Use and Abuse of Digital Terrain/Elevation Models

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Abstract

DTM's and DEM's are widely used for landscape reconstruction and GIS analysis. Very accurate models are possible to construct on a small scale with the aid of a 3d-scanner, or on a larger scale with the aid of photogrammetic processing of aerial images. But far more often archaeologists will have to rely on software to process point-data and contour lines.
The different kinds of software have many algorithms and parameters. They have to be used with care, as changing an algorithm or the parameters for an algorithm, will dramatically alter the resulting DTM or DEM. Especially if the model is used for further GIS analysis, any lack of knowledge on these differences may have serious repercussions on the conclusions of for instance site-locations and ways of communication.
Ken Kvamme already demonstrated these possible dangers almost a decade ago. Since then, many new and more elaborate algorithms came available, capable of both creating a better model as well as an even more distorted image of reality. This suggests that archaeology may benefit by an update on this subject.

Introduction

Letting a computer process a series of co-ordinates, representing a research-area and values within that area, seems pretty straightforward. In this paper, however, I will try to explain that there are many things to be considered, before the end-result may be used or presented, as a valid part of, or in future research.

Awareness of this started formally about ten years ago and has led to my workshop of this CAA in 2003.[1] Between these years, many well-known authors in the proceedings of the conference kept these ideas alive (f.i. Barceló 2000, Lock 1995, Niccolucci 2001, Stancic 1995) but far too often only in front of a "specialized audience".[2]

So in many aspects, this paper is a both a summary of these past efforts and warnings, as well as an enhancement towards the status quo of this moment. Certainly as I have added some calculable items, especially on the grid size of collecting data, and some examples, which will make the understanding of creating a functional DTM/DEM more useful to scientists in archaeology.

Using DTM/DEM's, from Simple to very Complex

In Archaeology, the very basic usage of using a digital model representing z-values within an area is to create a map with contour lines. This is very straightforward, and usually taken from existing maps. In many cases contour lines can be digitised directly form any topographical map, or easily obtained with an application able to convert available point-data into such a map.

More often, archaeologists want to present a "good-looking" 3d-model of the values. This requires a program with an algorithm to process point-data or digitised contour lines. If not used for further scientific research, please use the basic options of the available application, and see if it looks "reasonable". Be sure to provide meta-data, including the origin of the data, the program and the algorithm used.

The last phrase is very important. In the pre-computer era, detailed elevation maps were produced by highly skilled surveyors, using as many accurate measurements as could be taken, and a clear view on the landscape (they were there!). They could enhance their measurements on the map with any visible anomaly in the landscape. No computer has this advantage.

Available Types of Data Sets

All measurements needed for a DTM/DEM can be grouped into two kinds of data sets. They are either gathered within a grid (or the best equivalent to a grid), or they are irregular, as for instance digitising the original point-data maps of surveyors in the Netherlands or contour lines.

The Minimum Distance needed between two Data-Points (Nyquist-Limit)

Whether or not the data comes from point-data measured in an almost regular grid, or from an irregular distribution, the key-factor for a correct creation of a DTM/DEM is the maximum distance between two points in the survey-area. That distance will determine the minimum size of features in the landscape to be detected.

From an empirical test, it was easily discovered, that this distance should be at least one-third of the smallest anomaly in an area that has to be detected, in order to be sure that it reflects itself on a map. Using the knowledge of other sciences however, this idea can be scientifically enhanced and supported by the "Nyquist Limit".[3] This law, also known as "Shannon's Sampling Theorem' states: "A signal must be sampled with a frequency at least twice the frequency of the signal itself." Applied to the creation of a DTM/DEM in a two-dimensional environment, this will have to be: "The maximum distance between two points should be 0.5 times 0.5 equals 0.25 the size of the area/shape of a feature to be detected."

So the "Nyquist Limit", can be used as the best way to determine the lower-limit of any sampling in Archaeology. Please note, that this will also apply to any other spatial sampling.

The Main Algorithms and their Use

Perhaps the most common known algorithm is not actually an algorithm, but just a connection between 3d-points. It is called "Triangulated Interpolation Network", or short TIN. TIN, in it's originally use, does not change any of the given data-points, it just creates a triangular mesh between them. The advantage is of course a full representation of each measurement. The disadvantage is an "edgy" looking DTM/DEM.

The pure TIN would be almost perfect, if data would be evenly spaced within a grid, and with a maximum distance between points not exceeding 1/10th of the necessary "Nyquist Limit" and smoothed. In most cases however, the measurements will be quite close to the "Nyquist Limit", or they have other irregularities, and there is an actual need to "interpolate" the mesh on the basis of the distribution of measurements.

If this is needed, it is important to understand that every single measurement is still fully recognised, but the resulting DTM/DEM may be lower or higher on that exact spot. This can be best explained in describing measurements of a ploughed field on a slope. In that case the field is a mess of small "ditches" and "walls", with no measurement giving the exact slope. Each point, whether too high, or too low, is however part of the general overall slope. And we want to "average" all existing data, in order to filter out the noise. Or in other words: "Too Smooth and Curve."

Most algorithms for DTM/DEM's perform exactly this operation. And therefore they are both very useful and very dangerous. Hence this title "Use and Abuse of Digital Terrain/Elevation models". And there are a dozen of them available. Within archaeology, this amount can easily be reduced to five: "Inverse Distance to a Power; Kriging; Minimum Curvature; Natural Neighbour; Nearest Neighbour." All of these five perform a special operation with the data set, and will result in a less or more accurate 3d-model, giving the needs.

The differences are quite visible, but often not understood. This is the point where the archaeologist should want to have a statistician with knowledge of the subject, as there is no formal "Nyquist-limit" to calculate this effect.

Basic Parameters

Except for "pure TIN", almost every algorithm should have the ability to adjust "Search Radius". This is used to disallow points from beyond a certain distance to flatten mountains like the Alps, or (on the other hand) to allow them to smooth a ploughed field on a slope.

Most common applications for creating DTM/DEM's will also allow a special parameter. This parameter is called "anisotropy", which is best explained as the "knowledge of the most common shapes in a landscape." The Norwegian coastline, for instance, is on many places characterized by fjords.

These fjords show an existing overall tendency in the landscape, which is normally disregarded in an algorithm. Anisotropy as a parameter can use this tendency and change the normal "circular" way in which data-points are allowed to influence each other. It can narrow down the "Search Radius" in one direction. By this, measurements on steep edges could be limited in the "Search Radius" as far as the top of their (average) ridge. This will prevent all algorithms to "down-average" prominent features like fjords, which are very steep and narrow.

Mapmaking

Despite all other warnings, even a DTM/DEM is a map. The "Nyquist Limit" may give an indication for the smallest detail, but it cannot prevent the creation of a terrible representation. As it is no use of making a map with every house in Amsterdam, as part of a roadmap for the entire Netherlands, as it is to use a map with highways as a guide for the centre of Amsterdam. Scale and detail have to be in relation to the size of the documented area.

The "Idrisi" Factor

In the twelfth century the cartographer Abu Abdallah Idrisi[4] presented a silver sphere to the Norman King Roger of Sicily, representing the earth. This may seem an anachronism, given the date, but the king, who apparently fully appreciated the true nature of our planet, kindly accepted it.

Anyone working with DTM/DEM's has to appreciate this too. A DTM/DEM normally is a plan and therefore only a projection of a part of the earth's surface. In general this not so important, but it becomes critical if the research area is over ten kilometres wide, and the model will be used for certain GIS analyses like "viewshed".

Any further analysis that is not entirely map-based, like "viewshed" (the panorama from a certain point in the area), will have to take in account this "Idrisi"-factor. It will need the precise knowledge of the earth's curvature, in order to adjust the DTM/DEM accordingly.

Conclusions

DTM/DEM's are often easily created, but they tend to be just "nice images" instead of a true scientific basis for (further) research. And even the 'most appreciated' examples of the past decade, are presented without any metadata regarding the algorithm, or the parameters used.

This omission does not respect any of these models (and the results based on them), as it is impossible to validate the DTM/DEM for it's specific use.

The data sets themselves are also a main point of consideration. Detection of a feature on the basis of measurements within a 2d-environment is only feasible if the largest distance between two 2d-points follows the "Nyquist-Limit". This scientific limit, based on "Shannon's Sampling Theorem", should be at least 0.25 of the size (smallest diameter) of the least feature to be detected.

And finally, every DTM/DEM is an extended map. It has to follow the rules of a map and it has to know about the "Idrisi"-factor.

[1] The workshop used the program "Surfer 8.0". "Golden Software" allowed the use of their program for CAA2003.

[2] These papers were published in far more specialized publications (very restricted to subject or country, or both) than the CAA-proceedings. The best example is from Franco Niccolucci. A very clear "status quo" of this subject dating from 2001, but only available in the series "Archeologia e Calcolatori", on computer applications in Italy and in Italian.

[3] Many thanks to Sven Haveman, of the "Institut für ComputerGraphik", Braunschweig. He made me aware of this existing mathematical law considering 'sampling', during the CAA2003 conference. We both determined at that time, that this law had to be applicable in this case. Sven Haveman has agreed with the fact, that I have enhanced the paper with this important item.

[4] Abu Abdallah Muhammad Ibn Muhammad Ibn Abdallah Ibn Idrisi al-Qurtubi al-Hasani, as his full name is, was born in Ceuta, Spain; in 1099 A.D. Sources differ on the date of his death, either in 1166 or 1180. His name is nowadays widely known within CAA as the person who gave his name to Idrisi, the GIS-program for the PC.

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