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IMPROVING THE ACCURACY OF DIGITAL TERRAIN MODELS

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Abstract. The change from paper maps to GIS, in various kinds of geographical data analysis and applications, has made it easy to use the same spatial data for different applications and also for combining several layers into quite complex spatial models, including the three-dimensional reference space (surface), known as Digital Terrain Model (DTM). The objectives of this study are: (1) to compare the different algorithms involved in producing a DTM, (2) to establish the factors which affect the accuracy of the DTM and (3) to improve the quality of the generated DTM.

Key words: GIS technology, Digital terrain models, Surfaces accuracy

1. Introduction

The change from paper maps to digital data, in various kinds of geographical data analysis and applications, has made easy to use the same spatial data for different applications and also for combining several layers into quite complex spatial models.

Using GIS technology, contemporary maps have taken radical new forms of display beyond the usual 2D planimetric paper map. Today, it is expected to be able to drape spatial information on a 3D view of the terrain. The 3D view of the terrain is called Digital Terrain Model (DTM) or Digital Elevation Model (DEM) [2].

The digital terrain models are frequently used to take important decisions like to answer hydrological questions concerning flooding. In order to judge these decisions the quality of DTM must be known. The quality of DTM is, unfortunately, rarely checked. While the development of GIS advances, DTM research has so far been neglected. The objectives of this study are: (1) to compare the different algorithms involved in producing a DTM, (2) to

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establish the factors which affect the accuracy of the DTM and (3) to improve the quality of the generated DTM.

2. Digital Terrain Modeling

A digital terrain model (DTM) is a digital representation of ground surface, topography or terrain. It is also known as digital elevation model (DEM). DTM can be represented as a raster (a grid of squares), as contour lines or as a triangular irregular network (TIN) [3, 4, 9].

Two methods are frequently used to obtaining digital terrain model: cartographic digitizing, or automatic measurements [6]. The cartographic digitizing method is widely used because topographic maps are usually available. The input data form the basis for the computation of the DTM, consisting of points. The computation itself consists in spatial interpolation algorithms. Automatic measurement techniques like photogrammetry and airborne laser scanning, output bulk points, with a high density. The DTM is realized in the post processing phase usually by creating the TIN or by interpolation.

2.1. **Interpolation.** The current research and industrial projects in GIS require higher standards for the accuracy of spatial data. The data in geographical informational systems (GIS) are usually collected as points, where a point is considered a triplet (x,y,z), where x and y are the coordinates of the point and z is the specific information. This specific information can be for example: the altitude level in the point (x, y), the quantity of precipitations, the level of pollution, type of soil, socio-economic parameters etc.. The mapping and spatial analysis often requires converting this type of field measurements into continuous space. Interpolation is one of the frequently used methods to transform field data, especially the point samples into a continuous form such as grid or raster data formats.

There are several interpolation methods frequently used in GIS. The following eight widely used methods are compared and studied in this paper. These methods are Inverse distance weighted (IDW), Spline Biquadratic interpolation, Spline Bicubic interpolation, B-spline interpolation, Nearest neighbors - Voronoi diagrams , Delaunay Triangulation, Quadratic Shepard interpolation, Kriging interpolation [1, 5, 7].

2.2. **Quality of surface.** Measurement of errors for the results is often impossible because the true value for every geographic feature or phenomenon represented in this geographic data set is rarely determinable. Therefore the uncertainty, instead of error, should be used to describe the quality of an interpolation result. Quantifying uncertainty in these cases requires comparison of the known data with the created surface [10].

To analyze the pattern of deviation between two sets of elevation data, conventional ways are to yield statistical expressions of the accuracy, such as the root mean square error, standard deviation, mean, variance, coefficient of variation. In fact, all statistical measures that are effective for describing a frequency distribution, including central tendency and dispersion measures, may be used, as long as various assumptions for specific methods are satisfied [6, 10].

For the evaluation of DTM the most widely used measure, usually the only one, is the well known Root Mean Square Error (RMSE). Actually, it measures the dispersion of the frequency distribution of deviations between the original elevation data and the DTM data, mathematically expressed as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z_{d,i} - z_{r,i})^2}$$

where: $Z_{d,i}$ is the ith elevation value measured on the DTM surface; $Z_{r,i}$ is the corresponding original elevation; n is the number of elevation points checked.

It's important to mention that for an accurate evaluation, is necessary to evaluate the surface by using an independent set of data. In this case the RMSE mirrors the quality of the surface but for a correct evaluation we recommend to analyze at least one more statistical index like standard deviation or Median absolute deviation.

3. Experiments with real-world data

DTMs are the most popular results of interpolation. In the following, we will test different methods and algorithms for creation of DTM in order to compare the different algorithms involved in producing a DTM, to establish the factors which affect the accuracy of the DTM, and to determine how to improve the quality of the generated DTM. To test and compare the methods with real data we have selected an area from north hills of Oradea municipality.

For the first DTM we used photogrammetric measurement of spot elevations from orthorectified airborne image of the area. This is the fastest way of obtaining the digital elevation model. In the case of collecting data with close-range photogrammetry or airborne laser scan the result consists in a high density of points with three coordinates (x,y,z). By computing the TIN model of these points we obtain fast a DTM. The TIN of the area was generated using ARCGIS Desktop 9.1. In the figure 1 we represented the 3D model created.

This model will consider the reference for testing and evaluating the most popular interpolation algorithms used for DTM creation. These methods are Inverse distance weighted (IDW), Spline Biquadratic interpolation, Spline

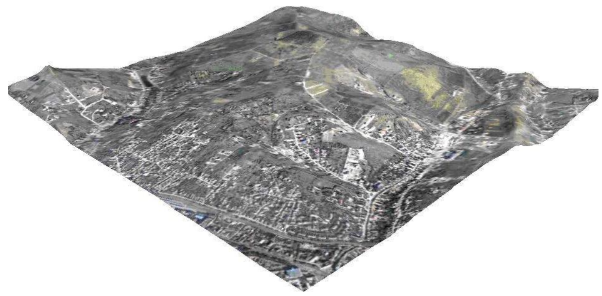

FIGURE 1. The Oradea 3D Model

Bicubic interpolation, B-spline interpolation, Nearest neighbors - Voronoi diagrams, Delaunay Triangulation, Quadratic Shepard interpolation and Kriging interpolation.

The comparisons of these algorithms were made by analyzing their results. The evaluation of the created surfaces was made by direct observation: with visual comparisons of the models using the spot image as reference and by using statistical parameters.

The first step was to create a regular grid with the step of 500 m, for a total of 30 points. On this set of points we tested the algorithms specified before. In Figure2 we represented the results of these algorithms.

In the second experiment, we have created a regular grid with the step of 250 m, for a total of 121 points. On this sets of points we tested the algorithms specified before. In Figure 3 we represented the results of these algorithms.

The visual comparisons show a high similarity with the reference for the Delaunay Triangulation and Shepard interpolation in both test cases.

In order to evaluate the surfaces generated by using statistical methods it is necessary to test the quality of the surfaces with an independent set of data, which were not considered in the interpolation.

In the following we will evaluate the surfaces generated by using a random set of points for which was determined the real value of the altitude. For this independent random set we have determined the following statistical parameters: variation, median absolute deviation, standard deviation and the root mean square error. The determined values are presented in the table below:

4. Results of test cases

The results obtained in the both cases show that the most accurate surfaces are generated, for the first case (grid of 500 m), by Kriging, Shepard

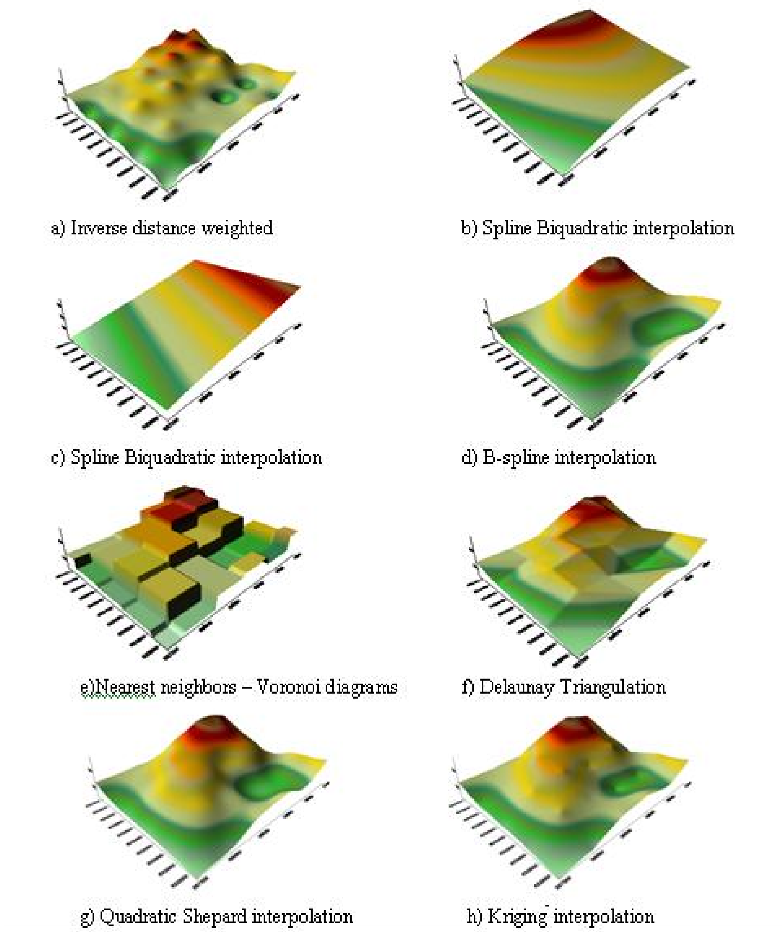

FIGURE 2. DTM model generated with 30 known points

and B-spline algorithms and for the second case (grid of 250m) by Delauney triangulation followed by Shepard and Kriging.

If we evaluate all the statistical data we notice that the Delauney triangulation represents the optimal method. Similar results can be obtained by Kriging and Shepard interpolation. Even these methods are sometimes more efficient than the Delauney triangulation. Nevertheless, the Delauney algorithm is recommended because it needs less computing time and it is not changing the original values of the points. The b-Spline algorithm gives also a good result but in this case the computing time is much higher and it is smoothing the

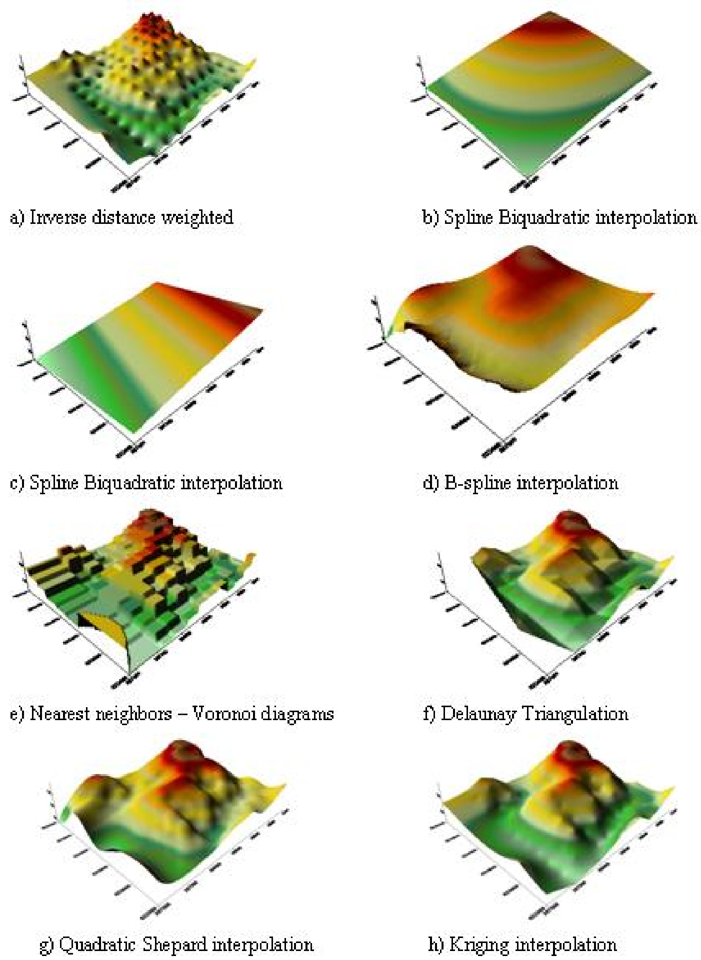

FIGURE 3. DTM model generated with 121 known points

surface, fact which is making this method inadequate for surfaces with a high altitude difference.

Many studies have examined the DTMs generated by interpolation but the earlier studies compare fewer methods, usually by testing a strong algorithm with a fast one or by testing one algorithm with two or three different point density. Some examples of studies are: a comparison between IDW and Voronoi [4], IDW vs. Kriging [11], and between IDW, Kriging, Thiessen polygons and TIN [8] and IDW, minimum curvature, modified Shepard and TIN [10]. Except the study made by Weng, all of them are using only one set of input data.

Methods	Variation 250	Variation 500	Median absolute deviation 250	Median absolute deviation 500	Standard deviation 250	Standard deviation 500	RMSE 250	RMSE 500
IDW	231	167	11.6	10.17	15.21	12.29	13.48	10.93
Bi-quadratic	390	426	16.17	16.56	19.75	20.64	15.35	13.84
Bi-cubic	947	1044	26.53	26	30.77	32	19.14	17.14
B-spline	166.2	145	9.67	9.9	12.89	12	12.54	10.37
Voronoi	246	94.5	11.38	7.3	15.71	9.75	13.79	9.27
Delaunay	218	36.63	10.85	3.41	14.78	6.05	13.34	7.99
Shepard	164	71.78	9.56	6.40	12.81	8.47	11.97	8.49
Kriging	160.06	78.97	9.74	6.81	12.65	8.88	11.75	8.94

TABLE 1. The statistics for all the created surfaces,based on a set of random control points

Our results regarding the accuracy of surfaces created by interpolation are similar with the earlier studies. By testing a higher number of methods and in two different cases we demonstrated that DTM accuracy can vary to a certain degree with different interpolation algorithms and interpolation parameters.

5. Conclusion

In this paper we compared the most popular algorithms involved in producing a DTM, in order to establish the main factors which affect the accuracy of the DTM and to improve the quality of the generated DTM.

The performance of eight methods, in two different cases, was evaluated in this paper, based on the accuracy of the generated surface. The first conclusion which is pointed up by the values presented in table 1 and by the analysis of the visual results, in the both cases, shows that input data form the basis for the computation of the DTM. The density of the known points is a more important factor in increasing DTM quality than the algorithm used in surface creation.

A second conclusion is that there is no optimal algorithm for any situation, the results given by different computational method are influenced by more factors like: the conformation of the field, the density of the initial points, the quality of the known values and nevertheless by algorithm used.

The last conclusion is that, we can improve the quality of the DTM by using the Delauney algorithm and a high density of known points. Regarding the way of computing for Delaunay triangulation, it is necessary to have at least 3 points for each hill or valley.

References

[1] M. R. Asim, M. Ghulam, K. Brodlie, *"Constrained Visualization of 2D Positive Data using Modified Quadratic Shepard Method,"* WSCG'2004, Plzen, Czech Republic.

[2] J. K. Berry and Associates *"The GIS Primer - An Introduction to Geographic Information Systems,"* http://www.innovativegis.com/basis/, May 2006.

[3] L. De Floriani, E. Puppo, P. Magillo *"Application of Computational Geometry to Geographic Informational Systems,"* Handbook of Computational Geometry, 1999 Elsevier Science, pp. 333-388.

[4] Chongjiang Du *"An Interpolation Method for Grid-Based Terrain Modeling,"* The Computer Journal,vol.39, nr. 10, 1996

[5] ESRI. Environmental Science Research Institute *"Arc/Info 8.0.1,"* ESRI, Inc. 1999.

[6] W. Karel, N. Pfeifer, C. Briese *" DTM Quality Assessment,"* ISPRS Technical Commission II Symposium , 2006 XXXVI/2, pp. 7-12.

[7] R. T. Trambitas *"Analiza numerica. Note de curs,* http://math.ubbcluj.ro/ tradu/narom.html, 2003

[8] P. Siska, I. Hung *"Assessment of Kriging Accuracy in the GIS Environment,"* Annual ESRI International User Conference, San Diego, CA, 2001.

[9] M. van Kreveld *" Algorithms for Triangulated Terrains,"* Conference on Current Trends in Theory and Practice of Informatics, 1997.

[10] Qihao Weng, *"Quantifying Uncertainty of Digital Elevation Model,"* http://isu.indstate.edu/qweng, December 2006.

[11] Y. Ziary, H. Safari, *"To Compare Two Interpolation Methods: IDW, KRIGING for Providing Properties (Area) Surface Interpolation Map Land Price,"* FIG Working Week, 2007

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