

IMPROVEMENT OF DEM PRODUCED FROM SRTM90 BY USING MATLAB

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ABSTRACT

The main objective of this study was to improve the DEM produced from SRTM90 by using the interpolation methods existing in MATLAB software. There are three types available of interpolations; bicubic, bilinear, and nearest neighbor interpolation methods. Using these methods does not require much effort or software to produce high DEM resolutions which can be rise up to about or smaller than 10 meters DEM resolution. In the current study, actual data of SRTM90 and SRTM30 was used for a part of USA concerned only with the area between 40°N to 41° N latitudes and 105° W to 106° W. The MATLAB interpolation methods used in this study can be easily used to sampling SRTM90 files into different types of DEM resolutions which can be easily convert 0.000833 arc-degrees resolution (SRTM90) to 0.000104 arc-degrees or less. The results obtained indicated extremely good improvement by using the bicubic sampling process besides its effortless.

1. INTRODUCTION

SRTM data are organized into individual rasterized cells or tiles, each covering one degree by one degree in latitude and longitude. Sample spacing for individual data points is either 1 arc-second or 3 arc-seconds defined as SRTM1 and SRTM3, respectively. Since one arc-second at the equator corresponds to roughly 30 meters in horizontal extent, the SRTM1 and SRTM3 are sometimes referred to as "30 meter" or "90 meter" data. The 1 arc-second original data have been made available to the public only for North America.

SRTM rasterized file (*.HGT) may be saved as a GeoTiff file that can be used in MATLAB image processing or used in Geographic Information Systems applications. The GeoTiff file contains coordinate information that will allow MATLAB to accurately resizing or resampling the image in latitude, longitude and elevations. GeoTiff DEMs are similar to Tiff (*.tif) graphics files except that the file contains a grid of 16 bit elevation measurements similar to SRTM DEM files (*.HGT) instead of color pixel values.

Interpolation of GeoTiff image is simply using image processing in MATLAB. The interpolation methods in MATLAB introduce low computational cost and low memory. The used algorithms such as the nearest neighbor and bilinear interpolation reveal computational simplicity but distort problems particularly in edge regions [25]. Linear approaches are used most frequently in spite of being nonlinear methods due to better effect of bicubic interpolation.

Several studies had evaluated the role of SRTM in improving the DEM resolution [12] where the authors presented a practical use of SRTM data in the tropics and compared it with digital elevation models generated from cartographic data. They found that SRTM three arc-second DEMs performed well for hydrological modeling.

Vertical accuracy of the SRTM and DTED level 1 was evaluated where SRTM and DTED-1 were not typical for plane regions. Sloping regions presented a greater mean error than the plane ones [16]. The necessary steps to improve the resolution of SRTM 30 using variograms modeling and kriging were reported and compared with those obtained by regularized splines [6].

In addition, a methodology for refinement 90 m DEM and reconstructed SRTM30 from SRTM90 was presented using bicubic polynomial interpolation at USA. Using SRTM90 as a source to generate DEM was similar to the original SRTM30 [13].

Moreover, the planimetric adjustment of elevation data to the SRTM DEM was evaluated by using correlation which applied to geo-reference any geographic dataset [8].

Evaluation the predicted SRTM30 from the freely available SRTM90 by using means of different interpolation orders were also reported [5], where the fourth polynomial order used and the interpolated SRTM30 was better than other polynomial degrees specially the third order (bicubic) which was widely used [13]. More studies are further warranted to create another interpolation method to improve the results [5].

All previous studied were concerned with SRTM30 DEM and SRTM90 DEM only (30 meter DEM resolution and 90 meter DEM resolution). However, in this study different types of interpolated data with

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different resolution had been used to achieve improvement in SRTM DEM resolution.

The 30 meter and 90 meter SRTM DEM are available without restraint and they are freely available for USA by using Seamless Data Distribution [19, 20] <http://seamless.usgs.gov/>

2. IMAGE RESIZING AND GEOTIFF IMAGE

Rescaling, resampling or resizing a raster image represents creating a new raster cell grid on a different alignment than the original raster. A value for each cell in the new raster object must be computed by resampling or interpolating over some neighboring cells in the corresponding position in the original raster object. This process offers a number of different resampling methods to compute the new raster values [14].

Increasing the size of an image is called up-sampling while reducing its size is called down-sampling. The resampling or resizing process is available in MATLAB and this process had been used by the author. However, the problem is how to keep the sample with the same dimension because SRTM90 DEM and the predicted DEM must have the same dimension tile where each covering one degree by one degree in latitude and longitude so it is called *sampling*. Therefore, the interpolated elevations *Z coordinates* had only taken into consideration without changes while the changes occur only for *X*, and *Y coordinates* which changed into a new cell dimension. This indicates the reason to export the data in ASCII format which is very suitable and had very good results. Image resize can be achieved by three interpolation methods that are available in MATLAB; bicubic, bilinear and nearest neighbor that had been discussed extensively in MATLAB product help.

Any terrain with geographic coordinates (Latitude-Longitude or UTM) and equal grid spacing between points can be saved as a GeoTiff DEM file. GeoTiff DEMs are similar to Tiff (*.tif) graphics files except that the file contains a grid of 16 bit elevation measurements instead of color pixel values. Both GeoTiff and Tiff graphics files use the (*.tif) file extension. GeoTiff DEMs can not be read as a graphics file by computer programs. They only can be read by programs such as DEM that are designed for their use. GeoTiff DEMs is a very efficient way to save large scale DEMs. For example, DEM made SRTM30 required approximately 98.8 Mbytes when saved as ASCII DEM. Saving the same area as a GeoTiff DEM required approximately 24.7 Mbytes. Therefore, GeoTiff DEMs have the advantage of being widely used by terrain visualization software.

3. THE WORKING PROCESS

The SRTM30 original data have been made available to the public only for North America. Therefore, this study belong a part of USA which has one arc-second (SRTM30). In the present study, the area bounded between 40° N to 41° N latitudes and 105° W to 106° W longitudes was considered as shown in Figure1. This area covered one degree by one degree squared, contains smoothly sloped, sharply sloped, flat terrain and rugged mountains and have elevations varied from 1466 meter to 4293 meter.

The available free data of the study area of SRTM90 version2_1 have the elevations in integer values and consist of (1201 rows *1201 columns) with pixel size of 0.000833 arc degrees. This available data only use the averaging method which constructed from SRTM30. Moreover, SRTM90 developed by using sampling method by the author to compare the averaging and sampling methods.

Figure 2 showed the working process flow chart where SRTM90 with pixels size of 0.000833 arc degrees exported as GeoTiff files with the same pixel size then using MATLAB image processing and interpolation method available in MATLAB to produce DEM with required pixel size. The produced DEM will be GeoTiff file which was exported as ASCII file. The elevation differences and statistics were estimated by a computer program.

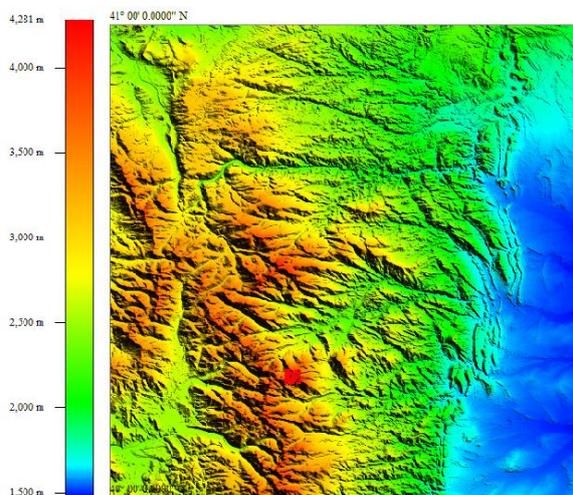


Figure (1): SRTM 30 of the Study bounded between 40° N to 41° N latitudes and 105° W to 106° W longitudes © NASA [17] and USGS [19]

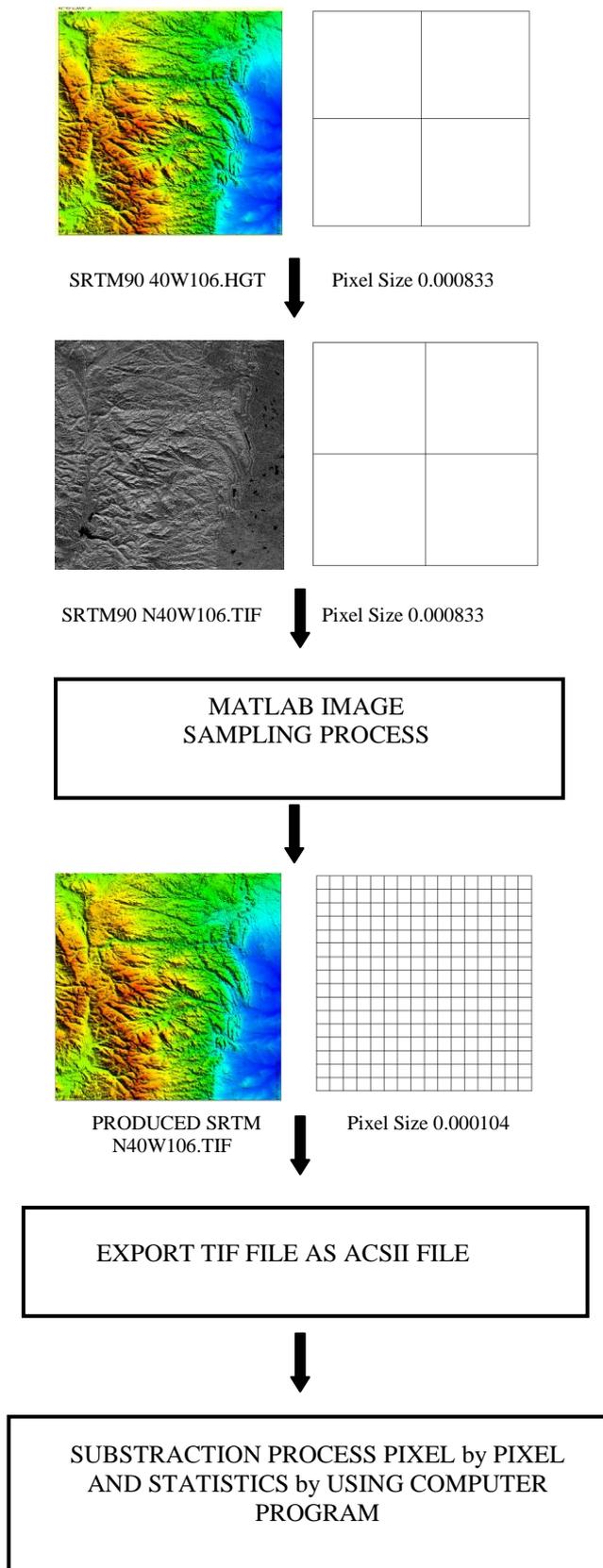


Figure 2: Flow chart of working process

4. MATLAB INTERPOLATION METHODS

Image interpolation refers to the reconstruction of a new version of image from a subset of image data. This process called resampling which could be achieved by using the interpolation methods. This study used the available interpolation methods in MATLAB which are bicubic, bilinear, and nearest neighbor.

4.1 Bicubic Interpolation

The closest 4 x 4 block of input cells is used to compute each output cells value. The weighting factors for the average of the input cells are computed using a cubic (third-order) function of distance.

Bicubic Interpolation attempts to reconstruct the exact surface between four initial pixels. It does this by extracting sixteen pixels based on the values of the model, the X slopes of those values, the Y slopes of those values, and the XY slope cross products of those values. It turns out that any point on a two dimensional unity normalized surface can be represented by a set of sixteen cubic polynomial equations [25].

4.2 Bilinear Interpolation

In this method the output cells value is the linear distance weighted the average of the four closest input cell values. It is more suitable for sampling of a smaller output cell size.

Bilinear interpolation is an easy method for interpolating values on a rectilinear grid. The function is called bilinear because if one variable set to a constant, the function is linear in the other variable. In other words, each cross section of a bilinear surface area taken parallel to a coordinate axis is a line segment [25].

4.3 Nearest Neighbor Interpolation

Each cell value in the sampled raster is determined by simply copying the value from the closest input cell. This method is more suitable for re-projecting a raster object (without a change in cell size) when preserving the original cell values for later quantitative analysis is important [25].

5. EXPERIEMNTS AND RESULTS

In order to compare the results between the produced DEM and SRTM30, many computer runs had been carried out using the SRTM90 (1201*1201) pixels data from the internet (using averaging method) and the developed SRTM90 (using sampling method) that have pixel size 0.000833 arc-degrees. The produced DEMs have pixels size values 0.000208, 0.000167, 0.000139, 0.000119 and 0.000104 arc-degrees. It could be done more or smaller pixels size but it will be exhausted and the results will have insignificant changes.

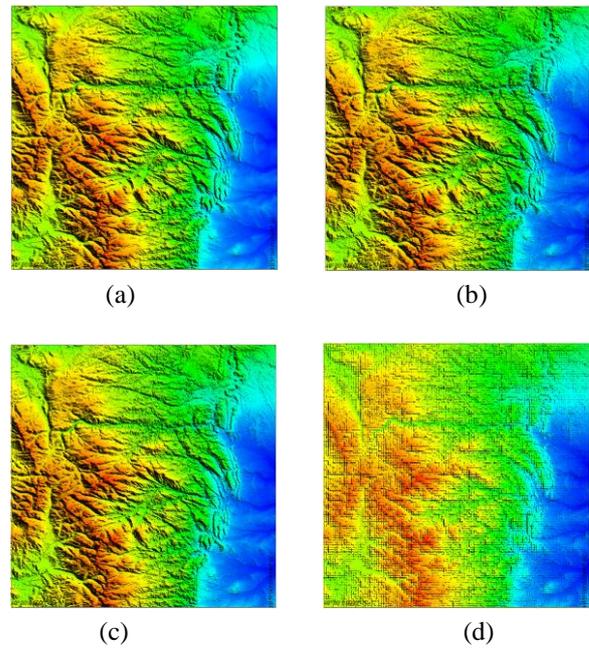
The created DEMs which have pixel size 0.000104 arc-degrees are shown in Figures 3 and 34. The created DEMs by using two methods; the available free SRTM90 which created from SRTM30 by using averaging method (Figure 3), and the developed SRTM90 by using sampling method (Figure 4).

The elevation differences between SRTM30 and the produced DEMs with different size of pixels from both averaging and sampling methods are shown in Figure 5 and Tables 1- 6.

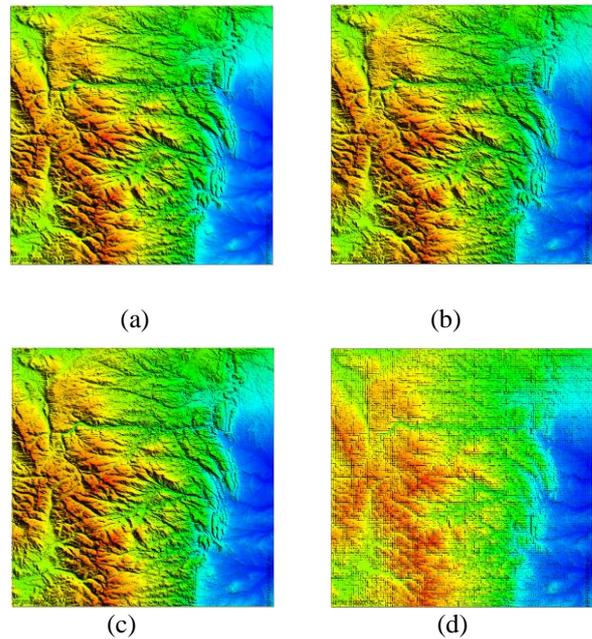
The results of produced SRTM DEM using different interpolations of SRTM90 version 2_1 with the methods available in MATLAB (bicubic, bilinear, and nearest neighbor) are shown in Tables 1- 3. The elevation differences between predicted SRTM DEMs with different resolutions and real SRTM30 together with their relevant statistics are presented. It can be noticed that the pixel size 0.000104 arc-degrees has better results than others types of pixels specially by using bicubic interpolation which has the least values about (0.09%) of area controlled by ± 16 meter. Also, the differences of means, and RMSE achieved by the bicubic interpolation, aligned with bilinear, and nearest neighbor interpolation were obvious. It could be concluded that the interpolation resulted in the best results compared with the other polynomial interpolation when the bicubic method was used.

The results of produced SRTM DEM using different interpolations of developed SRTM90 DEM from SRTM 30 DEM with the methods available in MATLAB (bicubic, bilinear, and nearest neighbor) are shown in Tables 4- 6. The elevation differences between predicted SRTM DEMs with different resolutions and real SRTM30 together with their relevant statistics are presented. It can be noticed that the pixel size 0.000139 arc-degrees has better results than others types of pixels specially by using bicubic interpolation which has the least values about (0.10%) of area controlled by ± 16 meter. Also the differences of means, and RMSE achieved by the bicubic interpolation, aligned with bilinear, and nearest neighbor interpolation were obvious. It could be concluded that the interpolation resulted in the best results compared with the other polynomial interpolation when the bicubic method was used.

It is obvious that SRTM90 using averaging method which have pixel size 0.000104 arc-degrees and by using bicubic interpolation have the best results at all and has minimum RMSE and mean differences. Also the sampling method had insignificant results compared with averaging method by using bicubic interpolation. It is apparent also that the worst interpolation method is nearest neighbor, while bilinear interpolation has significant differences from bicubic interpolation. By using bicubic interpolation and pixel size 0.000104 arc-degrees, the number of pixels controlled by ± 16 meter was 0.09 % of the total number of pixels while it was 0.11% by using the sampling method.



Figures (3): (a) SRTM90 freely available with averaging method [18], (b) pixel size 0.000104 arc-degrees DEM reconstruction by using bicubic (c) by using bilinear, and (d) by using nearest neighbor interpolation



Figures (4): (a) SRTM90 created from SRTM30 using sampling method, (b) pixel size 0.000104 arc-degrees DEM reconstruction by using bicubic (c) by using bilinear, and (d) by using nearest neighbor interpolation

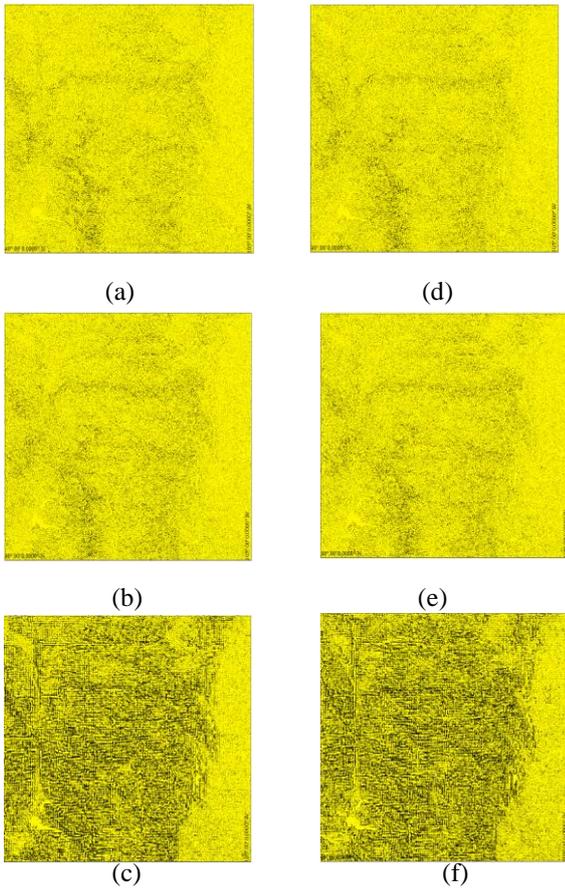


Figure (5): (a), (b), and (c) The elevation differences between averaging SRTM90 and produced DEMs which have pixel size 0.000104 arc-degrees by using bicubic, bilinear and nearest interpolation respectively. (d),(e), and (f) The elevation differences between sampling SRTM90 and produced DEMs which have pixel size 0.000104 arc-degrees by using bicubic, bilinear and nearest interpolation respectively.

6. EFFECT OF VOID EXISTING

Pre-processed data by using SRTM has some typical problems that could be found from the original SRTM DEM such as the existing of land data voids as shown in Figure 6.a and large voids of the water body.

During the acquiring of DEM data with bicubic interpolation, it was noticed that however decreasing the pixels size, the percentage area had difference elevations not less than 9% as shown in Figure 6.b. During analysis of results, it was noticed that the void existing in SRTM90 has an area about 0.08% of the total area as shown in Figure 6.a, where the SRTM90 constructed from SRTM30. Therefore, the voids have not a good treatment and the interpolation methods used to fill the voids were not quite ideal. Moreover, it was found that the voids existing affect the adjacent area so that it was impossible to get better results than that had been obtained as mentioned in Figures 7. Hence, the voids must be patched at first with new techniques to obtain superior results of DEM.

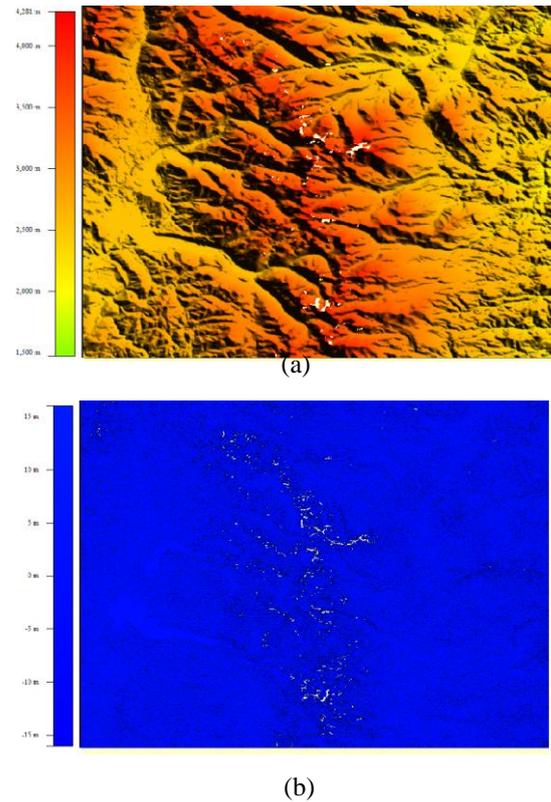


Figure (6): a) SRTM90 version2_1 with voids © NASA and b)The elevation differences between SRTM30 and created DEM using bicubic interpolation with pixel size 0.000104 arc-degrees have elevation differences controlled with ± 16.0 m (the white pixels)

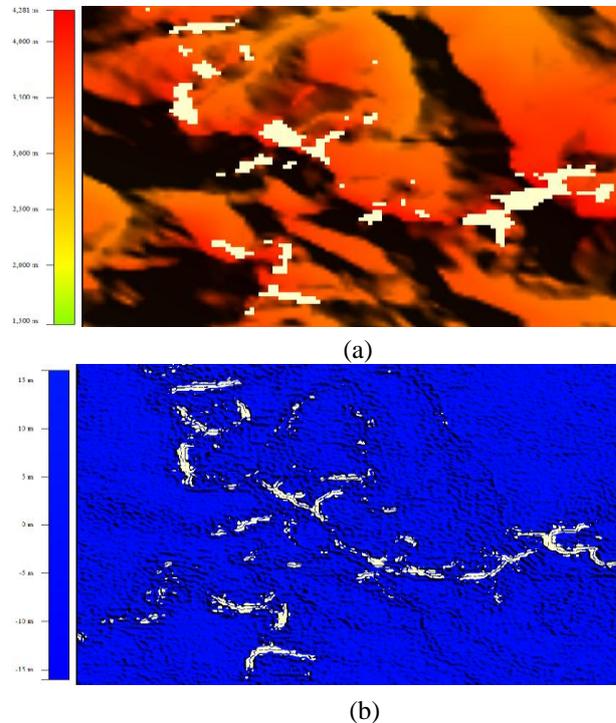


Figure (7): a) Focused area of SRTM90 version2_1 with voids © NASA and b)The elevation differences between SRTM30 and created DEM using bicubic interpolation with pixel size 0.000104 arc-degrees have elevation differences controlled with ± 16.0 m (the white pixels)

Table (1): The elevation differences between real SRTM 30 and created SRTM DEM using bicubic polynomial interpolation from SRTM90 using averaging method together with the statistics differences between real averaging SRTM 30 and created SRTM DEM using averaging method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using Bicubic polynomial interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	6531192	28.34	10883639	30.22	14740695	28.43	21527455	30.50	29200223	31.68
1.0	9092534	39.45	14226992	39.51	20220850	39.00	27673454	39.21	36144609	39.21
2.0	4091552	17.75	6159065	17.10	9177591	17.70	12062839	17.09	15198451	16.49
3.00	1781429	7.73	2560197	7.11	4029955	7.77	5022947	7.12	6280455	6.81
4.00	787879	3.42	1102522	3.06	1810278	3.49	2163067	3.06	2700522	2.93
5.00	360307	1.56	500690	1.39	851401	1.64	986438	1.40	1228723	1.33
6.00	172559	0.75	240786	0.67	423298	0.82	476128	0.67	594023	0.64
7.00	86998	0.38	123873	0.34	222408	0.43	245023	0.35	305277	0.33
8.00	46855	0.20	67377	0.19	122846	0.24	132712	0.19	166742	0.18
9.00	26916	0.12	39725	0.11	71474	0.14	77762	0.11	97027	0.11
10.00	16639	0.07	24765	0.07	44710	0.09	48152	0.07	60808	0.07
11.00	11154	0.05	16264	0.05	29195	0.06	32068	0.05	40464	0.04
12.00	7700	0.03	11325	0.03	19963	0.04	22431	0.03	28507	0.03
13.00	5498	0.02	8496	0.02	14468	0.03	16426	0.02	20615	0.02
14.00	4200	0.02	6382	0.02	10890	0.02	12537	0.02	15862	0.02
15.00	3284	0.01	5101	0.01	8572	0.02	9823	0.01	12206	0.01
≥16	22905	0.10	34802	0.10	55807	0.11	67539	0.10	84687	0.09
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	2.203		2.135		2.273		2.135		2.089	
Mean Diff.	0.0055		0.0015		-0.0113		0.0013		0.0011	
Min. Diff.	-202		-196		-226		-196		-237	
Max. Diff.	206		245		285		239		202	
Min. Elev.	1472		1473		1473		1473		1473	
Max. Elev.	4294		4294		4294		4294		4292	

Table (2): The statistics elevation differences between real SRTM 30, and created SRTM DEM using bilinear polynomial interpolation from SRTM90 using averaging method with the statistics differences between real averaging SRTM 30 and created SRTM DEM using averaging method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using Bilinear polynomial interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	5773195	25.05	9502451	26.39	11999189	23.14	17836726	25.27	23641224	25.65
1.0	7821519	33.93	12423373	34.50	17481189	33.71	24202522	34.29	31399164	34.06
2.0	4114374	17.85	6292167	17.47	9549232	18.42	12658045	17.94	16365823	17.75
3.00	2259268	9.80	3344791	9.29	5295118	10.21	6732882	9.54	8803004	9.55
4.00	1270553	5.51	1848066	5.13	3013385	5.81	3730251	5.29	4905184	5.32
5.00	728341	3.16	1045485	2.90	1750076	3.37	2129866	3.02	2796638	3.03
6.00	422366	1.83	602294	1.67	1033289	1.99	1243931	1.76	1627741	1.77
7.00	246118	1.07	353542	0.98	621196	1.20	741362	1.05	965698	1.05
8.00	145457	0.63	210739	0.59	378839	0.73	448880	0.64	581812	0.63
9.00	87308	0.38	126995	0.35	235110	0.45	276602	0.39	356544	0.39
10.00	52405	0.23	78828	0.22	149293	0.29	172609	0.24	221116	0.24
11.00	33052	0.14	50260	0.14	95819	0.18	110433	0.16	141549	0.15
12.00	21307	0.09	32456	0.09	63191	0.12	72052	0.10	92316	0.10
13.00	14114	0.06	21855	0.06	42427	0.08	48456	0.07	61638	0.07
14.00	9762	0.04	15207	0.04	29702	0.06	33886	0.05	42864	0.05
15.00	6884	0.03	10896	0.03	20991	0.04	23747	0.03	30877	0.03
≥16	43578	0.19	52596	0.15	96355	0.19	114551	0.16	146009	0.16
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	4.618		2.706		2.969		2.806		2.790	
Mean Diff.	0.025		0.00187		-0.088		0.0017		0.0476	
Min. Diff.	-195		-197		-292		-196		-209	
Max. Diff.	229		292		219		253		262	
Min. Elev.	1473		1473		1473		1473		1473	
Max. Elev.	4290		4291		4290		4291		4290	

Table (3): The elevation differences between real SRTM 30, and created SRTM DEM using nearest neighbor polynomial interpolation from SRTM90 using averaging method together with the statistics differences between real averaging SRTM 30 and created SRTM DEM using averaging method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using Nearest neighbor interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	4587817	19.90	5469731	15.19	9650242	18.61	12585434	17.83	16171839	17.54
1.0	6369869	27.64	7798597	21.66	12723709	24.54	16734027	23.71	22102838	23.98
2.0	3477805	15.09	4795582	13.32	7476885	14.42	10421303	14.77	13407602	14.55
3.00	2284223	9.91	3363943	9.34	5087065	9.81	7296604	10.34	9100624	9.87
4.00	1657367	7.19	2615057	7.26	3743248	7.22	5376036	7.62	6749105	7.32
5.00	1210551	5.25	2108085	5.85	2840074	5.48	4077769	5.78	5164972	5.60
6.00	900043	3.90	1711087	4.75	2188425	4.22	3154275	4.47	4012963	4.35
7.00	667748	2.90	1398418	3.88	1700104	3.28	2456459	3.48	3145459	3.41
8.00	492954	2.14	1147143	3.19	1327946	2.56	1909755	2.71	2482712	2.69
9.00	364344	1.58	943484	2.62	1045849	2.02	1479368	2.10	1970245	2.14
10.00	267976	1.16	782126	2.17	825843	1.59	1145138	1.62	1558840	1.69
11.00	197632	0.86	648612	1.80	652820	1.26	878960	1.25	1240856	1.35
12.00	144699	0.63	538518	1.50	518435	1.00	678089	0.96	988319	1.07
13.00	105627	0.46	447435	1.24	411825	0.79	523925	0.74	789085	0.86
14.00	77853	0.34	372637	1.03	326661	0.63	406882	0.58	629764	0.68
15.00	56470	0.24	309838	0.86	260152	0.50	315007	0.45	504185	0.55
≥16	186623	0.81	1561708	4.34	1075118	2.07	1137770	1.61	2159793	2.34
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	5.706		6.893		5.412		5.214		5.649	
Mean Diff.	0.1366		0.0018		0.0061		0.0016		0.022	
Min. Diff.	-298		-410		-387		-410		-387	
Max. Diff.	235		387		410		386		410	
Min. Elev.	1473		1473		1473		4291		1473	
Max. Elev.	5.705817		6.892873		5.412295		5.214386		5.649162	

Table (4): The elevation differences between real SRTM 30 and created SRTM DEM using Bicubic polynomial interpolation from SRTM90 using sampling method together with the statistics differences between real averaging SRTM 30 and created SRTM DEM using sampling method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using bicubic polynomial interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	7904126	34.29	12595081	34.97	19083272	36.80	24504488	34.72	32685609	35.46
1.0	9286217	40.29	14125644	39.22	20724159	39.97	27615943	39.13	36228292	39.30
2.0	3505927	15.21	5493707	15.26	7325409	14.13	10906408	15.45	13714338	14.88
3.00	1309941	5.68	2087253	5.80	2645427	5.10	4149696	5.88	5209594	5.65
4.00	523904	2.27	847851	2.35	1037041	2.00	1685707	2.39	2137982	2.32
5.00	229050	0.99	376822	1.05	452843	0.87	752073	1.07	958061	1.04
6.00	110291	0.48	183547	0.51	218683	0.42	365100	0.52	469333	0.51
7.00	58088	0.25	97964	0.27	116691	0.23	193622	0.27	250881	0.27
8.00	33652	0.15	56458	0.16	67146	0.13	112176	0.16	145289	0.16
9.00	20543	0.09	34881	0.10	41768	0.08	68835	0.10	89526	0.10
10.00	13598	0.06	22982	0.06	27810	0.05	45214	0.06	59169	0.06
11.00	9406	0.04	15841	0.04	19794	0.04	31448	0.04	40975	0.04
12.00	7021	0.03	11587	0.03	14390	0.03	22798	0.03	29779	0.03
13.00	5334	0.02	8801	0.02	11113	0.02	17438	0.02	22884	0.02
14.00	4181	0.02	6992	0.02	8790	0.02	13909	0.02	18084	0.02
15.00	3375	0.01	5583	0.02	6994	0.01	11105	0.02	14286	0.02
≥16	24947	0.11	41007	0.11	53071	0.10	80841	0.11	105119	0.11
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	2.082		2.116		1.990		2.128		2.112	
Mean Diff.	0.0021		0.0024		0.0018		0.0025		0.005	
Min. Diff.	-243		-283		-362		-287		-301	
Max. Diff.	305		366		312		361		381	
Min. Elev.	1472		1471		1471		1471		1471	
Max. Elev.	4301		4303		4303		4303		4303	

Table (5): The statistics elevation differences between real SRTM 30 and created SRTM DEM using bilinear polynomial interpolation from SRTM90 using sampling method together with the statistics differences between real averaging SRTM 30 and created SRTM DEM using sampling method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using Bilinear polynomial interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	6816144	29.57	11338891	31.49	16486468	31.79	21959518	31.11	27903536	30.27
1.0	8506025	36.90	12902657	35.83	19154323	36.94	25312607	35.87	33687507	36.55
2.0	3890500	16.88	5849389	16.24	8265759	15.94	11574753	16.40	15165733	16.45
3.00	1834351	7.96	2758243	7.66	3807825	7.34	5444953	7.71	7157931	7.77
4.00	906282	3.93	1387269	3.85	1867021	3.60	2751516	3.90	3611539	3.92
5.00	467169	2.03	734273	2.04	963900	1.86	1456187	2.06	1917248	2.08
6.00	250879	1.09	405021	1.12	519908	1.00	807583	1.14	1059976	1.15
7.00	138187	0.60	230107	0.64	290441	0.56	460125	0.65	607312	0.66
8.00	78778	0.34	134786	0.37	167133	0.32	271036	0.38	355754	0.39
9.00	46111	0.20	81821	0.23	100091	0.19	163230	0.23	216091	0.23
10.00	28699	0.12	51373	0.14	62526	0.12	102509	0.15	135320	0.15
11.00	18372	0.08	33301	0.09	40332	0.08	66015	0.09	87704	0.10
12.00	12164	0.05	22367	0.06	26767	0.05	44119	0.06	58238	0.06
13.00	8528	0.04	15514	0.04	18878	0.04	30625	0.04	40498	0.04
14.00	6228	0.03	11227	0.03	13613	0.03	22116	0.03	29565	0.03
15.00	4714	0.02	8505	0.02	10167	0.02	16498	0.02	22371	0.02
≥16	36470	0.16	47257	0.13	59249	0.11	93411	0.13	122878	0.13
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	4.414		2.476		2.357		2.491		2.499	
Mean Diff.	0.256372		0.0021		0.0011		0.0022		0.0551	
Min. Diff.	-212		-237		-217		-333		-245	
Max. Diff.	311		348		335		225		354	
Min. Elev.	1472		1472		1472		1472		1472	
Max. Elev.	4292		4293		4292		4293		4292	

Table (6): The statistics elevation differences between real SRTM 30 and created SRTM DEM using nearest neighbor polynomial interpolation, from SRTM90 using sampling method together with the statistics differences between real averaging SRTM 30 and created SRTM DEM using sampling method

Elev. Diff. in meter	Differences between real SRTM 30 and created SRTM DEM using nearest neighbor polynomial interpolation									
	0.000208 arc-degree		0.000167 arc-degree		0.000139 arc-degree		0.000119 arc-degree		0.000104 arc-degree	
	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area	Count cells	% area
0.0	5182620	22.48	5885852	16.34	9939679	19.17	13149717	18.63	15751283	17.09
1.0	6179170	26.81	7466365	20.73	12454513	24.02	15940033	22.59	20589682	22.34
2.0	3422793	14.85	4711088	13.08	7429134	14.33	10308245	14.61	13062771	14.17
3.00	2180648	9.46	3089323	8.58	5070873	9.78	7509691	10.64	9132302	9.91
4.00	1605085	6.96	2710802	7.53	3726003	7.19	5357689	7.59	6846137	7.43
5.00	1173613	5.09	2158499	5.99	2831343	5.46	4084041	5.79	5335485	5.79
6.00	835921	3.63	1662513	4.62	2183409	4.21	3242487	4.59	4202468	4.56
7.00	635494	2.76	1442380	4.01	1700194	3.28	2448845	3.47	3350693	3.63
8.00	472000	2.05	1165283	3.24	1331383	2.57	1923113	2.72	2659677	2.89
9.00	337850	1.47	937964	2.60	1049733	2.02	1522122	2.16	2133059	2.31
10.00	256303	1.11	799394	2.22	829601	1.60	1139190	1.61	1710817	1.86
11.00	191498	0.83	661713	1.84	658936	1.27	873461	1.24	1386412	1.50
12.00	137413	0.60	547209	1.52	523822	1.01	686272	0.97	1117004	1.21
13.00	104013	0.45	457825	1.27	415263	0.80	523316	0.74	902286	0.98
14.00	77876	0.34	380100	1.06	331762	0.64	406430	0.58	733246	0.80
15.00	56357	0.24	315960	0.88	265092	0.51	317447	0.45	592710	0.64
≥16	200947	0.87	1619731	4.50	1113661	2.15	1144702	1.62	2673169	2.90
Total Pixels	23049601		36012001		51854401		70576801		92179201	
	Statistics									
RMSE	5.729		7.044		5.521		5.295		6.107	
Mean Diff.	0.140408		0.0021		0.0021		0.0023		0.0024	
Min. Diff.	-452		-544		-583		-544		-544	
Max. Diff.	436		583		543		582		583	
Min. Elev.	1472		1472		1472		1472		1472	
Max. Elev.	4293		4293		4293		4293		4293	

7. CONCLUSION

The bicubic interpolation method that is available in MATLAB and used to interpolate SRTM90 DEM to get a new version of SRTM DEM was better than other interpolation method (Bilinear, and Nearest neighbor) and is characterized by its effortless and simplicity. Nearest neighbor interpolation is not desirable to use at all as bilinear interpolation gives rather accepted results.

Moreover, bicubic interpolation produced SRTM DEM with a high resolution could be rise up to 0.000104 arc- degrees that had the better results than the other resolutions. It could be concluded that the voids presented in SRTM90 DEM that were produced from SRTM30 DEMs affected the results which mean that the voids existing in SRTM90 DEM or SRTM30 were not treated enough.

More studies are further warranted to create another method to improve the filling of voids which exist in SRTM DEMs.

ACKNOWLEDGMENT

The author acknowledges NASA, USGS and JPL for providing the SRTM data set. The effort of those who offered reports and sources are greatly appreciated which was helpful and commonly spread by internet.

Note: All data used in this study are freely available from the sources mentioned in the text (see also references)

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Other Web sites of interest:

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- [18] NGA: <http://www.nga.mil/>
- [19] USGS: <http://seamless.usgs.gov/>.
- [20] SRTMFILL: <http://www.3DNature.com/SRTMFILL.html/>.
- [21] U.S. Geological Survey, EROS Data Center: <http://edc.usgs.gov/>.
- [22] http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/.
- [23] http://dds.cr.usgs.gov/srtm/version2_1/Documentation/SRTM_Topo.pdf.
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