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Creation and Evaluation of Digital Elevation Models from Ground Surveying Measurements

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ABSTRACT

Creation of a Digital Elevation Model (DEM) from point support files requires exploitation of an interpolation approach in order to get a continuous surface forming a DEM. The Inverse Distance Weighting (IDW) and the thin plate spline methods are two local interpolation methods that are very often exploited in the creation of DEMs. Different interpolation techniques have to be expected to provide different quality DEMs. This research has been focused towards evaluation of the quality of the DEMs generated from ground surveying measurements using IDW and thin plate spline. A test site in a hilly corrugated terrain area has been established and digital elevation measurements have been collected from field using conventional ground surveying methods where a total station instrument has been used for measuring the three dimensional coordinates (x, y, z) of the selected spot points. DEMs have been created from the field data using commercial spatial analysis systems; in addition qualitative analysis of the DEMs has been undertaken aiming at viewing differences between IDW DEM and the spline DEM in representing the earth's surface. Furthermore, quantitative analysis has been carried out using sets of external checkout points uniformly distributed over the test area. Visual analysis has shown that the IDW DEM possesses wide variations in the tone/colour throughout the DEM with rough texture compared to the thin plate spline DEM which shows narrower variations of the tone/colour and finer texture. The statistical analysis of the DEMs has shown that IDW DEM has given a minimum elevation, a maximum elevation and a range of elevations of values that have been very close to those of the original test data set while the corresponding values from the spline DEM have been very different from those values of the original data. The 3D view from IDW DEM has shown corrugated surface while that of the spline DEM has also shown a corrugated surface but with clear elevation spikes that can be interpreted as elevation interpolation noise. The accuracy assessment using external checkout points has shown that the maximum residual from IDW DEM has been greater than that from the spline DEM while the absolute minimum residual from IDW DEM has been smaller than that from spline DEM. Additionally, the absolute algebraic sum of residuals from IDW DEM has been much smaller than that from the spline DEM. Finally, the standard error of the extracted elevations and the standard error of the mean of the extracted elevations from IDW DEM have been smaller than their corresponding values from the spline DEM which refers to that IDW algorithm has generated more accurate digital elevation model compared to the DEM that has been generated by the thin plate spline approach.

Key words:- DEM/DTM/DSM, Ground Surveying, IDW, Thin plate spline, Digital Mapping, 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, analogue photogrammetry, analytical photogrammetry, digital photogrammetry and non imaging airborne techniques including Airborne Laser Scanning (ALS) and Airborne Synthetic Aperture Radar (SAR). The size and location of the project decides on the technique to be used for collecting the data used in the creation of a DEM. For example, if a project site is smaller than 100 acres or it is covered by tall trees with urban landscape, the conventional surveying techniques; total station and spirit leveling, are optimal for such a project [1], [2].

The concept of the digital elevation model can be used for digital representation of any single-valued surface such as a terrain relief model namely; Digital Terrain Model (DTM), or representing the top surface of an urban or rural area forming a Digital Surface Model (DSM). The DEM concept also, can be used in other disciplines; such as in demography to represent the variations of the population density over a certain region. Every day the digital elevation models gains new areas of applications in many environmental and engineering disciplines. They are intensively used in remote sensing and Geographical Information Systems (GIS) applications as a DEM constitutes a main input in ortho-rectification processing of images. Moreover, DEMs are widely used in topographic/contour mapping, in engineering design and in modelling different environmental phenomena. 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 an example they are employed in flood hazard analysis [3].

Digital Elevation Model Quality

Prior to the use of DEMs in various applications it is important to identify their qualities in order to determine the suitability of a certain DEM to the quality standards necessary for a specific application [4]. The quality of a DEM is subjected to some factors such as the density of the sampling points, the spatial distribution of the sampling points, the method of interpolation used, the propagated errors from the source data in addition to other factors [5], [6]. This research aims at studying the effects of the interpolation techniques, the Inverse Distance Weighting (IDW) and the thin plate spline employed in the generation of the digital elevation models on the quality of that DEM in addition to the effects of these techniques on the accuracy of the extracted elevations from the DEM, while keeping the other factors unchanged. Inverse Distance Weighting (IDW) and thin plate spline are two different techniques that are used in DEM creation from point data measurements. DEMs created from both techniques are expected to be of different characteristics, different qualities and different accuracies.

Creation of Digital Elevation Models from Discrete Spot Elevation Measurements

Interpolation: concepts, types and techniques

Elevation interpolation is a complicated operation that can be defined as a process of predicting a value of an attribute z at unsampled site from measurements carried out at neighbouring sites within given neighborhoods. The process aims at creation of a continuous surface from observations at sparsely located points or for resampled grid to different density or orientation as in remote sensing images [3]. Elevation interpolation could be considered as a spatial filtering process where the input data are not necessarily located at on a continuous grid. Interpolation operations can be expressed in a mathematical command language, however most users will encounter specialist packages so that standard terminology can be used. It may be useful to mention that predicting an elevation value outside the site area from the point data is known as extrapolation [6], [7]. 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 [6]. Interpolation operation is applied when the discretised surface has different levels of resolution from the required surface. It may be also applied when the continuous surface is represented by different models. Moreover, interpolation operation is performed when the data available does not cover the domain of the area of interest [6].

Interpolation methods may be divided into two main groups, global interpolation 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 neighbourhood and fitting as good as possible. As examples of global interpolation methods, classification using external information, trend surface on geometric coordinates, regression models on surrogate attributes and the methods of spectral analysis. However, local interpolation techniques encompass thiessen polygons and pycnophyactic methods, linear and inverse distance weighting and thin plate splines. Global interpolations in most cases are not used for direct interpolation, but for examining the effect of global variations and sometimes removal of this effect that may be caused by major trends. As soon as the effect of global variations in the data is removed the data can be interpolated using local interpolators in different types of gentle and corrugated terrains. All global and local interpolation methods are relatively straightforward as they require only understanding of simple statistical methods. Commercial GIS packages usually include these methods. Geo-statistical interpolation using methods of spatial autocorrelation is known as kriging as they require understanding of the principles of statistical spatial autocorrelation. These methods are used when the variation in elevations is so irregular and the density of the sample is such where simple interpolation methods may not give reliable predictions [5], [6], [7].

DEM interpolation using the Inverse Distance Weighting (IDW) technique

The ideas of proximity adopted by thiessen polygons are combined with the gradual change of the trend surface by the Inverse Distance Weighting (IDW) technique. It is assumed that the value of an attribute z at unvisited point is a distance weighting average of data points occurring within a neighbourhood or window surrounding the unsampled point. The original data points may be located on a regular grid as well as they can be distributed irregularly over an area where interpolation is performed to locations on a denser regular grid in order to produce a map. The weighted moving approach computes the interpolated elevation as [6]:

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

where:

λi = the weights, which are functions of the position of the point i, Thus,
$\lambda i = \varphi\,(d(x, xi))$

The value of φ(d) tends to the measured value as d tends to zero, which 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 [6]:

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

where,

xj = the points where the surface is to be interpolated,

xi = the data points.

r = the formula power, which can be 1, 2, ., ...n

As in equation (2) φ(d) tends to infinity as d tends to zero, the value of the interpolated point that coincides with a data point must be copied over. The simplest form of this interpolation is called linear interpolator, in, which the weights are computed from a linear function of distances between sets of data points and the points to be predicted. It should be noted that the inverse distance weighting is forced to the exact values at the data points. This means that if the input grid coordinates are equal to those of a sampling point, then the interpolated elevation at this location will be copied over by the exact elevation value of the sampling point. 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 testing the quality of the interpolation operation [5], [6].

The thin plate spline theory

The spline technique came from the spline (flexible) ruler used in best fitting curves to sets of data by the 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. The 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. The general definition of a piece-wise polynomial function is [6]:

P(x) = Pi(x)　　　xi < x < x i+1　　　(3)

where,

i = 0, 1, ………., k-1

Pj(x) = Pji+1(xi)　　j = 0, 1, ...r-1　　　(4)

i = 1, 2, ………., k-1

where,

xi ,………., xk-1 = the points which divide the distance x0xk into k sub-intervals. These points are called break points while the points of the curve at these values of x are called knots.

Pi(x) = polynomial functions of m degrees of freedom.

r = the constraints on the spline. As 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 the x0xk 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

In interpolating of surfaces using spline techniques an approximate function has to passes near as possible to the data points taking into account being as smooth as possible.

Assume that following [5], [6]:

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

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 [5], [6]:

$$A(f) + \sum_{i=1}^{k-1} w_i^2 \{ f(x_i - y(x_i) \}^2 \quad (6)$$

In equation (6), the first term represents the smoothness of the function while the second term represents the proximity to the data. The weights wi are calculated from the following equation [5], [6]:

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

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

MATERIALS AND METHODS

A test site in hilly corrugated terrain has been established to the east of Cairo, Egypt. Data has been collected from field using conventional surveying methods where a total station instrument has been used for measuring the three dimensional coordinates (x, y, z) of spot points. DEMs have been created from the field data using ESRI spatial analysis and 3-D analyst working under ArcView GIS commercial package. Qualitative analysis of the DEMs has been undertaken aiming at viewing differences between DEMs in representing the earth’s surface. Also, quantitative analysis has been carried out using sets of independent checkout points uniformly distributed over the test area. The checkout points haven’t been used in the creation of the DEMs which provides independency for the error analysis undertaken for the elevations measured from the DEMs. The analysis applies a comparative approach between DEMs generated using each of IDW and thin plate spline interpolators aiming at the assessment of the efficiency of each of those two interpolation techniques in the creation of better quality and more accurate DEM.

Figure 1 is a representation of real ground surveying data collected from field for the purpose of creating a digital elevation model in the area under study. The test site terrain covers an area of about 462000 metre squared (840 metres by 550 metres). About 1921 spot elevation measurements covering the whole area of the test site have been collected from field using a total station instrument. A spacing of 15 m between spot points was intended but due to field difficulties deviations from straight lines have been always the case in the observations. From calculations the density of points approaches to about one point per 240 meter squared in the average. The minimum elevation in the test site is 120.13 metres while the maximum elevation 138.46 metres. This refers to an elevation range of 18.33 metres. Also, the mean elevation is 128.17 metres where the median of the data is 128.79 metres which is not very far from the mean. The standard deviation within the set of elevations is 3.91 metres which is an indication to a considerably changeable surface.

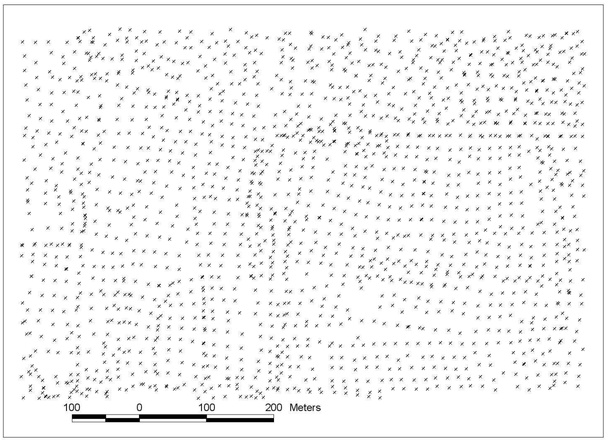

Figure 1: Spot leveling test data collected from corrugated terrain area.

RESULT AND DISCUSSION

Visual Interpretation of the DEMs Generated Using IDW and the Thin Plate Spline Algorithms

The Digital Elevation Model (DEM) is a continuous surface represented by 2D array of number of columns and number of rows, the building unit of the DEM is the grid cell that of a specific size similar to the pixel which is the building unit of the digital image. However, in the DEM the attributes of the grid cells; the elevations are represented by variations in the tone/colour [6], [7]. In this case the elements of digital image interpretation can be exploited in 2D visual interpretation of the DEM. the shape, size, 2D locations of the colour patches in addition to the changes in the tone/colour are main criteria that can be applied in 2D visual interpretation of the DEM. Also, the texture which expresses the arrangements and repetition of the tone; smooth, intermediate or rough adding to the pattern which is the arrangements of the spatial objects on the ground are other criteria that can be performed in this analysis [8], [9].

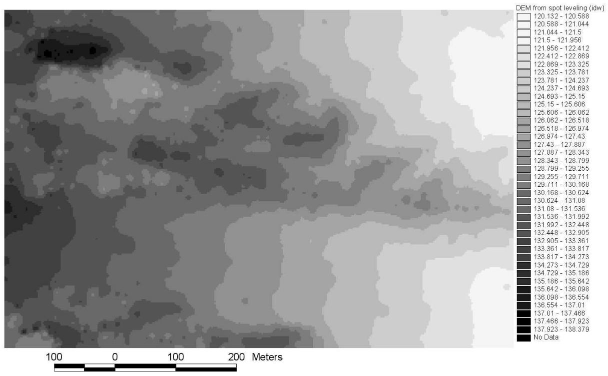

Figure 2: Digital Elevation Model created using the inverse distance weighing (IDW) algorithm.

Figure 2 depicts a digital elevation model created from IDW of power 2 (as the default settings of ArcView GIS) and a grid cell size of 2.0 meters. The no. of neighbors used in the creation of the DEM is 12 as the default settings of the ArcView GIS system. In figure 2 the DEM is structured showing sudden changes of elevations which is clear in the sudden changes in the tones within the DEM and the wide variations in that tones. Also, the DEM from IDW is showing numbers of tinny areas of different colours referring to different elevation areas impeded in big batches of unified colour classes. This is an indication of limited smoothing in the DEM. Also, a rough texture have been obtained with irregular pattern indicating a DEM of highly corrugated surface. Additionally, the legend of the DEM is showing a minimum elevation of 120.132 metres and a maximum elevation of 138.379 metres which indicates that a range of elevations of 18.247 metres. These values are very close to the corresponding values of the data set depicted in table 1. This means that IDW interpolation method has reserved the minimum and maximum values of the original data.

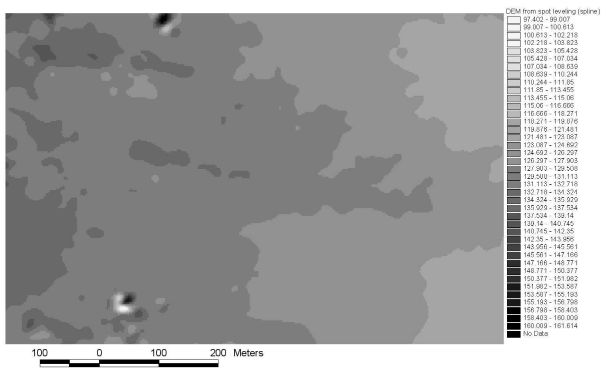

Figure 3: Digital Elevation Model created using the thin plate spline interpolation approach.

In figure 3 a digital elevation model created from spline using the same grid cell size 2.0 meters and weight value of 0.10 as the default settings of the GIS system is represented. Different from the DEM from the IDW, smoothness of the surface from spline is clear from the smooth tone and smooth texture with irregular pattern. This is obvious from the gradual changes in the tone in the DEM which has to be expected as the spline is a smoothness technique. Also, in the DEM there are batches of tinny areas of different shades but with less numbers compared to those that are distinguishable in figure 2, the DEM from IDW. The smoothness character of the spline technique is behind this phenomenon. Referring to the legend of the DEM in figure 3, it can be found that the minimum elevation in the DEM is 97.40 meters while the maximum elevation is 161.61 meters which leads to a range of elevations of 64.21 meters. This is a very wide range compared to the range of elevations in the original data of 18.33 metres.

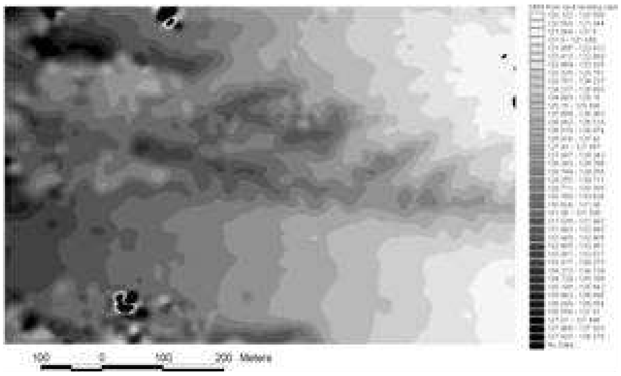

Figure 4: Digital Elevation Model created using the thin plate spline approach but viewed with the same legend as the DEM created using the IDW algorithm.

Figure 4 represents the same DEM generated from the thin plate spline algorithm but viewed with the same legend of the DEM produced using the IDW interpolation method, as exploitation of the great capabilities that ArcView GIS system enjoys . The view in figure 4 reserves the values of the minimum, maximum and range of elevations as well as the same no. of elevation classes in the viewed IDW DEM, figure 2 to applied on the spline DEM. Thus, the view shows only the areas of elevations that lie within this range, however, the elevations that are outside this range (higher than the maximum and lower than the minimum) have been treated as no data areas. Figure 4, shows patches of black shades that can be interpreted as no data areas as referred to in the legend. As stated before, these patches of black colour represent areas in the spline DEM, figure 3, of elevation values lower than the value of 120.13 meters, the minimum value in the legend and those elevations that exceed the value of 138.38 meters, the maximum value in the legend. These patches could be elevation spikes resulting from the application of the thin plate spline algorithm on the ground surveying data for the creation of a continuous surface. Resulting of such elevation spikes may be considered as main drawbacks of the thin plate spline interpolation method. The spline DEM in figure 4 has been improved the map view of the DEM but patches of no data values have been obtained while the smoothing of DEM is still distinguishable when comparing with figure 2, the DEM generated from the same ground surveying data but with the application of a different interpolation technique; namely the inverse distance weighting technique.

Statistical Analysis of the DEMs Generated Using IDW and the Thin Plate Spline Algorithms

Table 1 records the results of the statistical analysis of the test data shown in figure 1 in addition to the statistical analysis values of the digital elevation models generated using the inverse distance weighting and the thin plate spline algorithms. As the grid cell sizes used in the creation of both DEMs have been kept unchanged then the resulting number of rows, the resulting number of columns and the total number of cells (count) have been similar in both digital elevation models. However, as presented in section 4.1 the generated DEMs from each of IDW and thin plate spline approaches have been of different minimum elevation values, different maximum elevation value and different range of elevation values. This has to be expected since the theoretical basis of the inverse distance weighting and the thin plate spline are very different. However, when comparing with these statistical values, the minimum elevations, the maximum elevations and the ranges of elevations with their corresponding values resulting from the statistical analysis of the original test data, see table 1, it can be noticed that the statistical values; the minimum, the maximum and the range of the IDW DEM have been the same as those of the original data as the case of the minimum elevation and differ by only 8 centimetres as the cases of the maximum elevation and the range of elevations. In the case of the spline DEM, the minimum elevation has been lower than that of the original data by 22.73 metres. Also, the maximum elevation is higher than that of the original data by 23.15 metres.

Table 1: The statistical properties of the original test data, the DEM created using IDW interpolator and the DEM produced using the thin plate spline interpolation methods.

Statistical quantity	Original Spot Elevation Measurements	Inverse Distance Weighting (IDW) DEM	Thin plate Spline DEM
No of rows		221	221
No. of columns		335	335
Count (points/cells)	1921	74035	74035
Maximum elevation (m)	138.46.	138.38	161.61
Minimum elevation (m)	120.13	120.13	97.40
The range of the elevations (m)	18.33	18.25	64.21
Mean elevation (m)	128.17	128.39	128.380
The Median elevation (m)	128.79	129.09	128.79
Sum of elevations within DEM (m)	246214.6	9505270	9504605
Standard deviation of the elevations (m)	±3.91	±3.724	±3.951

The mean elevation from the IDW DEM is 128.39 metres which is very close to the mean elevation from the spline DEM of 128.38 meters, however, both of those values are higher than the value of the original data, 128.17 metres by 22 and 21 centimetres respectively. When comparing the median elevation, it can be seen that the spline DEM has recorded the same value of the original data; 128.79 metres but IDW DEM has recorded high medium elevation value of 129.09 metres. The sum of elevations in DEM from IDW is also, higher than the sum of elevation from the thin plate spline method and definitely both value are much higher than that the sum of elevation value of the original data as expected since the numbers of cells (count) in both DEMs have been much bigger than the number of spot elevation measurements.

The standard deviations of the surface elevations in both DEMs are very different and they are different from the standard deviation of the original data set. Thus, the standard deviation of the IDW DEM of ±3.724 metres is lower than that of the original data set of ±3.91 metres by about ±19 centimetres which could be due to the effect of smoothing of the surface done by the IDW interpolation. In the opposite, the standard deviation of the thin plate spline DEM of ±3.951 is higher than that of original data set by about ±4 centimetres which coincides with the high range of elevations depicted in the spline DEM.

Generation and Analysis of 3D Views of the DEMs Generated Using IDW and the Thin Plate Spline Algorithms

Figure 5: 3D view of the Digital Elevation Model Created using the IDW interpolation method.

As has been stated before in section 4.3, the elements of digital image interpretation including the shape, size and locations of the colour patches can be exploited in 2D visual interpretation of the digital elevation model. Additionally, the changes in the tone/colour are important criteria that can be applied in 2D visual interpretation of the DEM. Moreover, the texture which expresses the arrangements and repetition of the tone; smooth, intermediate or rough adding to the pattern which is the arrangements of the spatial objects on the ground are crucial criteria that can be performed in such analysis. Finally, the height/depth of objects and the shadows of the objects are critical criteria for 3D interpretation of the digital elevation model [8], [9].

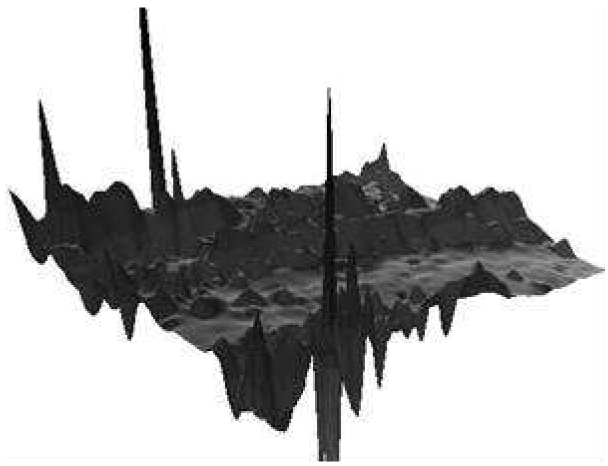

Figure 6: 3D view of the Digital Elevation Model Created using the Spline interpolation method.

Figures 5 and 6 are two 3D views of the digital elevation models resulting from IDW and spline interpolation methods. The two 3D views show clear differences between the DEMs which could help more understanding the differences between the legends in figures 2 and 3 and the differences in the results of the statistical analysis of the two DEMs section 4.2. Figure 5 depicts a considerably corrugated surface while figure 6 also shows a more corrugated surface but with clear elevation spikes especially at the bordering parts of the DEM. The interpreted spikes in the thin plate spline DEM are behind the very wide range of elevations contained by this DEM which is

64.21 meters compared to the range of elevations of 18.25 meters obtained from the IDW DEM and that is of the original spot elevation measurements 18.33 metres. Sharp peaks in the 3D view of the DEM from IDW are interpretable while peak elevations appear to be rounded and smoothed in the 3D view of the DEM from thin plate spline algorithm. 3D views provide clear understanding of the differences between the DEMs produced from the IDW and the spline interpolation approaches that can help better understanding of some features of the DEM that cannot be interpretable by some other testing analysis.

Accuracy Assessment of the Extracted Elevations from the DEMs Generated Using IDW and the Thin Plate Spline Algorithms

Visual analysis of the DEMs generated from IDW and the thin plate spline algorithms, statistical analysis of the same DEMs and visual analysis of the 3D views of the DEMs have shown differences between the DEM created using the IDW technique and that is obtained using the thin plate spline method. In the current test; accuracy assessment of the extracted elevations from the DEMs generated using IDW and the thin plate spline algorithms, the accuracy of each of the two DEMs will be estimated and analysed using a handful of external checkout points that have not been used in the creation of any of the two DEMs. In addition to the statistical analysis of the digital elevation models, this is an error analysis test that aims to quantifying the differences between the DEM generated using IDW and the DEM generated from the thin plate spline and provide those differences in numbers which can be more sensible to the Geomatics community through evaluation of the errors induced in the elevations extracted from the interpolated surfaces and consequently assessment of the accuracy of each of these two DEMs.

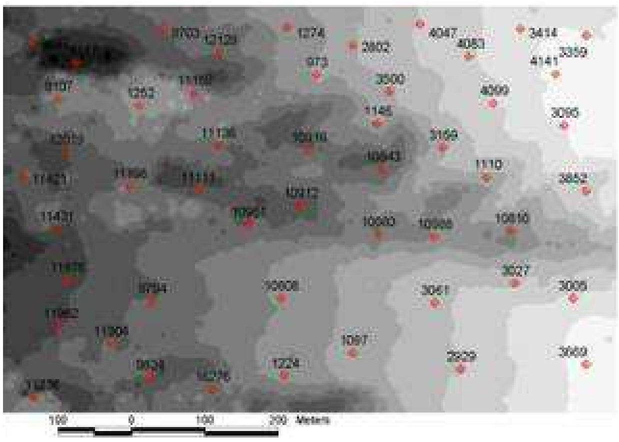

Figure 7: Distribution of the external checkout points observed with the test data but separated from them and retained too be exploited for accuracy assessment of the DEMs resulting from IDW and thin plate spline. The checkout points are viewed over a DEM created using IDW method.

In performing such error analysis test, independent observations have been collected from field for the purpose of measuring the accuracy of the elevations extracted from the generated DEMs. Fifty checkout points uniformly covering the test area, as possible have been observed using the same total station following the same measuring technique have been exploited in observing the spot elevation test data.. This means that the calculated residuals in the elevation measurements at the positions of the checkout points will be only due to interpolation uncertainty. The external checkout point measurements are expected to have the same accuracy levels of the spot level test data as they have been observed with the same instrument, following the same observing technique by the same observer and at the same time of observing the test data used in the creation of the DEMs. Again, it would be important to assure that the external checkout point measurements have not been used in the creation of any of the DEMs interpolated using the IDW technique or that is interpolated using the thin plate spline approach. This makes these external checkout point measurements as independent measurements and can treated as ground truth that can be exploited in the assessment of the accuracy of the generated DEMs.

Table 2: Results of the statistical analysis of the errors induced in the extracted elevations from the DEMs generated using IDW and the thin plate spline algorithms.

Statistical quantity	Inverse Distance Weighting (IDW) DEM	Thin plate Spline DEM
No. of checkpoint used	50	50
Maximum positive residual (m)	1.88	1.29
Maximum negative residual (m)	-1.62	-2.25
Sum of residuals (m)	-2.18	-8.17
Mean error of interpolated height (m)t	-0.044	-0.163
Median of residual set (m)	0.02	-0.01
Mode of residual set (m)	0.13	0.01
Standard error of the observed elevation from the DEM (m)	±0.577	±0.651
Standard error of the mean (m)	±0.0816	±0.092

Referring to table 2, which depicts the results of the statistical analysis of the errors induced in the extracted elevations from the DEMs generated using IDW and the thin plate spline algorithms, it can be noticed that the maximum residual from the DEM of IDW interpolation, 1.88 metres is higher than that from the DEM of thin plate spline generation, 1.29 metres. In the same time the absolute minimum negative residual from IDW DEM, -1.62 metres is smaller than that from spline DEM, -2.25 metres. Despite that the range of residuals from IDW DEM, 3.5 metres, is close to that from spline, 3.45 metres. Alternatively, the absolute algebraic sum of residual from IDW DEM, -2.18 metres is much smaller than that from spline DEM, -8.17 metres which leads to an absolute mean error from IDW DEM of -0.044 metres is much smaller than the absolute mean error from the spline DEM of 0.163 meters. The median elevation from IDW DEM is 0.02 metres while this is -0.01metres from spline DEM which is an indication that IDW tend to produce higher elevation than that from the spline which could be due to that thin plate spline is a best fitting algorithm that is not necessarily incorporate the original data measurements into the generated surface as the IDW algorithm obligatory does. Additionally, the Modes from both techniques support this assumption where it is 0.13 metres from IDW DEM while it is 0.01 metres from the spline DEM. When investigation the standard error of the individual extracted elevation and the standard error of the mean of the extracted elevations it can be found that elevations extracted from IDW DEM has provided extracted elevation standard error of ±0.577 metres and standard error of the mean of ±0.0816 metres which are smaller than their corresponding values of ±0.651 metres ±0.092 metres for the extracted elevations from the spline DEM. This is a clear indication that IDW algorithm provides a digital elevation model that is more accurate the digital elevation model generated by the thin plate spline approach.

Discussions

There is increasing availability of the digital elevation data that can be exploited in creation of digital elevation models which enjoy many environmental and engineering applications. Digital elevation data is usually in discrete point data formats that require an interpolation approach for the creation of a continuous surface representing a digital elevation model. The inverse Distance Weighting (IDW) and the thin plate spline are two local interpolation approaches that are often used in creation of digital elevation models. There has been always a question that arises which one of those two interpolation techniques gives better quality and more accurate DEM. Different testing techniques and analysis methods have been undertaken in order to assess the quality of the DEMs produced from ground surveying discrete point data sets using IDW and spline interpolation methods in addition to determination of the accuracy of the extracted elevations from that DEMs; the visual interpretation of the DEMs generated using IDW and the thin plate spline algorithm test, the statistical analysis of the DEMs generated using IDW and the thin plate spline algorithm test, generation and analysis of 3D views of the DEMs generated using IDW and the thin plate spline algorithm test and finally, accuracy assessment of the extracted elevations from the DEMs generated using IDW and the thin plate spline algorithm test.

In the first test, visual interpretation of the DEMs generated using IDW and the thin plate spline algorithm, the test has employed the elements of the digital image interpretation in visual analysis and interpretation of the differences between the DEMs from both interpolation techniques. The IDW DEM has shown wide variation in tone/colour throughout the DEM with rough texture and random pattern compared to the thin plate spline DEM with narrower variations of the tone/colour, smoother texture and less random pattern. Also, the legend of the IDW has given a minimum elevation, maximum elevation and a range of elevations of values that are very close to those of the original test data. In the contrary, the thin plate spline has given a DEM of corresponding values that have been very different from those of the original data with a very wide range of the elevations depicted in the DEM. When forcing the spline DEM to be viewed with the same legend of the IDW DEM, patches of no data have been interpreted as their elevation classes lie beyond the range of elevations in the IDW legend. Those patches of no data have been interpreted as spikes and elevation noise characterizing the thin plate spline DEM.

The statistical analysis of the DEM has been undertaken in order to view the differences between the generated DEMs in numbers. As has been seen before there has been clear differences between the legend of the IDW DEM and that of spline DEM where IDW DEM has produced legend of minimum, maximum and range of elevation values that have been close to their corresponding values in the original digital elevation data, the thin plate spline has produced a DEM of very different corresponding values. However, the mean elevation in the DEM from IDW has been very close to that of the spline DEM, but both of the two mean elevation values have been higher than the corresponding value of the original data, 128.17 metres by 22 and 21 centimetres respectively. Additionally, the median elevation from the spline DEM has recorded the same value of the original data; 128.79 metres but IDW DEM has recorded higher medium elevation value of 129.09 metres. The sum of elevations contained in the DEM from IDW has been higher than that has been depicted in the thin plate spline method and definitely both values are much higher than the sum of elevation value of the original data as expected since the numbers of cells (count) in both DEMs have been much bigger than the number of spot elevation measurements. The standard deviations of the surface elevations in both DEMs have been different and they have been different from the standard deviation of the original data set. This is expected since the two interpolation techniques have provided different ranges of elevations.

For clearer viewing and more understanding of the differences between the IDW DEM and the spline DEM, 3D views have been created from the two DEMs and analysed. The 3D view from IDW DEM has shown corrugated surface while spline has shown more corrugated surface but with clear and big elevation spikes especially at the bordering parts of the DEM. The interpreted spikes in the thin plate spline DEM have been behind the very wide range of elevations contained by this DEM which is 64.21 meters compared to the range of elevations of 18.25 meters obtained from the IDW DEM and that of original spot elevation measurements 18.33 metres. 3D view interpretation has provided clear understanding of the differences between the DEMs produced from the IDW and the spline techniques.

The Accuracy estimation using external checkout points has quantified the difference between the DEMs. The analysis has shown that the maximum residual from DEM of IDW has been higher than that from the DEM of thin plate spline while the absolute minimum residual from IDW DEM is -1.62 metres is smaller than that from spline DEM, -2.25 metres. Despite that the range of residuals from IDW DEM has been close to that from spline. Alternatively, the absolute algebraic sum of the residual elevation from IDW DEM has been much smaller than that from the spline DEM. The median elevation has indicated that IDW tends to produce higher elevations than the spline interpolation does. The standard error of the individual extracted elevation and the standard error of the mean of the extracted elevations has shown that the elevations extracted from IDW DEM has provided extracted elevations of standard error of ±0.577 metres and standard error of the mean of ±0.0816 metres which have been smaller than their corresponding values of ±0.651 metres and ±0.092 metres for the extracted elevations from the spline DEM. This has been clear indication that IDW algorithm has provided a more accurate digital elevation model than that has been given by the thin plate spline.

CONCLUSION

There is an increasing demand on good quality digital elevation models as they usually serve as crucial inputs in increasing areas of applications starting from surveying and mapping to various engineering and environmental applications. This constitutes great challenges to the Geomatics professionals. Creation of a digital elevation model from a point support file requires exploitation of an interpolation approach for the creation of a continuous surface. Different interpolation techniques are available for doing such job where the most important of them are the local interpolators including the Inverse Distance Weighting (IDW) and the thin plate spline methods. Since different interpolation methods are expected to produce different quality DEM, it has been important to assess the qualities of DEMs produced from different interpolation techniques.

A test site in hilly corrugated terrain has been established to the east of Cairo, Egypt. Data has been collected from field using conventional surveying methods where a total station instrument has been used for measuring the three dimensional coordinates (x, y, z) of spot points. DEMs have been created from the field data and qualitative analysis of the DEMs has been undertaken aiming at viewing differences between IDW DEM and the spline DEM in representing the earth’s surface. Additionally, quantitative analysis has been carried out using sets of independent checkout points uniformly distributed over the test area. The checkout points haven’t been used in the creation of the DEMs which provides independency for the error analysis undertaken for the elevations measured from the DEMs. The analysis has applied a comparative approach between DEMs from IDW and spline interpolation aiming at the assessment of the efficiency of both techniques in the creation of better quality and more accurate DEM. Some concrete conclusion can extracted from the analysis:

- The IDW DEM has shown wide variation in the tone/colour throughout the DEM with rough texture and random pattern compared to the thin plate spline DEM with narrower variations of the tone/colour, finer texture and less random pattern.
- The legend of the IDW has given minimum elevation, maximum elevations and a range of elevations of values that are very close to those of the original test data while the thin plate spline has given a DEM of corresponding values that have been very different from the original data with a very wide range of the elevations depicted in the DEM.
- The standard deviations of the surface elevations in both DEMs have been different and they have been different from the standard deviation of the original data set. This is expected since the two interpolation techniques have provided different ranges of elevations.
- The 3D view from IDW DEM has depicted corrugated surface while the 3D view from spline DEM has shown more corrugated surface but with clear elevation spikes especially at the bordering parts of the DEM.
- 3D view interpretation has provided clear understanding of the differences between the DEMs produced from the IDW and the spline techniques.
- The accuracy assessment using external checkout points has shown that the maximum residual from the DEM of IDW has been greater than that from the DEM of the thin plate spline while the minimum residual from IDW DEM is smaller than that from spline DEM.
- The absolute algebraic sum of residuals from IDW DEM has been much smaller than that from that from the spline DEM.
- The median elevation has indicated that IDW tends to produce higher elevation than the spline interpolation does.
- The standard error of the extracted elevations and the standard error of the mean extracted elevations from IDW DEM have been smaller than their corresponding values from the spline DEM which refers to that IDW algorithm has generated more accurate digital elevation model than that has been generated by the thin plate spline approach.

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