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Estimating the Accuracy of Digital Elevation Model Produced by Surfer Package

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***Abstract*– Heights or reduced levels are used in practically all aspects of construction: to produce ground contours on a plan; to enable the optimum design of road, railway or canal gradients; to facilitate ground modelling for accurate volumetric calculations; to deals with all applications require topographic data. Levelling can be defined as 'the operation required in the determination or, more strictly, the comparison of heights of points on the surface of the earth' [1]. Levelling is usually carried out as a separate procedure from that used for fixing planimetric position. It involves the measurement of vertical distance relative to a horizontal line of sight. Hence it requires a graduated staff for the vertical measurements and an instrument that will provide a horizontal line of sight. A datum is any reference surface to which the elevations of points are referred. The most commonly used datum is that of mean sea level (MSL). The vertical height of a point above or below a reference datum is referred to as the reduced level or simply the level of a point. Although, there are other conventional and modern methods for height determination but physical or direct observations of all points still tedious operation and time consuming. The Digital Elevation Model (DEM) is formed by 'sampling points over the land surface and using appropriate algorithms to process these points to represent the surface being modeled' [5]. In this research work, heights of sample area with 5m×5m grid were determined. Then, about half of theses points were withdrawal and predicted from 10m×10m grid using number of four interpolation methods used to generate digital elevation models provided by SURFER package. Results showed that the accuracy of the DEMs generated were within the range of 0.8m to 0.83m and all tested interpolation methods approximately produce the same results.**

***Index Terms*– DEM, Height, Interpolation, Levelling, Prediction and Surfer**

I. INTRODUCTION

SURVEYING may be defined as 'the science of determining the position, in three dimensions, of natural and man-made features on or beneath the surface of the Earth. These features may be represented in analogue form as a contoured map, plan or chart, or in digital form such as a Digital Elevation model (DEM)' [7]. In engineering surveying, either or both of the above formats may be used for planning, design and construction of works, both on the surface and underground. At a later stage, surveying techniques are used for dimensional control or setting out of designed constructional elements and also for monitoring deformation movements.

In the first instance, surveying requires management and decision making in deciding the appropriate methods and instrumentation required to complete the task satisfactorily to the specified accuracy and within the time limits available. This initial process can only be properly executed after very careful and detailed reconnaissance of the area to be surveyed. 'Data representation in analogue or digital form may now be carried out by conventional cartographic plotting or through a totally automated computer-based system leading to a paper or screen-based plot' [7].

II. PORTRAYING THE LAND-SURFACE FORM

'The story of how terrain portrayal developed is a search for suitable methods. The problem has been that the most effective visual techniques did not give precise terrain information. Likewise, methods that gave accurate terrain values were the least effective visually' [2]. Number of methods can be used to represent terrain such as:

- Spot points
- Contour lines
- Shading
- Digital terrain model

III. DIGITAL ELEVATION MODEL

A Digital Elevation (Ground) Model (DEM/ DGM); also known as Digital Terrain Model (DTM) 'is a three dimensional, mathematical representation of the landform and all its features, stored in a computer database. It can also be defined as a particular form of computer surface modeling which deals with the specific problems of numerically representing the surface of the earth. It referred originally to the use of cross-sectional height data to describe the terrain' [7]. Such a model is extremely useful in the design and construction process, as it permits quick and accurate determination of the coordinates and elevation of any point. The methods in common use are modelling by 'strings', 'regular grids' or 'triangulated irregular networks'. Regardless of the methods used, they will all reflect the quality of the field data. A ‘string’ comprises a series of points along a feature and so such a system stores the position of features surveyed. The system is widely used for mapping purposes due to its flexibility, accuracy along the string and the ability to process large amounts of data very quickly. However, as the system does not store the relationship between strings, a searching process is essential when the levels of points not included in a string are required. Thus the system’s weakness lies in the generation of accurate contours and volumes [7].

The ‘regular grid’ method uses appropriate algorithms to convert the sampled data to a regular grid of levels. If the field data permits, the smaller the grid interval, the more representative of landform it becomes. Although a simple technique, it only provides a very general shape of the landform, due to its tendency to ignore vertical breaks of slope. Volumes generated also tend to be rather inaccurate.

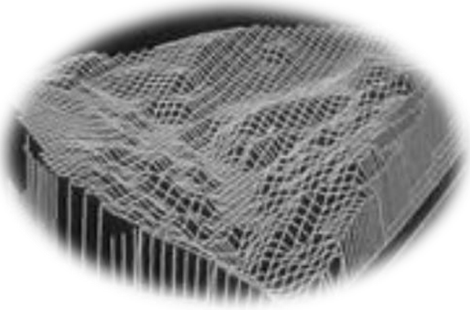

Fig. 1: Regular grid

‘In the ‘triangulated irregular networks’ (TIN) method, ‘best fit’ triangles are formed between the points surveyed. The ground surface therefore comprises a network of triangular planes at various inclinations. Computer shading of the model provides an excellent indication of the landform. In this method vertical breaks are forced to form the sides of triangles, thereby maintaining correct ground shape. Contours, sections and levels may be obtained by linear interpolation through the triangles’ [8].

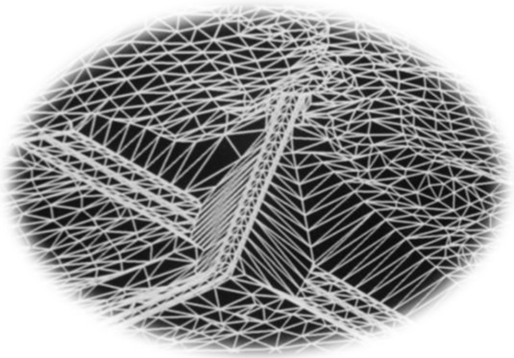

Fig. 2: Triangulated irregular networks

Different sources of data for DEM are available such as:

- Field survey work
- Photogrammetry
- Satellite or documents scanners
- Digitized maps

Digital elevation model can be represented either by mathematically defined surface or by point or line images. Line data can be used to represent contours and profiles, and critical features such as streams, ridges shorelines, and breaks in slope.

DEM can be used in different application such as, photogrammetry, engineering, hydrography, military, computer-aided design and landscape processes.

IV. INTERPOLATION

Interpolation can be defined as ‘the procedure of predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region. Predicting the value of an attributes at sites out-site the area covered by exiting observations is called extrapolation’ [6].

Interpolation is used to convert data from point observation to continuous fields so that the special patterns sampled by these measurements can be compared with the special patterns of other special entities.

Interpolation can be used when the data do not cover the domain of interest completely. This case may arise to represent variations in the elevation of the land surface (Digital Elevation Models - DEM).

V. INVERSE DISTANCE TO A POWER

‘The Inverse Distance to a Power gridding method is a weighted average interpolator, and can be either an exact or a smoothing interpolator’ [8].

With Inverse Distance to a Power, data are weighted during interpolation such that the influence of one point relative to another declines with distance from the grid node. Weighting is assigned to data through the use of a weighting power that controls how the weighting factors drop off as distance from a grid node increases. The greater the weighting powers, the less effect points far from the grid node have during interpolation as shown in Eq. (1):

$$z = \frac{\sum_{i=1}^{n} z_i \times w_i}{\sum_{\mathrm{i=1}}^{\mathrm{n}} w_i} \ldots\ldots\ldots.. \qquad (1)$$

Where,

z is the predicted height,

zi is the height of adjacent point,

wi is the weight of each point and

n represents the number surrounding points.

As the power increases, the grid node value approaches the value of the nearest point. For a smaller power, the weights are more evenly distributed among the neighboring data points.

Normally, Inverse Distance to a Power behaves as an exact interpolator. When calculating a grid node, the weights assigned to the data points are fractions, and the sum of all the weights is equal to 1.0. When a particular observation is coincident with a grid node, the distance between that observation and the grid node is 0.0, and that observation is given a weight of 1.0, while all other observations are given weights of 0.0. Thus, the grid node is assigned the value of the coincident observation.

VI. KRIGING

This method produces visually appealing maps from irregularly spaced data. 'Kriging attempts to express trends suggested in the data, so that, for example, high points might be connected along a ridge rather than isolated by bull's-eye type contours' [8].

Kriging can be either an exact or a smoothing interpolator depending on the user-specified parameters. It incorporates anisotropy and underlying trends in an efficient and natural manner. Mathematical form of kriging can be expressed as in Eq. (2).

$$z = \sum_{i=1}^{n} xi \times z(xi) \ldots\ldots\ldots. \qquad (2)$$

VII. NEAREST NEIGHBOR

'The Nearest Neighbor method assigns the value of the nearest point to each grid node. Alternatively, in cases where the data are nearly on a grid with only a few missing values, this method is effective for filling in the holes in the data' [8]. Nearest neighbor formula can be expressed as:

$$z = \frac{\sum_{i=1}^{n} z_i}{\text{n}} \ldots\ldots\ldots\ldots. \qquad (3)$$

Consider a set of Thiessen polygons (the dual of a Delaunay triangulation). If a new point (target) were added to the data set, these Thiessen polygons would be modified. In fact, some of the polygons would shrink in size, while none would increase in size. The area associated with the target's Thiessen polygon that was taken from an existing polygon is called the "borrowed area". The *Natural Neighbor* interpolation algorithm uses a weighted average of the neighboring observations, where the weights are proportional to the "borrowed area".

VIII. LOCAL POLYNOMIAL

The Local Polynomial gridding method assigns values to grid nodes by using a weighted least squares fit with data within the grid node's search ellipse.

'Polynomial equations are used to represent the terrain surface in the global and patchwise methods of interpolation' [7].

The two dimensional complete n-th degree of polynomial equation can be given by:

$$z(x, y) = \sum_{i=1}^{n} a_k x^i y^i \ldots\ldots..(4)$$

Where,
a is coefficients, *i* and *j* are permuted accordingly (i + j ≤ k).
x and *y* are the planimetric coordinates of point.

IX. SURFER

'Surfer is a powerful contouring, gridding, and surface mapping package for scientists, engineers, educators, or anyone who needs to generate maps quickly and easily. Producing publication quality maps has never been quicker or easier. Maps can be displayed and enhanced in Surfer. Adding multiple map layers, customizing the map display, and annotating with text create publication quality maps' [8].

Surfer is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid. Grids may also be imported from other sources. The grid is used to produce different types of maps including contour, vector, image, shaded relief, 3-D surface, and 3-D wireframe maps. Many gridding and mapping options are available allowing you to produce the map that best represents your data.

An extensive suite of gridding methods is available in Surfer. The variety of available methods provides different interpretations of the data, and allows choosing the most appropriate method for required needs. In addition, data metrics allow gathering information about gridded data. Surface area, projected planar area, and volumetric calculations can be performed quickly in Surfer. Cross-sectional profiles can also be computed and exported.

'The grid files themselves can be edited, combined, filtered, sliced, queried, and mathematically transformed. For example, it can create an isopach map from two grid files. It will need the original surface grid file and the surface grid file after a volume of material was removed. Subtract the two surfaces to create an isopach map. The resulting map displays how much material has been removed in all areas' [8].

X. MEASURMENTS AND RESULTS

In this research work, a sample area of 100×100m was selected and divided into 5m×5m grids.

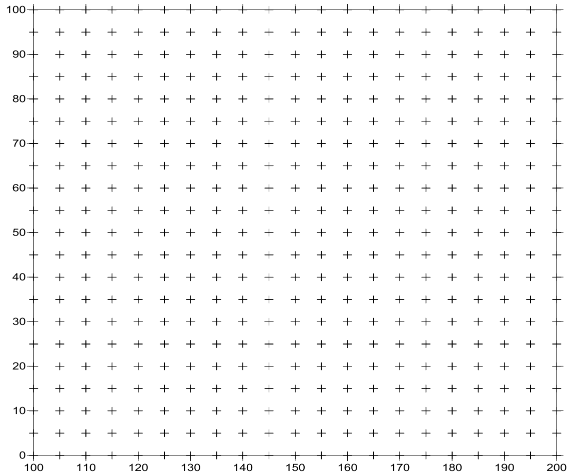

Fig. 3: Study area

Levelling was carried out using total station instrument, assuming the coordinates of the south east corner of the area to be (0m, 100m) in Easting (E) and Northing (N) respectively with 100m height (H), i.e., Reduced Level (RL) as shown in appendix.

In order to estimate the accuracy of digital elevation model produced by surfer package, about half of the grid field data was omitted by assuming the grid to be 10m×10m rather than 5m×5m. Then the omitted RLs were predicted using numbed of interpolation techniques provided by surfer.

Four interpolation methods were tested. These are:

i. Inverse distance to power
ii. Kriging
iii. Natural neighbor
iv. Local polynomial

In each test, predicted heights of points were compared with the original field heights and the differences were computed as:

$$Differece = Predicted\ height - Field\ heigh \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

In order to estimate the accuracy of digital elevation models generated by SURFER PACKAGE in each test, the Root Mean Square Error (*RMSE*) was used as accuracy estimation factor.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(Difference)^2}{n-1}} \ldots\ldots.. \quad (6)$$

Where, *n* is number of points.

The estimated accuracy- i.e., computed RMSE- for each method was found to be as shown in Table 1:

Table 1: Estimated accuracy of DEMs

No.	Interpolation Method	RMSE (m)
1	Invers distance to power	0.798≈0.80
2	Kriging	0.826≈0.83
3	Natural Neighbor	0.827≈0.83
4	Local polynomial	0.796≈0.80

XI. CONCLUSION

- Although the study area was flat and resolution of the data was 10m×10m the accuracy of predicted digital elevation models was limited to the range of 0.80 to 0.83m.
- Results also reflect that the digital elevation models generated by surfer package are suitable for preliminary study.
- Kriging and natural neighbor almost produce predicted heights of digital elevation models with the similar accuracy. On the other hand invers distance to power and local polynomial are of similar predicted results as well.
- Referring the maximum difference between the four studied methods (0.03m) to the better accuracy obtained (0.8m) =3.75% it can said to be that the four methods approximately produce equal results.

REFERENCES

[1] A Bannister and others (1998), Surveying. Seven edition, Personal Eucation Limited, Ddinburgh, Harlow, Essex CM20 2JE, England.

[2] Arthur H. Robinson and other (2004), elements of cartography, John wiley & son (Asia) Pte. Ltd.

[3] Kavanagh Barry F. (2004), Surveying with construction applications - 5th Ed., Personal prentice hall, USA.

[4] Paul R. Wolf and Charlis D. Ghilani (2006), Elementary Surveying, 11th Edition, Pearson prentice hall, New Jersey.

[5] Peter A. Burrough and Rachael A. McDonnel (1998), Principles of Geographical Information System, Oxford University Press Inc., New York.

[6] Surfer10 (2011), Surfer mapping system, Golden software Inc.

[7] T. S. M. Kennie and G. Petrie (1993), Engineering Surveying Technology, Blackie Academic and professional, an imprint of chapman and Hall, wester cleddens road, Bishopbriggs, Glassggow G64 2n2. U K.

[8] W. Schofield and M. Breach (2007), Engineering Surveying, Butterworth-Heinemann is an imprint of Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP, UK.

Appendix:

Field data

E	N	H	E	N	H
(m)			(m)		
100	100	300.000	185	90	300.111
105	100	299.886	190	90	300.088
110	100	299.901	195	90	300.046
115	100	299.732	200	90	299.879
120	100	299.935	100	85	300.080
125	100	299.604	105	85	300.059
130	100	298.983	110	85	300.050
135	100	298.252	115	85	300.137
140	100	297.923	120	85	298.446
145	100	297.619	125	85	298.231
150	100	297.528	130	85	299.881
155	100	297.344	135	85	299.656
160	100	297.017	140	85	298.950
165	100	297.620	145	85	299.525
170	100	299.084	150	85	299.298
175	100	298.912	155	85	299.310
180	100	298.984	160	85	297.936
185	100	297.994	165	85	298.190
190	100	297.742	170	85	297.762
195	100	297.923	175	85	297.785
200	100	298.946	180	85	300.146
100	95	299.953	185	85	300.041
105	95	299.932	190	85	300.065
110	95	299.847	195	85	300.053
115	95	299.999	200	85	299.921
120	95	299.954	100	80	299.312
125	95	299.681	105	80	299.345
130	95	299.972	110	80	300.112
135	95	298.981	115	80	300.155
140	95	297.915	120	80	300.142
145	95	297.981	125	80	300.213
150	95	297.547	130	80	299.316
155	95	297.457	135	80	299.264
160	95	298.810	140	80	299.825
165	95	297.609	145	80	298.314
170	95	298.107	150	80	298.366
175	95	299.313	155	80	299.365
180	95	299.196	160	80	298.312
185	95	297.985	165	80	297.001
190	95	297.873	170	80	297.316
195	95	298.116	175	80	297.978
200	95	298.318	180	80	297.234
100	90	299.799	185	80	298.936
105	90	300.035	190	80	298.132
110	90	300.073	195	80	298.300
115	90	299.906	200	80	299.300
120	90	300.093	100	75	299.358
125	90	299.578	105	75	299.956
130	90	298.404	110	75	300.210
135	90	300.045	115	75	300.004
140	90	298.055	120	75	299.366
145	90	298.299	125	75	299.678
150	90	298.797	130	75	299.311
155	90	299.908	135	75	298.332
160	90	299.526	140	75	298.655
165	90	299.568	145	75	297.086
170	90	297.855	150	75	297.310
175	90	298.227	155	75	297.322
180	90	300.151	160	75	299.330
165	75	299.178	195	60	297.856
170	75	298.456	200	60	297.846
175	75	298.397	100	55	299.945
180	75	298.360	105	55	300.142
185	75	298.465	110	55	300.786
190	75	297.988	115	55	300.123
195	75	299.301	120	55	299.645
200	75	300.121	125	55	299.333
100	70	300.255	130	55	298.245
105	70	300.017	135	55	298.345
110	70	300.145	140	55	298.784
115	70	299.312	145	55	298.645
120	70	299.645	150	55	297.322
125	70	300.121	155	55	297.885
130	70	300.222	160	55	297.047
135	70	299.932	165	55	297.264
140	70	298.314	170	55	299.465
145	70	298.765	175	55	300.123
150	70	297.322	180	55	300.712
155	70	297.913	185	55	300.056
160	70	297.546	190	55	299.147
165	70	297.285	195	55	299.645
170	70	298.302	200	55	299.465
175	70	298.365	100	50	300.012
180	70	299.330	105	50	300.154
185	70	299.345	110	50	300.341
190	70	297.456	115	50	300.123
195	70	297.485	120	50	300.152
200	70	297.235	125	50	299.341
100	65	297.265	130	50	299.789
105	65	298.369	135	50	299.465
110	65	298.365	140	50	299.645
115	65	298.310	145	50	298.645
120	65	298.450	150	50	298.798
125	65	298.227	155	50	299.626
130	65	298.656	160	50	298.315
135	65	298.326	165	50	300.121
140	65	299.365	170	50	300.644
145	65	300.012	175	50	300.165
150	65	300.145	180	50	299.956
155	65	299.689	185	50	299.362
160	65	298.369	190	50	299.321
165	65	298.774	195	50	298.032
170	65	297.690	200	50	298.475
175	65	297.441	100	45	298.356
180	65	298.655	105	45	298.365
185	65	299.326	110	45	298.475
190	65	298.365	115	45	298.132
195	65	298.745	120	45	299.365
200	65	298.365	125	45	298.214
100	60	298.123	130	45	299.547
105	60	297.365	135	45	298.623
110	60	297.145	140	45	297.366
115	60	297.365	145	45	297.312
120	60	297.147	150	45	297.392
125	60	298.996	155	45	299.645
130	60	299.840	160	45	300.021
135	60	300.010	165	45	300.363
140	60	300.230	170	45	298.347
145	60	299.647	175	45	298.694
150	60	299.588	180	45	298.341
155	60	299.450	185	45	298.362
160	60	299.410	190	45	300.212
165	60	300.004	195	45	300.954
170	60	300.007	200	45	300.265
175	60	299.689	100	40	298.632
180	60	299.878	105	40	298.362
185	60	299.645	110	40	298.411
190	60	297.347	115	40	298.715
120	40	299.326	150	25	299.364
125	40	297.324	155	25	299.346
130	40	297.623	160	25	299.174
135	40	300.145	165	25	300.014
140	40	300.132	170	25	300.025
145	40	300.624	175	25	300.029

150	40	300.258	180	25	300.061
155	40	300.265	185	25	299.364
160	40	300.670	190	25	299.679
165	40	298.320	195	25	299.251
170	40	298.310	200	25	300.014
175	40	297.600	100	20	300.465
180	40	297.410	105	20	299.367
185	40	298.374	110	20	299.659
190	40	297.396	115	20	300.021
195	40	300.156	120	20	300.072
200	40	300.264	125	20	300.120
100	35	298.364	130	20	299.541
105	35	300.241	135	20	299.626
110	35	297.396	140	20	299.011
115	35	300.124	145	20	299.328
120	35	300.287	150	20	299.173
125	35	297.374	155	20	299.491
130	35	297.566	160	20	299.369
135	35	298.322	165	20	299.258
140	35	297.368	170	20	299.147
145	35	300.510	175	20	300.021
150	35	300.600	180	20	299.365
155	35	300.214	185	20	300.021
160	35	299.400	190	20	300.161
165	35	299.800	195	20	300.051
170	35	299.846	200	20	299.512
175	35	299.870	100	15	300.010
180	35	299.325	105	15	300.080
185	35	299.365	110	15	300.031
190	35	299.645	115	15	299.612
195	35	300.147	120	15	299.332
200	35	300.265	125	15	299.446
100	30	300.265	130	15	300.145
105	30	299.365	135	15	299.312
110	30	300.179	140	15	299.378
115	30	299.365	145	15	299.651
120	30	298.679	150	15	299.312
125	30	299.365	155	15	300.021
130	30	298.312	160	15	300.161
135	30	300.265	165	15	300.087
140	30	297.365	170	15	300.014
145	30	300.026	175	15	299.623
150	30	300.059	180	15	299.326
155	30	298.346	185	15	299.652
160	30	298.679	190	15	299.312
165	30	299.300	195	15	299.512
170	30	298.265	200	15	299.651
175	30	297.365	100	10	300.214
180	30	299.010	105	10	300.298
185	30	300.050	110	10	300.154
190	30	300.653	115	10	300.165
195	30	300.148	120	10	300.456
200	30	299.325	125	10	300.076
100	25	300.065	130	10	300.142
105	25	300.021	135	10	299.624
110	25	300.230	140	10	299.871
115	25	299.369	145	10	300.025
120	25	300.065	150	10	299.839
125	25	298.347	155	10	300.278
130	25	299.365	160	10	300.154
135	25	298.365	165	10	300.165
140	25	300.021	170	10	300.319
145	25	300.256	175	10	299.623
180	10	299.312	195	5	300.081
185	10	299.699	200	5	299.819
190	10	299.811	100	0	300.213
195	10	299.871	105	0	300.314
200	10	299.341	110	0	300.645
100	5	300.001	115	0	300.484
105	5	300.320	120	0	299.314
110	5	300.650	125	0	299.629
115	5	299.326	130	0	299.317
120	5	300.231	135	0	299.846
125	5	299.367	140	0	299.648
130	5	299.978	145	0	299.668
135	5	299.348	150	0	299.677
140	5	299.314	155	0	299.891
145	5	300.031	160	0	300.088
150	5	300.267	165	0	299.825
155	5	300.165	170	0	299.314
160	5	300.198	175	0	299.712
165	5	300.187	180	0	299.911
170	5	299.678	185	0	299.407
175	5	299.716	190	0	300.264
180	5	299.774	195	0	299.617
185	5	299.886	200	0	300.197
190	5	300.015	-	-	-