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Comparison of Accuracy in DEMs at different resolutions

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Summary

There are a variety of methods to compute DEM's from contours, here we made a comparison on DEM's accuracy as results of three different approaches and at different resolutions. In order to cheek DEMs performance it's not only important to study the DEMs accuracy in function of DEM's resolution as well to observe visually its contour maps.

Introduction

Two structures are currently used in terrain representation: regular grids and triangulated irregular networks. A regular grid is a matrix of elevations where the constant spacing of the grid is known by grid resolution. It's assumed that the resolution decreases with the increasing of the grid cells dimension. A triangular irregular network is a set of irregular points connected by edges in a set of non overlapping triangles. Associating a function to the interior of each quadrangular or triangular cell will define a numerical model known as digital terrain model (DTM). In the case that the structure is a grid the model will be a digital elevation model (DEM) and in the case the structure is a triangular irregular network will be a triangulated irregular network (TIN). There exists a long bibliography on the subject and we mention without be exhaustive [1], [5], [8], [7], [2].

The classical method to build a DEM from contours is to reduce data to the intersection points of a set of vertical and horizontal lines with the contours [6], and then to apply a global interpolating method such as the Shepard [4] method to compute elevations at a grid. Other method consists on computing the elevation at a grid from a TIN of plane faces, whose nodes are all the data points on the contours. Taking in mind that the terrain surface is a smooth surface we can assume that cutting a contour map with a line will define a spline along that line. So if we intersect the contour map with a series of vertical, or horizontal, lines we can compute a grid from the splines defined for each line.

For the examples we use a contour map of $[2Km \times 2km]$ with an equidistance of 10 metres (figure 1).

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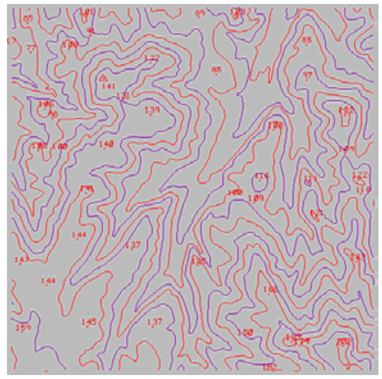

Figure 1: Original contour map

DEM form Shepard method

In order to compute a DEM at a resolution of 200 metres the contour map was intersected by 11 equal spaced vertical and horizontal lines. The intersections points of those lines with contours where taken as scattered data set and a grid elevation matrix was computed by a localized Shepard method. Similarly grid at resolutions 50, 25, 20, 10 and 5 metres where computed with the same method, from scattered data obtained by the intersection of the suitable vertical and horizontal lines.

This method produces effects such as picks and pits in the neighbour of data points. Those effects are independent of the resolution and can be seen in figure 2 a) corresponds to a 20m DEM resolution, and in the corresponding contour map figure 2 b).

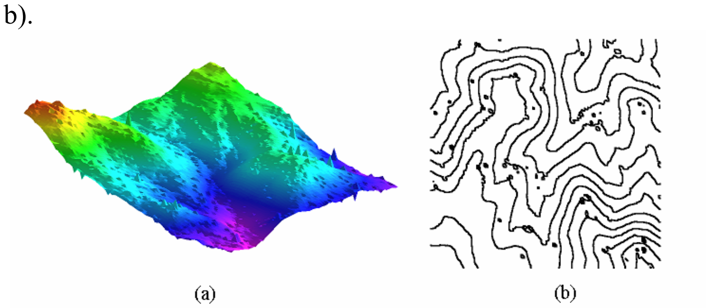

Figure 2: DEM from localized Shepard method

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DEM from TIN

In this case a triangulation of the contours was computed. Then a piecewise triangular surface was build over the domain and the elevations at grids of resolutions mentioned in the previous method were computed from this prismatic surface. However, independently of the resolution, this model produces terraces as it can be seen on the contour map of Figure 3 corresponding to a 20 meters resolution DEM.

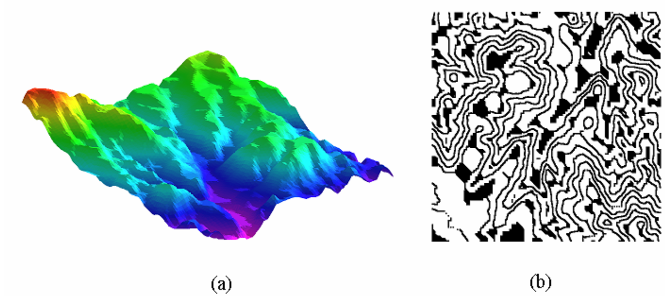

Figure 3:DEM from TIN

DEM from splines

To compute a grid at 200 metres resolution, we intersect the region with 11 equally spaced vertical lines. The intersection points with the contours were used to compute splines. Each spline was used to compute 11 equally spaced elevations. Similarly series vertical splines where used to compute grids at resolutions mentioned above. For comparison we can observe figures 4 a) and 4 b) of a DEM of 20 metres resolution, and as we can see there are no artefacts such as picks, pits or terraces.

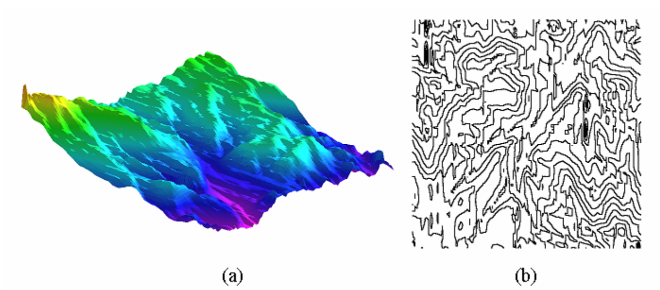

Figure 4: DEM from vertical splines

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Measuring accuracy

To determine the accuracy of a DEM, we will need some independent knowledge of the topography to determine the difference between the computed surface and the actual one. So if we know the values z_{gi} of the elevations of the actual surface at some number of n points distinct of the data points we can compute the deviations d_i between the actual surface and the computed surface z_{DEMi}, and the root mean square error (RMSE) [3]

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}}, \qquad (1)$$

between DEM and ground truth elevations can be used to measure DEM accuracy. Alternatively it can be used the standard error S and the mean error $\overline{d}$

$$S = \sqrt{\frac{\sum_{i=1}^{n} \left(d_i - \overline{d}\right)^2}{n}} \; with \; \overline{d} = \frac{\sum_{i=1}^{n} d_i}{n}. \qquad (2)$$

To test the accuracy of the mentioned methods we use the set of scattered spot eights on figure 1 as true elevation points. As an example we can observe figure 5 corresponding to a representation of the RMSE and standard error for DEMs computed from splines at different resolutions. It can be seen that it both estimators decreases rapidly for bigger resolutions, staying almost stable for resolutions grater than 25 metres.

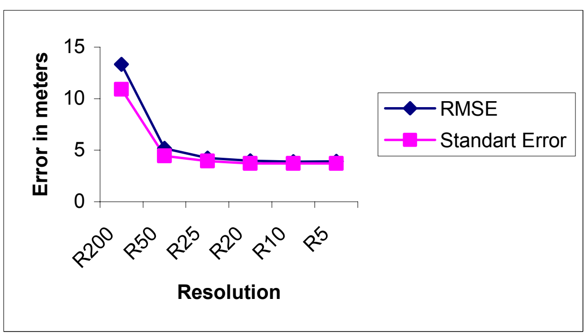

Figure 5: RMSE and Standard Error from DEMs computed from a set of vertical splines

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Degree of the interpolation

In order to analyze the variation of both estimators with the degree of the interpolation algorithm testes where made for bilinear and quadratic interpolation on the grid. We conclude that both estimators diminish with the increasing of the degree of the interpolation. The difference in the estimators is significative for resolutions smaller than 10 metres, but there are no significative deviations for resolutions of the order of 5 metres, as it can be seen on figure 6 relatively to the plot of the RMSE for DEMs from TIN computed for a bilinear and a quadratic interpolation.

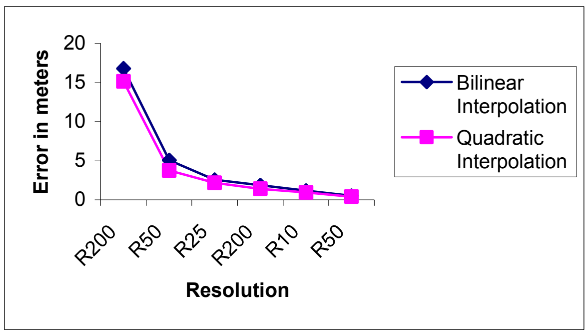

Figure 6: RMSE computed on DEMs from bilinear and quadratic interpolation

Conclusions

In order to compare the three methods (DEM from Shepard method, DEM from TIN and DEM from splines) we plot the corresponding RMSEs at different resolutions on the graphic of figure 7. It can be observed that the root mean square error is smaller to DEMs from splines for big resolutions comparatively to the other 2 methods, however for small resolutions the method that presents smaller values of those estimators corresponds to DEMs from TIN. For any resolution DEMs from localized Shepard method present bigger estimators.

Our study point to different choices, that depends on the grid resolution. So for small resolutions the DEM from spline method present smaller errors so is without doubt the best of the three methods presented. For bigger resolution in spite of the method that present smaller errors be the DEM from TIN, in our opinion the best choice is DEM from splines due to the fact that the previous one presents terraces.

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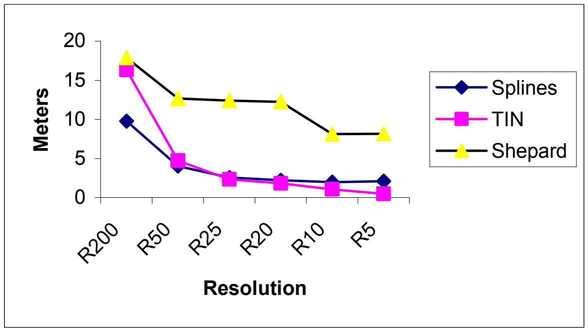

Figure 7: Comparison of RMSE for the different methods

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