*Available online a*t www.scientiaresearchlibrary.com

Scientia Research Library **ISSN 2348-0424**
USA CODEN: JETRB4

Journal of Engineering And Technology Research, 2014, 2 (2):81-92
(*http://www.scientiaresearchlibrary.com/arhcive.php*)

Comparative Analysis of IDW and Spline in Generation of Digital Elevation Models from Airborne LiDAR in Bare Lands

Fahmy F. F. Asal
Civil Eng. Department, Faculty of Engineering, Menoufia University, Shebin El-Kom, Egypt.

ABSTRACT
Light Detection and Ranging (LiDAR) is a recently established remote sensing technology, however its capabilities have not been fully exploited. Airborne Laser Scanning (LiDAR) is characterized by high density of point measurements that can be utilized in creation of digital elevation model (DEM) with levels centimetre accuracy. Since LiDAR measurements are always in discrete point data format, there is always a need for interpolation operations in order to create a continuous surface forming a DEM. As different interpolation techniques are expected to provide different quality DEMs it has been important to analyze the outcomes from those techniques. This research is focused towards evaluation of DEMs generated from raw airborne LiDAR measurements in bare lands using the Inverse Distance Weighting (IDW) and the spline interpolation approaches. A sample of raw LiDAR data for Gilmer county, USA has been exploited in the study. Digital elevation models have been generated from the data using IDW and spline approaches using a specialized spatial analysis system. A well designed group of qualitative and quantitative analysis tests have been exploited in the analysis of the generated DEMs. The analysis has shown that the spline approach has provided DEM of more corrugated surface, coarser tones and coarser texture compared to the DEM produced by the IDW algorithm. Also, IDW DEM possesses statistical quantities that are close to their correspondings of the raw LiDAR data while the spline DEM has statistical values with noticeable deviations from those of the raw LiDAR data. Additionally, spline DEM has provided corrugated contour lines in addition to numbers of tinny closed contour lines that could be spikes while the IDW has provided smoother contour lines with absence of any spikes. Finally, the slope map from IDW LiDAR DEM has shown fine tones, smooth texture and regular patterns referring to a terrain of gently varied slopes while the spline LiDAR DEM has interpreted coarser tone, coarser texture and disturbed patterns referring to corrugated slopes of the terrain.

Key words:- DTM/DEM/DSM, IDW, Spline, LiDAR, Airborne Laser Scanning, Spatial analysis.

INTRODUCTION

Digital Elevation Model

A Digital Elevation Model (DEM) is a continuous surface forms an array of a set of earth's surface points of X (Easting), Y (Northing), and Z (height). DEM data can be collected or generated using

GPS or ground Surveying techniques, analytical/analog/digital Photogrammetry and non imaging airborne techniques including Airborne Laser Scanning (LiDAR) and Airborne Synthetic Aperture Radar methods (SAR). The size and location of the project decides on the technique to be used for collecting DEM data. As an example if a project site is smaller than 100 acre area and is covered by tall trees and/or it is an urban area, the conventional surveying techniques (total station and spirit leveling methods) are optimal for such a project [1].

The concept of digital elevation model (DEM) can also, be used for digital representation of any single-valued surface such as a terrain relief model, Digital Terrain Model (DTM) or for representing the top surface of an urban or rural area to form a digital surface model (DSM). The concept also, can be used in other disciplines such as in demography to represent the variation of the population density over a certain region. DEMs are widely used in remote sensing and geographical information systems (GIS) as they are mainly used for ortho-rectification of images, topographic mapping, and engineering design and modeling. Furthermore, DEMs are used in numerous disciplines, ranging from geo-information to civil engineering. In various applications a DEM serves as an input for decision making, as examples they are employed in flood hazard analyses [1].

Airborne Laser Scanning (LiDAR)

LiDAR (Light Detection and Ranging) technology is a remote sensing technology measuring distances from a light source to targets. For surveying and mapping applications, the targets in general can be water or land. The light source of the topographic LiDAR works at the infrared portion of the electromagnetic spectrum, which is mostly reflected by land and absorbed by water [2]. LiDAR equipments can be mounted on a tripod, on a ground vehicle, onboard an airplane, or even on board a satellite. For urban remote sensing airborne topographic LiDAR is the most popular one. LiDAR instruments must work with other instruments as an integrated calibrated system to provide accurate geo-referenced three-dimensional measurements. As seen in figure 1, a typical Airborne Laser Scanning system consists of three main subsystems [2], [3]. The first system is a laser unit which transmits laser pulses to the target and receives the returned signals. This unit is provided with very high accuracy clock that records the round-trip travel time between the transmitted pulse and received signal. The recorded travel time is divided by two and multiplied by the speed of light yielding the distance (range) between the laser emission unit and the target. The second system onboard is an Inertial Measurement Unit (IMU) that measures the orientation of the LiDAR scanner (roll, pitch and yaw), and the third system constitutes a complete Global Positioning System (GPS) (two units; a reference unit on the Ground and a GPS receiver mounted onboard the airplane for determining the position of the airplane. Post-processing the measurements from the three systems determines the three-dimensional geo-spatial coordinates of every LiDAR return [2], [3].

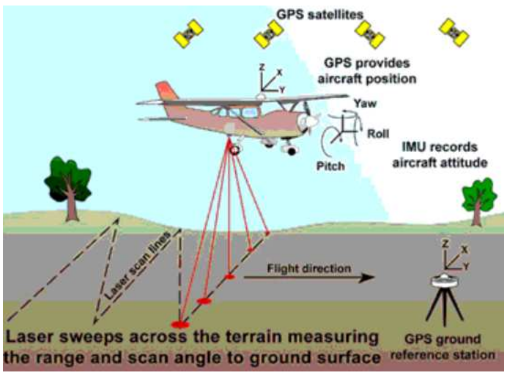

Figure 1: Airborne Laser Scanning System [7]

Airborne LiDAR provides solutions for extracting urban information from range measurements [4], [5]. Compared to the other conventional Aerial Photogrammetry and Satellite imagery capture technology, LiDAR is an active remote sensing technology and thus data can be collected at night which can be very important for certain applications especially in large municipalities. LiDAR is also a three-dimensional remote sensing technology with which planimetric and vertical positions can be obtained as direct measurements. In terms of quality, present LiDAR data can have sub-metre resolution and centimetre positional accuracy. This property is superior to almost all other remote sensing data and therefore greatly extends the capabilities and potentials of urban remote sensing [6].

DEM Interpolation

Prior to using DEMs in various applications, it is important to identify the errors induced in the created DEMs to ensure that they meet the required accuracy standards necessary for a specific application [8]. Achieving and maintaining the accuracy of the Z component of a DEM is a challenging and difficult job. However, estimating the accuracy of a DEM is an essential issue in the acquisition of spatial data, particularly for applications that require a highly accurate DEM, such as engineering applications. The accuracy of a DEM is subject to many factors such as the number of sampling points, the spatial distribution of the sampling points, the method of interpolation of the surface, the propagated errors from the source data and other factors [9], [10].

Elevation interpolation can be defined as the process of predicting a value of attribute z at unsampled site from the measurements carried out at sites within given neighborhoods. Interpolation is used to create discrete continuous surface from observations at sparsely located points or for resampled grid to different density or orientation as in remote sensing images. Interpolation may be considered as spatial filtering process where the input data are not necessarily located at a continuous grid. Interpolation is usually a complicated operation. Also, interpolation operation can be expressed in a mathematical command language, however most users will encounter specialist packages so that standard terminology can be used. It is important to note here that predicting the elevation value outside the site area from the point data is known as extrapolation. [11], [12].

The main purpose of an interpolation operation is the conversion of point data files into continuous fields so that the spatial patterns of these measurements can be compared with the spatial patterns of other entities. Interpolation operation is also, applied when it is required to have different levels of resolutions of a surface. It may be also applied when the continuous surface is represented by different models. Moreover, an interpolation operation is performed when the data available does not cover the domain of the area of interest [11].

Interpolation methods may be divided into two main groups, global interpolation methods and local interpolation techniques. Global interpolation uses all available data to provide prediction of the whole area of interest. On the other hand, local interpolators operate within a small zone around the point being interpolated to ensure that the estimates are made only with data from locations in the immediate neighborhood and fitting the surface as good as possible. As examples of global interpolation methods, classification using external information, trend surface or geometric coordinate regression methods or surrogate attributes and the methods of spectral analysis. However, local interpolation techniques encompass Thiessen polygons and pycnophyactic methods, inverse distance weighting, and thin plate splines [12].

Inverse Distance Weighting (IDW) Algorithm

Inverse distance methods of interpolation combine the ideas of proximity adopted by thiessen polygons with the gradual change of the trend surface. It is assumed that the value of an attribute z at unvisited point is a distance weighting average of data points occurring within a neighborhood or window surrounding the unvisited point. The original data points may be located on a regular grid or they can be distributed irregularly over an area and interpolation made to locations on a denser regular grid in order to make a map. The weighted moving approach computes [12]:

$$z = \sum_{i=1}^{n} \lambda_i z(x_i) \quad \text{and} \quad \sum_{i=1}^{n} \lambda_i = 1 \tag{1}$$

where:

λi = the weights which are functions of the position of the point i , Thus,
λi = φ(d(x, xi))

It is required that φ (d) tends to the measured value as d tends to zero. This is given by the exponential function e^{-d} and e^{-d^2}.
The most common form of φ(d) is the inverse distance weighting predictor whose form is [12]:

$$z(x_0) = \sum_{i=1}^{n} z(x_i) d_{ij}^{-r} \ / \ \sum_{i=1}^{n} d_{ij}^{-r} \tag{2}$$

where,

xj = the points where the surface to be interpolated,
xi = the data points.
r = the power of the formula which can be 1, 2, ….n

As in equation (2), φ(d) tends to infinity as d tends to zero thus, the value of the interpolation point that coincides with a data point must be copied over. The simplest form of this is called linear interpolator, in which the weights are computed from a linear function of distance between sets of data points and the points to be predicted. It should be noted that, at the data point the inverse distance weighting is forced to the exact value of the point data. This means that if the input grid coordinates are equal to those of a sampling point then the observed points will be copied over unsmoothed. The quality of the DEM produced from the IDW interpolation may be assessed by using additional observations as the method has no inbuilt technique for the testing the quality of interpolation [11], [12].

Spline Algorithm

The spline technique came from the spline (flexible) ruler used in fitting curves to sets of data by draftsmen before the development of computers allowing them to be used in doing this job. The best fitting smooth line produced by eye using the spline ruler is approximately a part of a cubic polynomial that is continuous and has continuous first and second derivatives. Spline functions are mathematical equivalence of the flexible ruler. These are piece-wise functions. This is to say that they are fitted to a small number of data points exactly. In the same time they ensure the continuous joins between one part of the curve and another. This means that with splines it is possible to modify one part of the curve without having to recompute the whole of curve. The general definition of a piece-wise polynomial function is [11], [12]:

$$P(x) = P_i(x) \qquad x_i < x < x_{i+1} \qquad (3)$$

where,

i = 0, 1, ………., k-1

$$Pj(x) = P^j_{i+1}(x_i) \qquad j = 0, 1, …………….r-1 \qquad (4)$$

where,

i = 1, 2, ………., k-1.

x_i ……….x_{k-1} = the points which divide the distance x_0,x_k into k sub-intervals. These points are called break points while the points of the curve at these values of x are called knots.

$P_i(x)$ = polynomial functions of m degrees of freedom.

r = the constraints on the spline. Thus, r = 0 means that there are no constraints on the spline, however, r = 1 refers to a continuous function without any constraints. At r = m+1 x_0,x_k can be represented by a single polynomial. The spline is linear at m = 1 while being quadratic at m = 2 and cubic at m = 3

When interpolating a surface using spline techniques an approximate function passes as near as possible to the data points taking into account the surface becoming as smooth as possible.
Assume that following [11], [12]:

$$y(xi) = z(xi) + \varepsilon(xi) \qquad (5)$$

where: z = the measured value of the elevation at the pint xi.
ε = the random error in the elevation measurement.

The spline function p(x) should pass as close as possible to the data values. So the smoothing spline is the function f that minimizes the following quantity [12]:

$$A(f) + \sum w_i^2 \{ f(x_i - y(x_i) \}^2 \qquad (6)$$

In equation (6), the first term represents the smoothness of the function while the second term represents the proximity to the data. The weights w_i^2 are calculated from the following equation [11], [12]:

$$w_i^2 = p / Var[\varepsilon(x_i)] = p / s_i^2 \qquad (7)$$

Where the value of P refers to a relative importance given by the operator to each characteristics of the smoothing splines.

MATERIAL AND METHODS

This research concentrates on studying the effects of interpolation technique exploited in the generation of LiDAR DEM in bare lands on the quality of the DEM while keeping the other factor unchanged. Inverse Distance Weighting (IDW) and spline are two different local interpolation techniques that are often used in DEM creation from point data measurements. DEMs created from raw LiDAR data using both techniques are expected to be of different characteristics, different quality and different accuracy. The study aims at evaluation of the quality of DEMs created raw LiDAR data in bare lands using each of these two interpolation techniques.

Figure 2 shows a sample of raw LiDAR data collect at bare lands for Gilmer county, USA in March and April 2004. The sample data consists of about 12000 points and covers an area of about 16800 squared-meters giving point density of one point per 1.4 squared-metres. The statistical properties of the sample data has been compute and shown in table1. DEMs have been created from the raw LiDAR data using ESRI spatial analysis and 3-D analyst working under ArcView GIS commercial package using IDW and spline algorithms. Qualitative analysis of the DEMs has been undertaken aiming at viewing differences between IDW LiDAR DEM and spline LiDAR DEM in representing the earth's surface. Also, statistical analysis has been carried out for both IDW and spline LiDAR DEMs in addition to the test sample raw LiDAR measurements. Moreover, contour line maps have been created from IDW DEM and from spline DEM and analyzed visually and statistically. Finally, creation and analysis of the slope maps have been executed The analysis applies comparative approach between LiDAR DEMs from IDW and spline algorithms aiming at assessment of how efficient each of these two interpolation techniques in the creation of better quality and more accurate DEM.

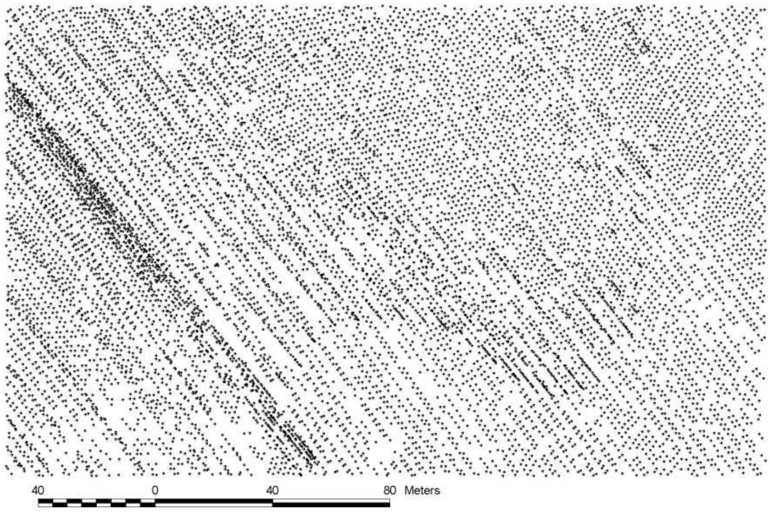

Figure 2: Row LiDAR measurements at bare lands for Gilmer county, USA in March and April 2004

RESULTS AND DISCUSSION

Visual Analysis of IDW and Spline LiDAR DEMs

Figure 3 is a digital elevation model created from raw LiDAR data using IDW of power 2 as the default settings of ArcView and grid cell size of 0.25 meters. The no. of neighbours used in the creation of the DEM is 12 as the default setting of the ArcView GIS systems. The DEM is showing wide variations in the tone/colour with fine tone and fine texture referring to gently varied terrain. In figure 3 there is absence of any spikes which refers to smooth terrain. Analyzing the attached legend of the LiDAR DEM, figure 3, shows a minimum elevation of 329.151 metres and a maximum elevation of 382.32 metres which gives a rage of elevations of 53.17 metres depicted by the DEM. These values are very close to the corresponding values of the raw LiDAR data set recorded in table 1.

Figure 4 is a digital elevation model created from the same raw LiDAR data using the default setting of the spline algorithm in ArcView system (weight =0.10) with reserving the same grid cell size of the IDW DEM at 0.25 metres. Different from the DEM from the IDW, a bit more corrugated terrain has been obtained from spline algorithm which is much clearer at the border lines separating the different colour/elevation classes. Despite the wide range of tones and the fine tones that have been obtained, a coarser texture DEM has been the case if it is compared to the DEM in figure3. Again no presence of tinny colour batches as the same outcome from figure 3 of smooth terrain. Referring to the legend of the LiDAR DEM in figure 4, it can be found that the minimum elevation in the DEM is 328.81 meters while the maximum elevation is 382.442 meters which leads to a range of elevations of 53.66 metres. This is a wider range of elevations compared to that of the raw LiDAR data of 53.21 metres.

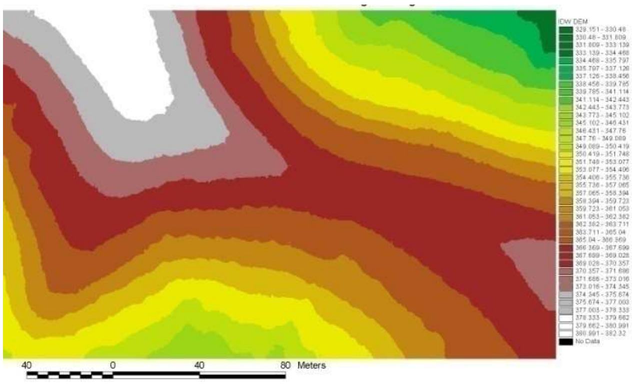

Figure 3: LiDAR DEM created using the IDW algorithm.

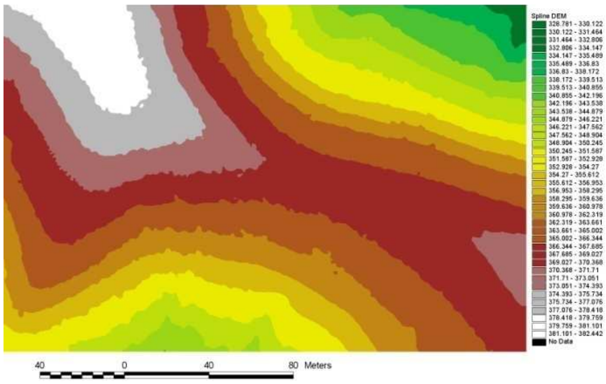

Figure 4: LiDAR DEM created using the spline algorithm.

Statistical Analysis of IDW and Spline LiDAR DEMs

Table 1: The statistical analysis of the raw LiDAR sample test data, the DEM created using IDW and the DEM obtained from spline Algorithms.

Statistical Value	Raw LiDAR Data	DEM from IDW	DEM from Spline
Count (No. points/cells)	11176	662004	662004
Sum of elevations (m)	4059268.17	239897977.7	239893918.6
Maximum elevation (m)	382.34	382.32	382.44
Minimum elevation (m)	329.13	329.15	328.78
Mean (Average) elevation (m)	363.213	362.3815	362.3753
Median elevation (m)	365.34	364.43	364.44
Mode elevation (m)	369.43	368.39	368.38
Range of elevations (m)	53.21	53.17	53.66
Variance elevation (m^2)	103.6222	104.089	104.4423
Standard Deviation of elevations (m)	10.1795	10.2024	10.2197

Table 1 records the results of the statistical analysis of the raw LiDAR sample test data, the IDW DEM and the spline DEM generated from these raw LiDAR data. As the grid cell size used in the creation of the DEMs has been kept unchanged then the no. rows, the no. of columns and the total no. of cells (counts) are similar in both DEMs. However, the IDW LiDAR DEM is giving higher sum of elevations than that is given by the spline LiDAR DEM. Also, regarding the minimum elevation the IDW LiDAR DEM records a value of 329.15 metres which is higher than the minimum value in the raw LiDAR data, 329.13 metres, by about 2.0 cm. The spline LiDAR DEM records a corresponding minimum value of 328.78 metres which is lower than the corresponding value in the raw LiDAR by about 37 cm. For the maximum values, IDW LiDAR DEM records 382.32 metres which is lower than that of the raw LiDAR data, 382.34 metres, by only 2 cm. The spline LiDAR DEM gives a maximum value of 382.44 cm which higher than that of the raw LiDAR data by 10 cm. When analyzing the mean values it can be found that both IDW and spline LiDAR DEMs record mean values of 362.3815 and 362.3753 metres respectively which are very close, however those two values are lower than that of the raw LiDAR data of 363.213 metres by more than 80 cm which indicates that the interpolation operation from both techniques has made clear smoothing of the surface. The same can be said for the median which is medium value in the DEM and the Mode which is the value of highest frequency in the set where both record lower values compared to those of the raw data by more than 90 cm which supports the same outcome from the mean value analysis. When comparing the variance and the standard deviation of the surface, it can be said that IDW LiDAR DEM gives closer values to the raw LiDAR data than their corresponding values given by the spline LiDAR DEM. In general it can be said that IDW LiDAR DEM in some cases records statistical values that are closer to those of the raw LiDAR data than their corresponding values given by the spline LiDAR DEM.

Visual Analysis of Contourline Maps Extracted from IDW and Spline LiDAR DEMs

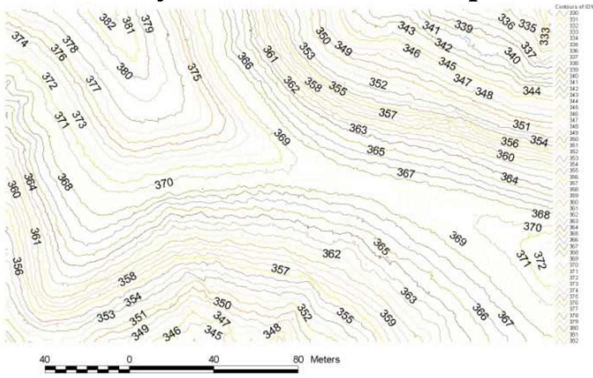

Figure 5: Contour line map extracted from a LiDAR DEM generated using IDW algorithm.

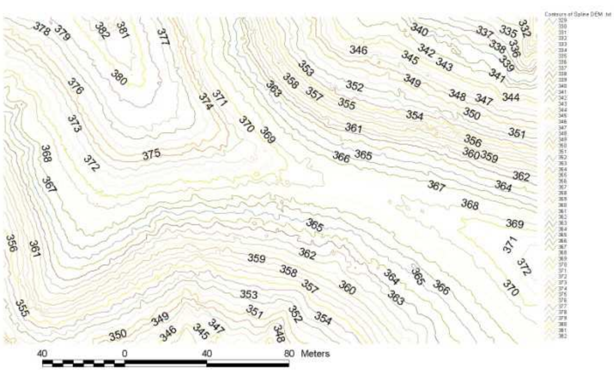

Figure 6: Contour line map extracted from LiDAR DEM generated using spline algorithm.

Figures 5 shows a contour line map generated from the IDW LiDAR DEM while figure 6 represents a contourline map produced from the spline LiDAR DEM. Both maps have been created with 1.0 metres contour interval so that individual contour lines can be distinguishable and the map as a whole can be visually interpretable (where smaller contour intervals create high crowding of contour lines which makes visual interpretation a bit difficult). In figure 5 the individual contour lines mostly run smooth with some corrugation. When comparing, figure 6, the situation is a bit different where more corrugated contour lines are observables referring to that more corrugated surface have been produced from the spline technique. Also, a number of tinny closed contour lines are interpretable in figure 6 referring to spikes in the contour line map from IDW while this is very rarer in the contour line map from IDW LiDAR DEM, figure 5. Additionally, referring to the legends of the two maps it can be found that the minimum contour in the map from IDW is 330 while that is from the spline approach is 329.0 metres. Also, the maximum contours are 382.0 metres in both contour line maps.

Statistical Analysis of Contourline Maps Extracted from IDW and Spline LiDAR DEMs

Table 2 records results of the statistical analysis of the two contour line maps. The count of the contour lines in the map from spline is 234 which is bigger than that in map from IDW, 228. The same may be said for the mean contour comparing the value of 357.664 from spline map with that of 357.382 from the IDW map. Also, the range of contours which is bigger in the case of the spline map than that from the IDW map. Additionally, the standard deviation of the contours expresses the same result. This means that spline approach gives more structured contour map in the meanwhile the IDW algorithm provides more smoothed contour line map. This result has to be explained in the light of the outcomes from further testing analysis.

Table 2: the statistical analysis of the contour maps generated from IDW and spline LiDAR DEMs

The Statistical Value	Contour Map from IDW LiDAR DEM	Contour Map from spline LiDAR DEM
Count of contours	228	234
Minimum contour (m)	330	329
Maximum contour (m)	382	382
Mean contour (m)	357.382	357.664
Sum of contour elevations (m)	81483	47927
Range of contours (m)	52	53
Standard Deviation of contours	12.642	13.076

Visual Analysis of Slope Maps Produced from IDW and Spline LiDAR DEMs

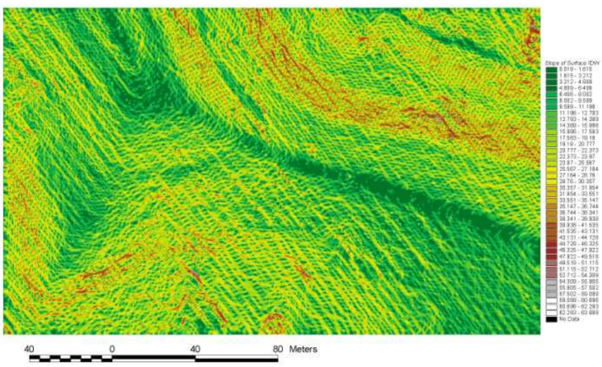

Figure 7: Slope map extracted from a LiDAR DEM generated using IDW algorithm.

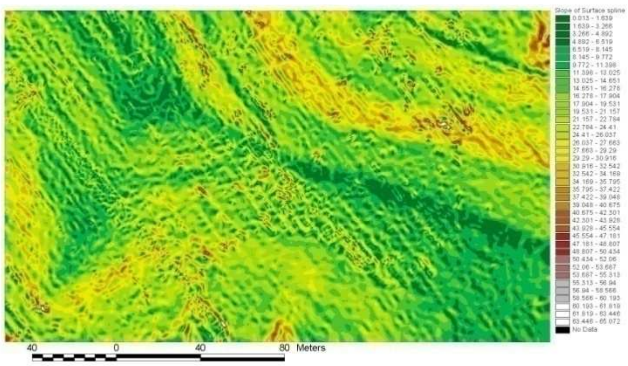

Figure 8: Slope map extracted from a LiDAR DEM generated using spline algorithm.

Figure 7 shows a slope map generated from the IDW LiDAR DEM while figure 8 represents a slope map produced from the spline LiDAR DEM. Figure 7 shows fine tone and smooth texture referring to terrains of gentle slopes. In the contrary, figure 8 interprets coarser tone and coarser texture referring to a more corrugated surface. Also, comparing the pattern which is the arrangements of objects in the DEM it can be seen that the slope map from spline DEM provides coarser and disturbed patterns compared to that has been given by the slope map from IDW DEM which gives less disturbed pattern slope map. Additionally the legend of the slope map from IDW, records a minimum slope of 0.0129 degrees and a maximum slope of 62.999 degrees giving a range of slopes of 63.87 degrees. However, the legend of the slope map from the spline DEM records a minimum slope of 0.013 degrees while the maximum slope is 65.072 degrees which refers to a wider range of terrain slopes as 65.059 degrees.

Statistical Analysis of Slope Maps Developed from IDW and Spline LiDAR DEMs

Table 3 depicts the statistical analysis of the slope maps generated from IDW and spline LiDAR DEMs. The no. rows, the no. of columns and the total no. of cells (counts) are similar in both DEMs. Referring ,to the sum of slopes depicted in the two maps it can be seen the slope map from the spline LiDAR DEM is giving higher sum of slopes than that is given by the slope map from the IDW LiDAR DEM. Regarding the minimum slopes the IDW LiDAR DEM records a value of 0.01855 degrees which is higher than the minimum value given by slope map from the spline LiDAR DEM which is of 0.01291 degrees. For the maximum values, the slope map from IDW LiDAR DEM records 63.88933 degrees which is lower than that from the slope map from spline LiDAR DEM recording 65.07203 degrees. When analyzing the mean value it can be found that the slope map from IDW gives a lower value of 17.3022436 degrees compared to that is given by the slope map from spline DEM of 17.9185925 degrees. However, when comparing the variance and the standard deviation of the surface, it can be said that slope map from IDW DEM gives higher values of slopes compared to those given by the spline DEM which could be due the tendency of the spline algorithm to best fit and consequently smooth the surface.

Table 3: Results of the statistical analysis of the slope maps generated from IDW and spline LiDAR DEMs respectively

Statistical Value	Slope of IDW LiDAR DEM	Slope of spline LiDAR DEM
No. of rows	639	639
No. of columns	1036	1036
Count (no. of cells)	662004	662004
Sum of Slopes (degrees)	11454154.48	11862179.9
Minimum Slope (degrees)	0.01855	0.01291
Maximum Slope (degrees)	63.88933	65.07203
Mean Slope (degrees)	17.3022436	17.9185925
Range of Slopes (degrees)	63.87078	65.05912
Variance of the Slopes $(\text{degrees})^2$	87.649	72.352
Standard Deviation of Slope (degrees)	9.36211	8.50594

CONCLUSION

Airborne laser scanning (LiDAR) has been recently a well established technology that is characterized by high density of measurements that can be reaching submetre point spacing (depending of the flying height and the scanning increment angle). LiDAR measurements can be utilized in the creation of digital elevation model (DEM) of levels of centimetre accuracy which makes it superior to any other remote sensing technique in that context. There is always a need for an interpolation operation for creation of a continuous surface represented by DEM for LiDAR point data measurements. Different interpolation techniques are expected to provide different quality DEMs. For this reason it has been important to study the outcomes from the different interpolation techniques. This research has been focused towards evaluation of the DEMs generated from airborne raw LiDAR measurements in bare lands using each of the Inverse Distance Weighting (IDW) and spline interpolation approaches. Raw LiDAR data for Gilmer County, USA has been exploited in the study. Digital elevation models have been generated from the data using IDW and spline interpolation approaches keeping the default settings of ArcView system. A well designed group of analysis tests including, visual analysis of the DEMs, statistical analysis of the DEMs, contour line mapping from the DEMs, statistical analysis of the contour line maps from the DEMs, slope maps from the DEMs and finally, statistical analysis of the slope maps from the DEMs have been exploited in the analysis of the DEMs from IDW and spline. From the analysis some concrete conclusions can be extracted:

- The spline approach provides a DEM of more corrugated surface, coarser tones and coarser texture compared to the DEM given by IDW algorithm.
- The statistical analysis of the DEMs has indicated that IDW DEM possesses statistical quantities that are very close to the corresponding quantities of the raw LiDAR data. In the opposite the spline DEM has statistical values with bigger deviations from those of the raw LiDAR data especially, the minimum, the maximum and the range of elevations.
- The contourline map from spline DEM has provided corrugated contour lines in addition to a number of tinny closed contour lines interpreted as spikes in the contour line maps while the IDW has provided smoother contour lines with absence of any tinny closed contours that could be spikes.
- The slope map from IDW LiDAR DEM has shown fine tone, smooth texture, regular pattern referring to a terrain of gently varied slopes while the slope map from spline LiDAR DEM has interpreted coarser tone, coarser texture and mixed and disturbed pattern referring to a bit more corrugated surface.
- Further analysis is necessary for the assessment of the differences between IDW LiDAR DEM and spline LiDAR DEM.

REFERENCES

[1]. Acharya, B., Fagerman, J. and Wright, C. Accuracy Assessment of DTM Data: a Cost Effective Approach or a Large Scale Digital Mapping Project, International Archives of Photogrammetry & Remote Sensing, Vol. XXXIII, Amsterdam, **2000**.

[2]. Wehr, A. and U. Lohr,. Airborne laser scanning — an introduction and overview, *ISPRS J. Photogrammetry Remote Sensing*, 54(2–3), 68–82, **1999**.

[3]. Fowler, R. *Topographic LIDAR, in Digital Elevation Model Technologies and Applications: The DEM Users Manual*. David F. Maune, Ed., The American Society for Photogrammetry and Remote Sensing, Bethesda, MD, 539 pp, **2001**.

[4]. Ackermann, F. Airborne laser scanning — present status and future expectations, *ISPRS J. Photogrammetry Remote Sensing*, .54(2–3), 64–67, **1999**.

[5]. Baltsavias, E. A comparison between photogrammetry and laser scanning, *ISPRS J. Photogrammetry Remote Sensing*, 54(2–3), 83–94, **1999a**.

[6]. Lee, J., Biging, G. S., Radke, J. D. and Fisher, J. B. 2013. An improved topographic mapping technique from airborne lidar: application in a forested hillside. *International Journal of Remote Sensing* Volume 34, Issue 20, **2013**.

[7]. Bureau of Economic Geology. *Mapping Shorelines Using Airborne LiDAR*, http://www.beg.utexas.edu/coastal/poster_measuringchange.htm, the University of Texas, USA, **2013**.
[8]. Acharya, B. and Chaturvedi, A. Digital Terrain Model: Elevation Extraction and Accuracy Assessments. *Journal of Surveying Engineering*, Vol. 123, No.2, May **1997**, pp. 71-76.
[9]. W. Karl, N. Pfeifer and C. Briese, “DTM Quality Assessment”, Working Group 11/7, **2006**.
[10]. Zhu, C., Shi, W., Wang, Q. Li, G. , Cheung, T. C. K., Dai, E. and Shea, G. Y. K. Estimation of Average DEM Accuracy under Linear Interpolation Considering Random Error at the Nodes of TIN Model. *International Journal of Remote Sensing*, Volume 26, Number 24, **01D2005**, pp. 5509-5523(15).
[11]. Lo, C. P. and Yeung, A. K. W. *Concepts and Techniques of Geographic Information Systems*. Prentice-Hall of India Private Limited, New Delhi – 110 001, **2004**.
[12]. Burrough, P. A. and McDonnell, R. A. *Principles of Geographical Information Systems*. Oxford University Press, **2000**.