RECONSTRUCTION OF 30M DEM FROM 90M SRTM DEM
WITH BICUBIC POLYNOMIAL INTERPOLATION METHOD

Chaiyapon Keeratikasikorn [a], Itthi Trisirisatayawong [b]

[a]Dept. of Survey Engineering, Chulalongkorn University, Bangkok, 10330 – chaiyapon.k@student.chula.ac.th
[b]Dept. of Survey Engineering, Chulalongkorn University, Bangkok, 10330 – itthi.t@eng.chula.ac.th

Commission I, WG I/5

KEY WORDS: Reconstruction, DEM, SAR, Radar, Resolution, Accuracy

ABSTRACT:

This work presents a methodology for the refinement of 90m digital elevation model (DEM) of Shuttle Radar Topographic Mission (SRTM) data. The SRTM DEM is publicly available through the Seamless Data Distribution System (SDDS) at two resolutions: 30m for the United States, and 90m for the areas between 60°N and 56°S of latitude including the US. The selected test areas stretch east-west from gently-slope flat land in western part of Kansas (N40W102.5) to rugged mountainous region in eastern Colorado (N40W107). All 90m DEM files, however, are generated from the 30m DEMs by subsampling only the center value of each 3x3 cells of the 30m SRTM DEM. Thus, the 90m DEM can be regarded as, in interpolation sense, regular sampling points that can be used to generate height values over a finer grid, which is set to be 30m in this study. Each height value is computed by choosing 16 nearest sampling points to determine 10 parameters of bivariate cubic polynomial equations in a least-square fashion. The reconstructed 30m DEMs are compared with the 30m SRTM DEMs. The interpolation errors, defined as the height differences at the same location between the 30m SRTM DEMs and the corresponding interpolating DEMs, are computed. Statistics show that the interpolation results are extremely good. For all reconstructed 30m DEM files, the RMS errors of the DEM files N40W102.5 - N40W107 are 0.936, 1.024, 1.081, 0.908, 0.817, 1.207, 1.923, 2.307, 2.330 and 1.865m respectively. The files having larger RMS error are those covering mountainous areas in the west (N40W105.5 - N40W107) while those in the flat and smooth terrains have RMS error better than 1.2 m. The result clearly demonstrates that for most cases using 90m SRTM DEMs as a source, the generation of 30m resolution DEMs of the same quality as the original 30m SRTM DEMs can be achieved by using the bicubic polynomial interpolation technique. This would be beneficial for a great number of users whose working areas are outside the US and requires higher resolution DEMs than the 90m SRTM DEM currently available.

1. INTRODUCTION

The Shuttle Radar Topography Mission (SRTM) is a joint project between NASA and NGA (National Geospatial-Intelligence Agency) to map the world in three dimensions. Flown aboard the NASA Space Shuttle Endeavour February 11-22, 2000, SRTM successfully collected data over 80% of the Earth's land surface.This set is publicly available at two postings: 1 arc-second (30m) for the United States and its territories and possessions, and 3 arc-seconds (90m) for regions between 60 degrees N and 56 degrees S latitude. (SRTM FAQ, 2004) Due to the increasing demand for higher resolution DEMs at the present. The use of higher resolution DEMs usually gives more accurracy on research result, especially in the fields where topographic are a critical issue such as flood control, post-seismic deformation or glacial movement. There are some studies related to DEM resolution improvement, mostly with variogram modelling and kriging. Carlos (2006) found that variograms calculated with linear trend residues of topographic data have adequate fits to classical variogram models, this model can then be used by kriging to interpolate the whole dataset at a finer resolution which produced good results. Marcio et al (2006) presents the methodology for the refinement of shuttle radar topographic mission (SRTM-90 m) data and was found to be an interesting solution to construct DEMs with more adequate presentation of landforms than the original data. However, DEMs at the resolution of 90m can be considered suitable for small or medium-scale analysis, but it is too coarse for more detailed purposes. In the case of users outside the USA which only be able to obtain DEMs resolution limited to 90m. The present alternative is to interpolate the DEM at a finer resolution. This brings to the objective of this experiment, to improve the resolution of the original 90m SRTM DEMs to a finer resolution DEMs at 30m. Using the bicubic polynomial interpolation technique, the process was adapted from the method NGA used to produce the 3 arc-second data. Detail discussion of the process was given later in section 3.

2. STUDY AREA

Study area is within the USA, between N40W102.5-N40W107, ranging from flat plain area in Eastern Kansas (N40W102.5) to mountainous area in western Colorado (N40W107) as seen in figure 1.

Figure 1. Study area ranging from flat to mountainous area.

3. METHODOLOGY

3.1 Initial concept

It is clearly stated that the method NGA used to produce 3 arc-second data from the 1 arc-second set is "subsampling", namely selecting the center value from the set of nine centered on a particular posting location (SRTM FAQ, 2004) as shown in figure 2 Thus, the 90m DEM can be regarded as, in interpolation sense, regular sampling points that can be used to generate height values over a finer grid, which is set to be 30m in this study.
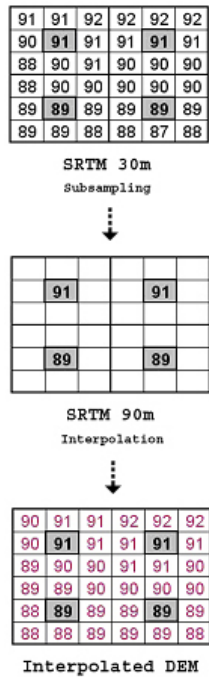
Figure 2. Show experimental concept.

3.2 Bicubic polynomial

From many types of curve-fitting functions, polynomial is widely used because of its unique characteristics. For example, polynomial is a continuing function and thus could be derived at every position. However, there are many downsides especially when computing with complicate data, higher order of polynomial is needed and usually causes oscillation. However, in order to use a lower order of polynomial for a more complex interpolation purpose, it is necessary to have excessive data and use a well-known calculation technique called "least square adjustment". In this experiment, Bicubic polynomial was used as an interpolation method . It is basically to form 10 equations which are the relationships between height value(z) and horizontal parameters (coordinate x,y) in order to solve 10 unknown coefficient values. In this study, we formed 16 polynomial equations for height estimation by the process of least square. General form of bicubic polynomial is shown in equation (1).

$$z = a_1x^3 + a_2y^3 + a_3x^2y + a_4xy^2 + a_5x^2 + a_6y^2 + a_7xy + a_8x + a_9y + a_{10} \tag{1}$$

3.3 General working process

SRTM DEMs can be freely downloaded from SDDS website at http://seamless.usgs.gov/. A total of 20 DEM files (half latitude each in size) were downloaded, containing 10 files of 30m SRTM DEMs and 10 files of 90m SRTM DEMs, each covered the totla area of 29,160 sq.km. (10x54km.x54km.). The following steps show how to obtain SRTM data from SDDS website. After logged on to the website, the first step was to specify user's area of interest. In this study, we chose the area within the USA by clicking the button "View and Download United States Data". Then define area of interest by typing the area coordinate by clicking the button "Define Download Area by Coordinate" , after that chose size of resolution of data being dowloaded (30m and 90m) which were of the same area. Chose type of data as ".bil" (for the convenient of mathematic processing in MATLAB later on) and finally clicked "OK", 30m and 90m SRTM data were downloaded in separated files. Table 1 shows statistics of 90m SRTM DEMs originally downloaded from SDDS website. While figure 3 shows working process flow chart. After obtained all of 20 SRTM DEMs downloaded from SDDS website. All data had to be pre-processed because there are some typical problems that could be found from the original SRTM DEMs. One of them is the existing of data voids. Voids are points on the SRTM data that contain error data, this happens due to bad radar scattering, which can be defined into 2 types: the first one contains zero value, which normally appear as large planes around mountainous areas. The other one in contrast, appears as speckle noises in flat land areas, mostly around river banks where data value usually exceeds possible terrain height (>65,000m)

Figure 3 shows working process flow chart. After obtained all of 20 SRTM DEMs downloaded from SDDS website. All data had to be pre-processed because there are some typical problems that could be found from the original SRTM DEMs. One of them is the existing of data voids. Voids are points on the SRTM data that contain error data, this happens due to bad radar scattering, which can be defined into 2 types: the first one contains zero value, which normally appear as large planes around mountainous areas. The other one in contrast, appears as speckle noises in flat land areas, mostly around river banks where data value usually exceeds possible terrain height. For the pre-processing step, in the case of error with large area, all were made buffers and were not considered for further statistic calculations. While errors that appeared to be speckles were not buffered out, but re-calculating all the errors with 3x3 averaging window. The moving widow's calculating process was done by averaging 8 surrounding pixel value and replace the center value (the error) with the new one. This process kept the regularity of grid-like data for further proccessing. After interpolating process, results which are some interpolated dems at 30m resolution were compared with the original 30m SRTM DEMs, on a pixel by pixel basis. Finally, height difference map was computed and statistics such as mean difference, maximun/ minimum differences and root mean squared error (rmse) were shown graphically using scatter plot defining the interval with the vertical accuracy of the SRTM at 16 m. (Bamler, 1999)

No.	File name	Mean	STD	Max	Min	Total pixel	error pixel	%
1	n40w102.5	1170	49.2	1285	1006	361200	0	0
2	n40w103	1317.6	49.4	1444	1200	361200	0	0
3	n40w103.5	1473.4	57.7	1643	1346	361200	0	0
4	n40w104	1507.5	74.6	1705	1351	361200	20	0.00554
5	n40w104.5	1611.4	91.6	1904	1439	361200	9	0.00249
6	n40w105	1681.3	101.1	1960	1504	361200	100	0.02769
7	n40w105.5	2128.4	434.9	3497	1558	361200	32	0.00886
8	n40w106	3229.5	363.4	4337	2286	361200	120	0.03322
9	n40w106.5	2974.5	348.6	4114	2130	361200	197	0.05454
10	n40w107	2558.8	350.1	3976	1896	361200	35	0.00969

Table 1. Shows statistics of 90m SRTM DEMs originally downloaded from SDDS website

No.	File name	Mean Diff	Max. Diff	Min. Diff	RMSE	Total pixel	No. of pixel exceed srtm vetical error (>16m)	%
1	n40w102.5	0.0007548	49.6	-50.9	0.936	3243601	152	0.004
2	n40w103	0.0006580	15.3	-11.1	1.024	3243601	0	0
3	n40w103.5	0.0007611	13.8	-16.9	1.081	3243601	1	0
4	n40w104	-0.0015906	8.1	-12.6	0.908	3243601	0	0
5	n40w104.5	0.0009402	14.9	-12.8	0.817	3243601	0	0
6	n40w105	0.0002961	63.7	-48.2	1.207	3243601	156	0.004
7	n40w105.5	-0.0006349	92.8	-49.2	1.923	3243601	647	0.020
8	n40w106	-0.0012113	88.5	-86.2	2.307	3243601	2385	0.074
9	n40w106.5	-0.0037254	107.1	-99.8	2.33	3243601	5303	0.163
10	n40w107	-0.0010582	61.3	-65.7	1.865	3243601	713	0.022

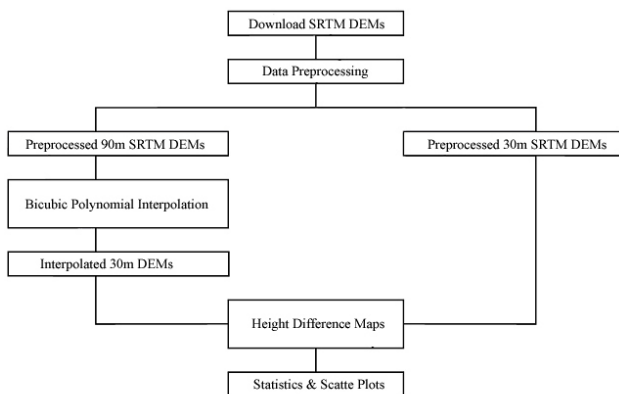Table 2. Shows statistics calculated from difference map.

Figure 3. Shows flow chart of the general working process.

4. RESULTS

From statistical point of view, difference maps showed very good results. The rmse was between 0.817-2.330 m as shown in table 2. When observing the results by terrain types, from flat area to mountainous area (N40W102.5 – N40W107), rmse

were 0.936, 1.024, 1.081, 0.908, 0.817, 1.207, 1.923, 2.307, 2.330 and 1.865. Large errors were found mostly in the west where mountainous areas dominate (N40W105.5-N40W107) while flat area in the east showed less errors. The magnitude of maximum error found were 50.9, 15.3, 16.9, 12.6, 14.9, 63.7, 92.8, 88.5, 107.1 and 65.7 m respectively. There were 4 out of 10 data sets (N40W102.5-N40W105) which had no error

exceeding SRTM vertical error. The largest amount of errors was found in N40W106.5 data file which was mostly represented mountainous area. The error ratio compared to original SRTM DEM was 0.163% while the other 5 data files showed error ratios between 0.005 %-0.074 %. As an example, a test site of the size 13.5 km.x13.5 km. (182.25 sq.km.) from rugged mountainous areas (subfile from N40W107 file) was chosen as an example. It was found that rmse was as high as 4.912 m. Histogram of difference map from sample test site was shown in figure 4. From the histogram, blue bar represented no.of pixels which values from 30m interpolated DEMs were higher than 30m original SRTM DEMs (overrated). While red bar represented no.of pixels which values from 30m interpolated DEMs were higher than 30m original SRTM DEMs (underrated). SRTM vertical accuracy at 16 m was used as a reference for histogram bar interval value. Overall result showed that, even area with high rmse, mean error still shifted toward zero and almost all of the errors fell within SRTM vertical accuracy. The overrated errors (blue) in this sample test site were found to be a little bit more in amount than the underrated ones (red). From the scatter plot (figure 5), error locations could be visually explored. Blue points represented overrated scattering while red points represented underrated scattering. Overall result showed that errors that fell within ±16 m were randomly distributed while errors that fell outside of ±16 tended to group around void areas of the original SRTM DEMs. However, within the grouping, red and blue points within there happened to be randomly or evenly distributed. One of the main reasons that errors from mountainous area deviated more than flat area was because bicubic polynomial had only the power of 3 and not capable of following the actual terrain, especially in rugged mountainous areas.
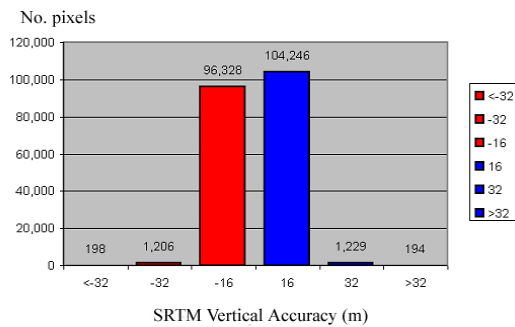
Figure 4. Shows histogram of difference map from test site over rugged mountainous areas (subfile from N40W107).
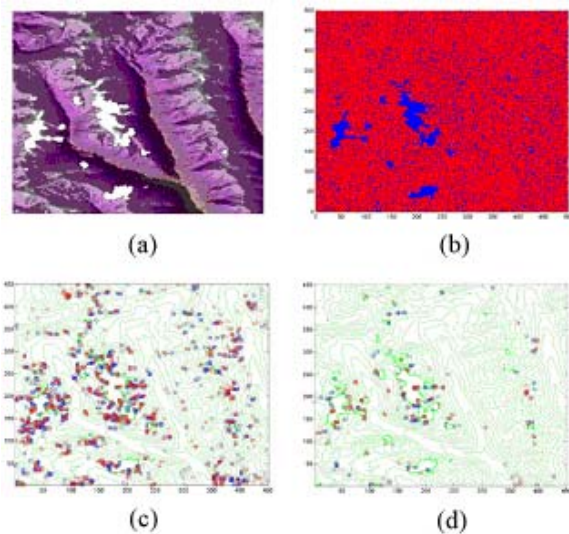

Figure 5. shows scatter plot of sample test site over rugged mountainous areas (subfile from N40W107). (a) Voids in the original SRTM DEMs, (b) Scatter plot of errors that fell within ±16 m were randomly distributed, (c) Scatter plot of errors that fell within ±32 m, (d) Scatter plot of errors that fell fell outside of ±32 m tended to group around void areas of the original SRTM DEMs.

Eventhough higher power could be applied to solve the problem but it must be well aware the affect from oscillation which normally caused over-interpolated edge values. Another main reason was because of the highly existing amount of voids in the original SRTM DEMs (figure 5-a). Eventhough, they were buffered out early in the pre-processing step, but with high differences around the edge aeas between buffered data and non-buffered data still remained. This cause high amount of errors around such areas (figure 5-c, 5-d). This reminds how important the difference of void filling techniques can do to the outcome of the interpolated DEMs. Figure 6 graphically compared the results between 30m interpolated DEMs and 30m original SRTM DEMs (rmse 1.16).

5. CONCLUSIONS

From the experiment, it was clearly demonstrated that using 90m SRTM DEMs as a source to generate DEMs of the same quality as the original 30m SRTM DEMs was done quite successfully. Eventhough there were some limitations

mentioned above, but this would be beneficial for a great number of users whose working areas are outside the US and requires higher resolution DEMs than the 90m SRTM DEMs currently available. Finally, it could be stressed that, using the bicubic polynomial would be one of the choices to choose as an interpolation technique, not only because it produced acceptable results but also with less complexity in the whole working process.
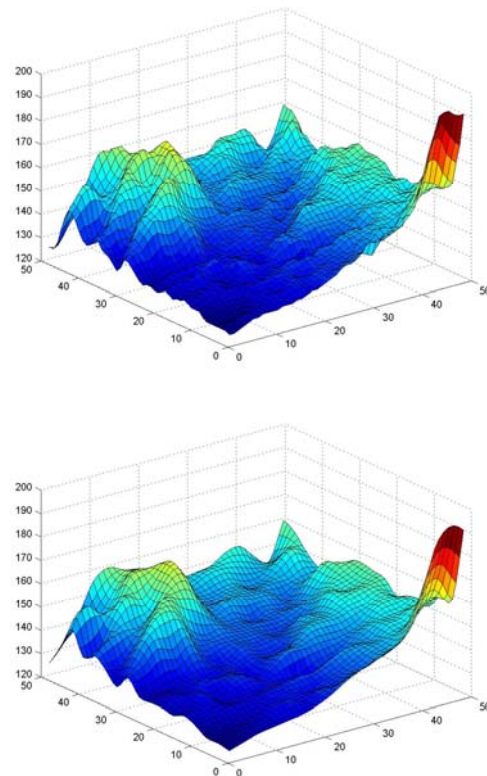

Figure 6. Graphically compared the results between 30m original SRTM DEM (above) and interpolated DEM (below).

References

Bamler Richard, 1999. "The SRTM Mission: A World-Wide 30m Resolution DEM from SAR Interferometry in 11 Days", *Photogrammetric Week 1999*, Wichmann Verlag, Heidelberg, pp. 145-154.

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.

Marcio M. Valeriano, Tatiana M. Kuplich, Moises Storino, Benedito D. Amaral, Jaime N. Mendes Jr., Dayson J. Lima, 2006. "Modeling small watersheds in Brazilian Amazonia with shuttle radar topographic mission-90 m data", *Computers & Geosciences*, Vol. 32, Issue 8, pp. 1169-1181.

Shuttle Radar Topography Mission (SRTM) FAQ, 2004. http://seamless.usgs.gov/website/seamless/faq/srtm_faq.asp (accessed 8 April 2007)