEM data in which the average of the nearest 16 cells is used to calculate the new cell value. This is used for resampling continuous datasets and will smooth the resulting DTM (Carlos Henrique Grohmann, 2006).

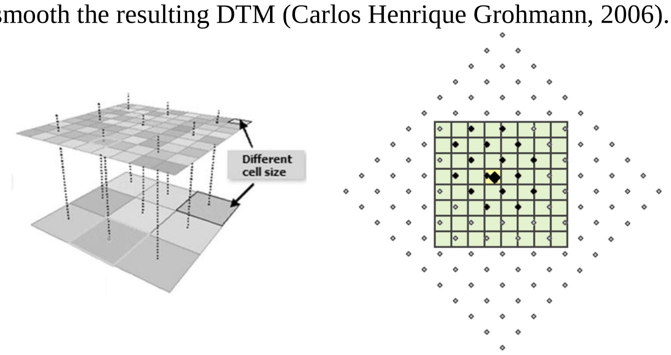


Figure 1: Cubic Convention Resampling

The ground control points were observed using GPS technique to obtain the common and check points. Four solutions for each case study were carried as described in Table (1), while the rest of GPS points are used as check points (235 for study area (1) and 1000 for study area (2)). In order to get the SRTM DEM coordinates for the same GCP points an extraction process is applied.

Table 1: Description of the applied solutions

	Number of common points (Study area 1)	Number of common points (Study area 2)	Average spacing (m)
Solution (1)	6	66	500
Solution (2)	12	104	375
Solution (3)	24	183	250
Solution (4)	40	399	125

B. Data Processing

Herein, we are going to generate the polynomial coefficients of the different ranks for each solution by using a group of common points and a software package for Equation (1). Then, the generated coefficient with the SRTM coordinates of the check points are used to get the interpolated coordinates. Finally, the height differences between the interpolated coordinates and the GPS of the check points over each study area with their statistics are computed.

C. Accuracy Assessment

The last stage is to assess the accuracy of the SRTM DEM after applying the polynomial interpolation. The assessment methods are divided into two general sets which are descriptive statistical method and visual inspection.

1) Statistical Methods

Statistical calculations are applied to assess the accuracy of the DEM. It is based on both the descriptive statistics calculations and the robust statistics calculations (Saati, A et al. 2011).

In statistics and probability theory, Mean error (average, or arithmetic mean) is the best estimator of the measured value and it is given by the sum of the height difference in the distribution divided by the number of such GCPs:

$$Mean = \frac{1}{n}\sum_{i=1}^{n} |\Delta h_i| \qquad (2)$$

Where $\Delta h_i = Z_{GPS(i)} - Z'_{(i)}$ is the height difference between the interpolated elevation and the elevation of the GPS coordinates of the check points, and n is the number of check points.

RMSE can be used as a standard measure of data accuracy. It is the best measure for the amount of error in dataset. It indicates the degree of precision or degree of reliability of data set, where it considers both random and systematic errors introduced during the data generation process. The RMSE is given by:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \Delta h_i^2} \qquad (3)$$

Where Δh_i the individual height is difference of $i = 1,2, \ldots, n$ and n is the number of check points. The dispersion from the average (mean) or the expected value is defined by the standard deviation σ. Standard deviation is given by:

$$\hat{\sigma} = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(\Delta h_i - \hat{\mu})^2} \qquad (4)$$

Where $\hat{\mu}$ is the mean error of Δh_i .

Median is the statistical quantities (or 0.5th quantile) that were carried out to give an indication of the value within a data set that tends to exist at the center. Median (M) can be obtained by:

$$M = \begin{cases} \Delta h_{(n+1/2)}, & if\ n\ is\ odd \\ \frac{1}{2}[\Delta h_{(\frac{n}{2})} + \Delta h_{((\frac{n}{2})+1)}], & if\ n\ is\ even \end{cases} \qquad (5)$$

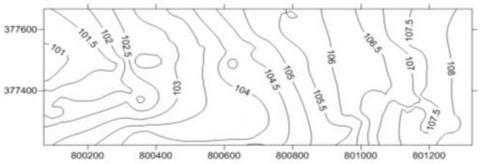
For more details see (F. F. Asal, 2012 and Höhle, J., and Höhle, M. 2009).

2) Visual Methods

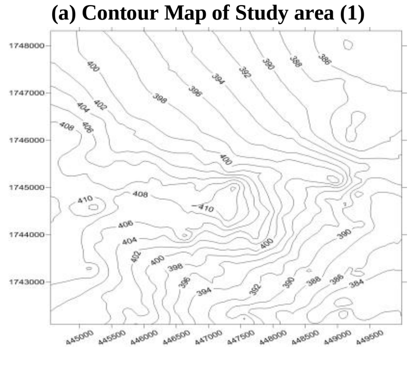
Many researches are focusing only on the statistical analysis methods in-spite of the fact that the visual analysis is important for evaluating the quality of the DEM. According to (Inese Linuza, 2014) visualization is a qualitative approach to quality assessment which is an effective way of understanding spatial data. It represents one of the most diagnostic methods for investigating errors through various rendering techniques like 3D view. Visual assessment is achieved by inspecting the appearance of a DEM that distinguish the pattern and spatial distribution (Qiming Zhou, Brian Lees, Guo-an Tang, 2008).

III. Results and Analysis

In this research, the proposed methodology is applied at two sites (Figure 2) with different elevation ranges. Site 1, which is located in Qena governorate – Egypt of area 3 Km^2, has an elevation range of about 21 m and represents a flat surface. Site 2 is located in Al-Menia governorate - Egypt of area 30 Km^2 with elevation range of about 220 m; it is semi-flat terrain. Figure (2) represents the terrain of the two sites.



(a) Contour Map of Study area (1)



(b) Contour Map of Study area (2)

Figure 2: Contour Map of the two sites of the study area

We applied the mentioned technical steps to the four different solutions. In order to evaluate the results, residual statistics of the check points for the different solutions of each study area are tabulated with some comparisons between them. The main items in the tables are the minimum and maximum values, the mean, the root mean square error, the standard deviation, and the median of the absolute residual.

A. Case Study (1):

Statistics of the changes in elevation of the check points that represent the height difference between the GPS height and the interpolated height are computed in all solutions of the first study area. Each solution represents different distribution and density of the solution points. The interpolated height yields from the SRTM height after applying the polynomial model showed that the first order gave the appropriate results. Table 2 represents the summary statistics of the residuals of polynomial of first order.

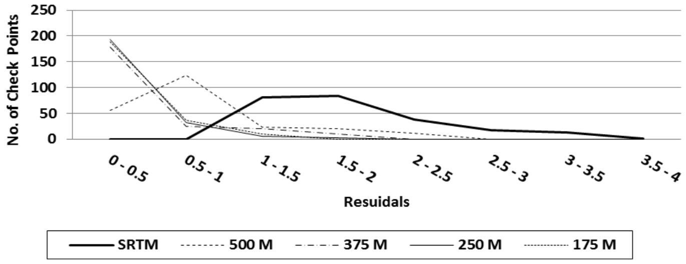
Table 2: Statistics of the residuals of the check points

	Original Δ (H_{GPS} - H_{SRTM})		Solution (1) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (500 m)		Solution (2) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (375 m)	
	Original	**Resample**	**Original**	**Resample**	**Original**	**Resample**
Min.	1.21	0.21	0.16	0.01	0.00	0.00
Max.	3.55	3.16	2.27	2.07	1.74	1.73
Mean	1.84	1.46	0.84	0.64	0.40	0.34
RMSE	1.91	1.54	0.99	0.77	0.60	0.48
Std. Dev.	0.55	0.51	0.55	0.43	0.45	0.35
Median	1.71	1.46	0.69	0.58	0.24	0.21
	Original Δ (H_{GPS} - H_{SRTM})		**Solution (3) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (250 m)**		**Solution (4) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (125 m)**	
	Original	**Resample**	**Original**	**Original**	**Original**	**Original**
Min.	1.21	0.21	0.00	0.00	0.00	0.00
Max.	3.55	3.16	-1.55	1.65	1.30	1.30
Mean	1.84	1.46	0.30	0.32	0.32	0.32
RMSE	1.91	1.54	0.42	0.43	0.42	0.42
Std. Dev.	0.55	0.51	0.30	0.29	0.28	0.28
Median	1.71	1.46	0.19	0.24	0.22	0.22

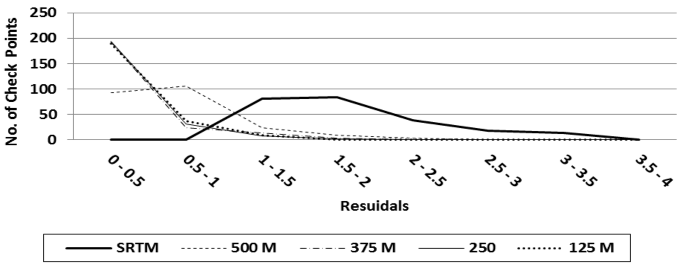
We have to highlight that the four solutions gave varied results; before applying the polynomial, where the elevation differences range from 1.21 m to 3.55 m before the resampling process. After applying resampling technique, the results are enhanced to be between 0.21 m and 3.16 m. For solution (1) the elevation difference, mean, RMSE, and median enhanced by about one meter. Solution (2) gave relatively better results. Solution (3) represents the best results. While, solution (4) remains with no difference behaviour.

It should be noted that after applying the polynomial, the resampling operation has no effect on the results.

Figure 3a, 3b represents the absolute residuals for the different solutions in both cases before and after applying the resampling technique respectively.



(a) The graph of the absolute value of the residuals without resampling



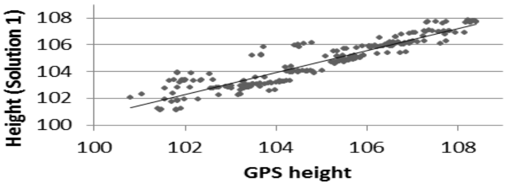
(b) The graph of the absolute value of the residuals after resampling

Figure 3: The histogram of the absolute value of the residuals

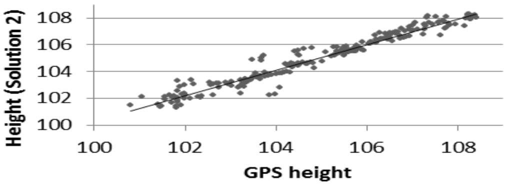
Endorsing the above mentioned results, the graph before and after resampling gave similar behaviour, where the major frequencies of the absolute residuals of the original SRTM lies between 1 m to 2.5 m, and solution (1) with 500 m separation ranges from 0.5 m to 1 m. Solution (3) (250 m separation) represented the best results, where the majority of the points is less than 0.5 m elevation difference.

The residuals have very much close values to the absolute residuals; the best results were obtained from Solution (3).

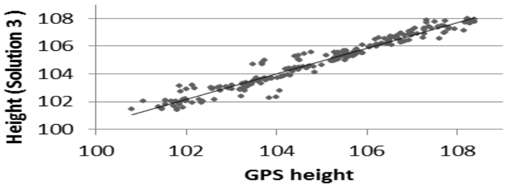
Figure (4) represents the analysis that measures the correlation between the GPS height and the interpolated one for the different solutions.



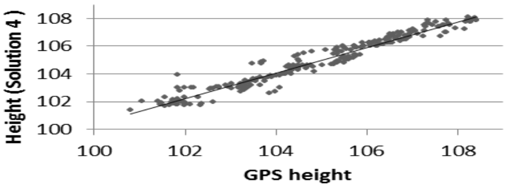
(a) The relation between GPS heights and height (Solution 1)



(b) The relation between GPS heights and height (Solution 2)



(c) The relation between GPS heights and height (Solution 3)

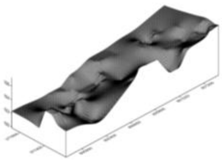


(d) The relation between GPS heights and height (Solution 4)

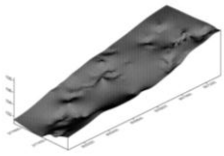
Figure 4: Scattered Plot depicting the interpolated elevation versus the GPS elevation

The four graphs in figure 4 reveal a linear and positive slope between DEMs of the different solutions and GPS elevation. The existence of this positive slope between the two variables (DEMs and GPS elevation) points out that both variables are moving in the same direction. Also, the graphs show the relatively high confidence limits for the polynomial analysis.

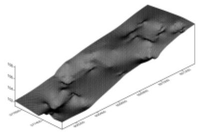
A visual inspection is applied through a 3D analysis as shown in Figure 5. This analysis is carried out to confirm how the original SRTM and the best solution DEM represented relative to the referenced GPS.



(a) SRTM 3D Surface



(b) GPS 3D surface



(c) 3D Interpolated surface (solution 3)

Figure 5: 3DView of the referenced GPS data, SRTM and the interpolated DEM

The graphs in Figure 5 illustrate that the 3D interpolated surface of Solution (3) is “closer” to the GPS reference surface.

B. Case Study (2):

The results for the check points are presented in Table 3, where it mainly shows similar behavior as the statistics presented in the first case study.

Table 3: Statistics of the residuals of the check points

	Original Δ (H_{GPS} - H_{SRTM})		Solution (1) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (500 m)		Solution (2) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (375 m)	
	Original	Resample	Original	Resample	Original	Resample
Min.	0.00	0.00	0.00	0.00	0.00	0.00
Max.	7.29	6.30	5.59	5.58	5.50	5.49
Mean	1.57	1.56	1.13	1.13	1.13	1.13
RMSE	1.94	1.92	1.44	1.44	1.44	1.44
Std. Dev.	1.15	1.13	0.89	0.90	0.90	0.89
Median	1.37	1.37	0.97	0.97	0.97	0.97
	Original Δ (H_{GPS} - H_{SRTM})		**Solution (3) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (250 m)**		**Solution (4) Δ (H_{GPS} -$H_{SRTM\ predicted}$) (125 m)**	
	Original	Resample	Original	Resample	Original	Resample
Min.	0.00	0.00	0.00	0.00	0.00	0.01
Max.	7.29	6.30	5.15	5.12	5.16	5.15
Mean	1.57	1.56	1.02	1.01	1.04	1.03
RMSE	1.94	1.92	1.21	1.21	1.22	1.22
Std. Dev.	1.15	1.13	0.78	0.77	0.78	0.78
Median	1.37	1.37	0.85	0.83	0.87	0.85

Similar to the first case study, the resampling enhanced the original SRTM by about one meter; however after applying the polynomial the resampling has changed a little bit in the statistics values. The statistics values of the solutions are close to each other’s, where the relatively best accuracy is obtained from solution (3). Again increasing the common points and decreasing the average spacing to improve the polynomials solution is useless as presented in solution (4). The maximum value of the residuals and its RMSE are enhanced by 2.14 m and 0.73 m respectively.

The histograms of the absolute residuals before and after applying the resampling technique are displayed respectively in Figure 6a, 6b.

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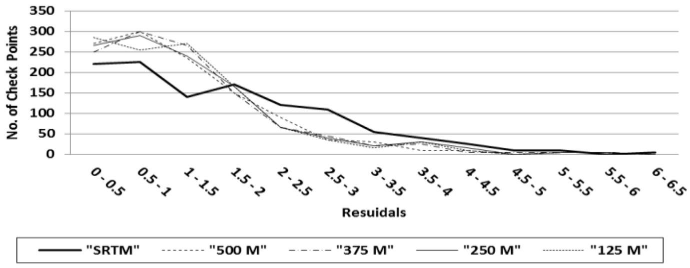
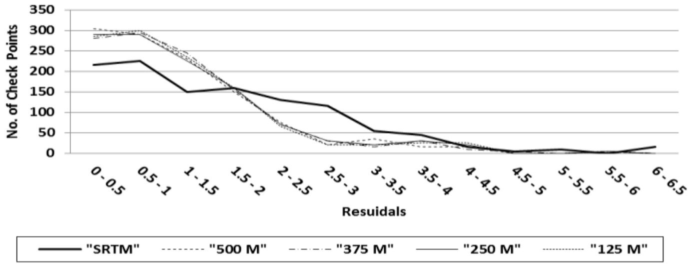


(a) The histogram of the absolute value of the residuals without resampling



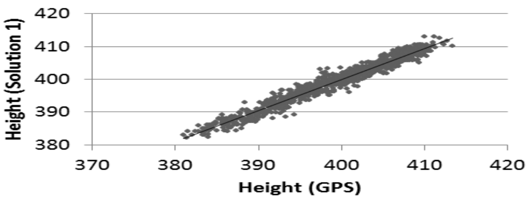
(b) The histogram of the absolute value of the residuals after resampling

Figure 6: The histogram of the absolute value of the residuals

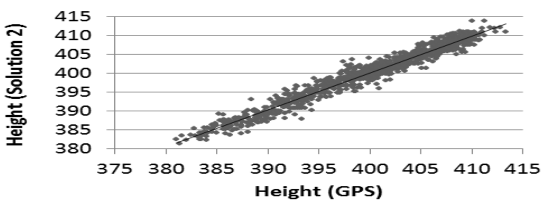
The results before and after resampling gave almost the same behaviour. Solution (3) with 250 m average spacing represented the best results, where the majority of the points have a range of elevation difference less than 2 meter.

Likewise, the residuals have very much close values to the absolute residuals; the best results are obtained from solution (3).

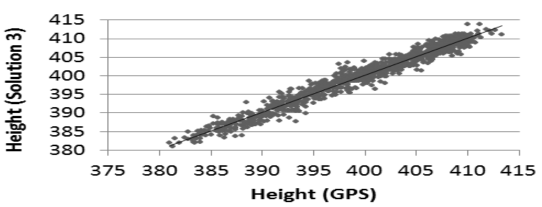
The scatter plot that illustrates the correlation between the interpolated heights of the check points using the different solution as a function of the GPS height are shown in Figure (7).



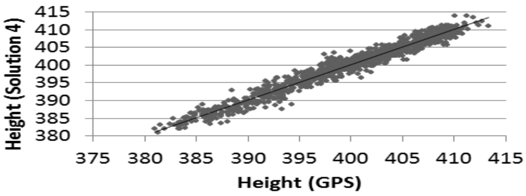
(a) The relation between GPS heights and height (Solution 1)



(b) The relation between GPS heights and height (Solution 2)



(c) The relation between GPS heights and height (Solution 3)

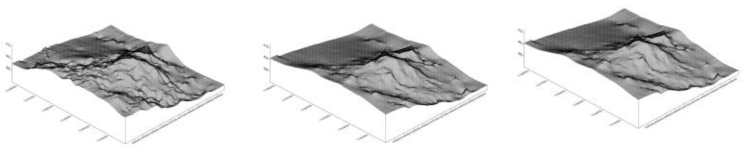


(d) The relation between GPS heights and height (Solution 4)

Figure 7: Scattered Plot depicting the interpolated elevation versus the GPS elevation

Recalling, the graphs in Figure7 above reveal a linear and positive slope between the two variables (DEMs and GPS elevation). These graphs show relatively high confidence limits for the regression analysis.

Figure 8 represents the visual inspection analysis, where it reveals that 3D interpolated surface of Solution (3) is “closer” to the reference and still has more complex details as the original GDMEM.



(a) SRTM 3D Surface **(b) GPS 3D surface** **(c) 3D Interpolated surface (solution 3)**

Figure 8: 3DView of the referenced GPS data, SRTM and the interpolated DEM

IV. Conclusion

In this research we provide an enhanced space mission SRTM Global DEM with accuracy close to the DEM generated using accurate GPS observations. The proposed methodology that improves the SRTM DEM accuracy is based on polynomial model. First, a mathematical model for the polynomial is introduced then the methodology for accuracy assessment is defined. Two case studies have been inspected in order to ensure the advantages of the proposed approach after the examination of the interpolated DEMs. Also, the investigation of the cubic convention resampling effect has been tested. The resampling enhanced the maximum height of the original SRTM by 0.39 m for flat area and one meter for the semi-flat area; however after applying the polynomial the resampling has no effect on the statistics values.

The DEM qualities which are considered appropriate for Geomatics application were compared in flat and semi-flat area. The best vertical accuracy in comparison with applied GPS ground control points (check points) for flat area is ±0.42 m and ±1.21 m for the semi-flat one in terms of their RMSE. These optimal results were obtained when the polynomials of first order are created using control points with average spacing 250 m. Three dimensional model endorses that the 3D interpolated surface of the most suitable polynomial is very closer to the GPS reference DEM.

References

1. Bridget Smith and David Sandwell, 2003, Accuracy and resolution of shuttle radar topography mission data, GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 9, 1467, doi: 10.1029/2002GL016643, 2003.
2. Carlos Henrique Grohmann, 2006, "Resampling SRTM 03- data with kriging, GRASS/OSGeo-News Open Source GIS and Remote Sensing information, Vol. 4, pp. 21-25.
3. Chaiyapon Keeratikasikorn and Itthi Trisirisatayawong, 2008, RECONSTRUCTION OF 30M DEM FROM 90M SRTM DEM WITH BICUBIC POLYNOMIAL INTERPOLATION METHOD,the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing 2008.
4. Endan Suwandana 1, Kensuke Kawamura , Yuji Sakuno , Eko Kustiyanto and Beni Raharjo, 2012, Evaluation of ASTER DEM2 in Comparison with DEM1, SRTM DEM and Topographic-Map-Derived DEM Using Inundation Area Analysis and RTK-dGPS Data, Remote Sensing 2012, 4, 2419-2431; doi:10.3390/rs4082419.
5. F. F. Asal, 2012, VISUAL AND STATISTICAL ANALYSIS OF DIGITAL ELEVATION MODELS GENERATED USING IDW INTERPOLATOR WITH VARYING POWERS, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-2, 2012.
6. Gerald Forkuor and Ben Maathuis, 2012, Comparison of SRTM and ASTER Derived Digital Elevation Models over Two Regions in Ghana - Implications for Hydrological and Environmental Modeling, Studies on Environmental and Applied Geomorphology, Dr. Tommaso Piacentini (Ed.), ISBN: 978-953-51-0361-5, InTech, DOI: 10.5772/28951. Available from: http://www.intechopen.com/books/studies-on-environmental-and-applied-geomorphology/comparison-of-srtm-and-aster-derived-digital-elevation-models-over-two-regions-in-ghana.
7. Höhle, J., and Höhle, M. 2009, Accuracy assessment of digital elevation models by means of robust statistical methods. ISPRS Journal of Photogrammetry and Remote Sensing, 64(4), 398-406. 10.1016/j.isprsjprs.2009.02.003
8. Inese Linuza, 2014, Accuracy Assessment in Glacier Change Analysis (Master's thesis), Lund University, retrieved from Lund University Publications.
9. K. Karwel, I. Ewiak, 2008, ESTIMATION OF THE ACCURACY OF THE SRTM TERRAIN MODEL ON THE AREA OF POLAND, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7. Beijing 2008.
10. Manoj Karkee, Brian L. Steward, and Samsuzana Abd Aziz, 2008: Improving quality of public domain digital elevation models through data fusion, Biosystems engineering 101 (2008) 293–305.
11. Manuel A. Aguilar, Fernando J. Aguilar, Francisco Agüera, and Jaime A. Sánchez 2007, Geometric Accuracy Assessment of QuickBird Basic Imagery Using Different Operational Approaches, Photogrammetric Engineering & Remote Sensing Vol. 73, No. 12, December 2007, pp. 1321–1332. 0099-1112/07/7312–1321/$3.00/0 © 2007 American Society for Photogrammetry and Remote Sensing.
12. Odutola Christian Amans, Prof. Wu Beiping, and Yao Yevenyo Ziggah, 2013, Vertical Accuracy of SRTM Ver 4.1 and ASTER DEM Ver 2 Using Differential GPS Measurements – Case Study in Ondo State Nigeria, International Journal of Scientific & Engineering Research, Volume 4, Issue 12, December-2013 523 ISSN 2229-5518 IJSER © 2013 http://www.ijser.org Assessing.
13. Qiming Zhou, Brian Lees, Guo-an Tang, 2008, Advances in Digital Terrain Analysis, Springer – Verlag Berlin Heidelberg.
14. R.J. Peckham, and Gyozo Jordan, 2007 "Digital terrain modeling: Development and Applications in a policy Support Environment, Springer – Verlag Berlin Heidelberg.
15. Saati, A., Arefi, H., Schmitt, M., Stilla, U., 2011,Statistically robust detection and evaluation of errors in DTMs, Urban Remote Sensing Event (JURSE), 2011 Joint , vol., no., pp.305-308, 11-13 April 2011, doi: 10.1109/JURSE.2011.5764780.
16. Zhilin Li, Qing Zhu, and Chris Gold, 2005, Digital terrain modeling: principles and methodology, by CRC Press, United States of America.