UPDATING ELEVATION DATA BASES
- MERGING OLD AND NEW DATA

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ABSTRACT

Information on data origin, quality, structure and distribution is essential to the updating as well as the use of an elevation data base and should be stored in conjunction with the data base.
Running updating procedures on a part of an elevation data base often results in a non-homogeneous quality and distribution of the data. This must be communicated to the user before the data base is used for analysis, which means that new facilities for data merging and updating must be introduced in the digital cartographic system that manages the data base.

KEY WORDS: Updating, Elevation model, Data base

INTRODUCTION

Extensive research on digital elevation models (DEM) has been carried out over the last 20 to 25 years. The construction of the models, and in particular the study of interpolation procedures, were *the* research subjects in the 1970s. A substantial number of interpolation methods were introduced.

Later, the research focused on the quality of the models and the relationship between data acquisition method, point distribution and terrain characteristics. It was concluded that the choice of interpolation method had little influence on the accuracy of the terrain model, while the crucial factors were the nature of the terrain and the point density (Kubik and Botman, 1976. Frederiksen, 1981).

Several procedures for control of data acquisition and prediction of the quality of the models have been developed (Frederiksen et al.,1986. Tempfli, 1986. Fritsch, 1988).

Today, there are a number of effective DEM program packages on the market developed within almost every earth science discipline. However, most of these packages are stand alone programs and not until lately has the DEM become an integrated part of the GIS environment (Sandgaard, 1988).

Future research will focus on this integration, the use of the models and the maintenance of the huge amount of data that will be captured and stored in elevation data bases.

The purpose of this paper is to identify some of the problems that must be treated when a digital elevation data base is updated, and to propose a few solutions to overcome these problems.

DEM AND ELEVATION DATA BASES

A digital elevation model is defined as a collection of points with known x-,y- and z-coordinates. The points represent the terrain surface with an accuracy determined by the measuring method. The distribution of the points should vary according to the characteristics of the terrain. The points in a DEM may be organised in a regular grid or a triangular network, may be measured in profiles, may represent break lines or structure lines or follow contours as a result of digitising maps or measuring contours in a photogrammetric stereoplotter.

An interpolation procedure is attached to the DEM data in order to estimate the z-value of a new point at a given planimetric position.

When the measured and/or interpolated points of a digital elevation model are stored they make up the terrain data of the *digital elevation data base.* Apart from these, the data base is characterized by a number of parametres originating from the DEM, i.e. accuracy, point distribution etc. This "historical" information should be stored in conjunction with the terrain data to constitute the complete elevation data base and in order to make a proper updating possible.

The updating of a digital elevation data base can be defined as replacing parts of the data base by new points or adding new points to the data base. Similar to the interpolation method of a DEM the updating procedure consists of a strategy for merging new and old data in the data base. Implicitly, the updating should improve the capability of the data base to represent the terrain surface.

IDENTIFYING THE PROBLEMS

The simplest way of updating an elevation data base is to replace the whole data base by new data. In that case, of course, none of the above mentioned parametres of the old data base have to be considered.

However, when just a single point in the data base is replaced or a new point is added to the data base a number of the historical parametres must be considered. First of all:

- *The reference system must be identical for new and old data .*

This has to be investigated before updating and action taken to ensure the same reference level for the entire data base.

Normally, an updating takes place in a limited part of the data base initiated by the requirement of a higher quality of the z-values. In that case:

- *The quality of the updated database is non-homogeneous.*

The updating may be motivated by the desire for a higher point density in a specific area, or a grid model is updated by merging the grid with a cartographic data base comprising z-values of the measured entities such as roads and houses. This will probably have the effect that:

- *The point density varies in the data base*

The data acquisition method for the new points can determine a point distribution which leads to a data structure different from the original database. For instance, the data base may be organised in a grid and the new data may originate from the measurements of a technical map. Consequently:

- *The data structure varies in the data base*

Some of these problems can be illustrated by the analysis of the updating process of a grid data base.

THE GRID DATA BASE

Besides general information on reference system, time and method of data acquisition the grid data base is characterized by the following parametres:

- *Grid spacing*
- *Grid orientation*
- *Point accuracy*

The grid spacing is often the same in both directions forming a square grid. However, the spacing may change across the data base due to data acquisition method or sampling stategy. Progressive sampling (Charif and Makarovic, 1988) and Fourier transformations (Frederiksen, 1981) are examples of sampling and prediction procedures introduced in order to achieve an optimal grid spacing. In both cases, the grid spacing will vary according to the type of terrain and the accuracy requirements.

Normally, the grid is oriented parallel to the x- and y-axis of the reference system, a procedure which also facilitates the use of the data base as regards interpolation and extraction of data.

Basically, the accuracy of the z-values is related to the accuracy of the planimetric positions of the acquired points, but in this context, the quality of the elevation data base is considered to be dependent on the z-values only.

The most evident advantage of a grid data base is the data structure. Data can be compressed, for instance by run-length coding, and only the z-values need to be stored in conjunction with the above mentioned characteristics. This holds as long as the grid size does not change. If the grid size varies from one part of the data base to another, the compressed data storage can only be preserved if additional information specifying the locations of the changes of the grid size is stored.

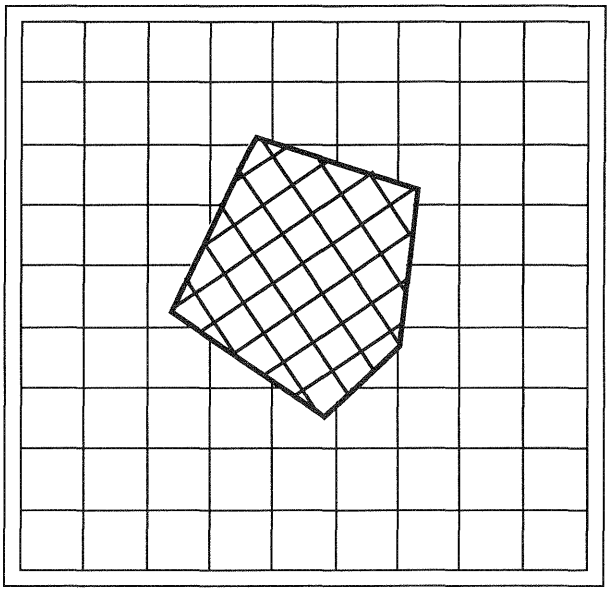

Figure 1.

New data captured to update the elevation data base in a limited area may be organised in a grid with orientation, spacing or accuracy differing from the original data base. Irregularly distributed elevation data must be considered as well.

If the grid orientation of the new data differs from the grid of the data base, or if the new data are irregularly distributed, an interpolation procedure must be introduced to accomodate the grid data structure, either in order to preserve the original grid spacing of the data base or to define a grid with a new spacing in the updated area.

OLD AND NEW DATA

Independently of the structure of the new data it, must be decided whether the new data will replace the old data or whether both data sets will contribute to the updated data base.

In case the new data are sampled at the same positions as the points of the existing data base, two possibilities exist:

- *The new z-values can replace the old data at the grid points* or
- *New and old data can be merged to a new estimate of the height.*

In case the new z-values are sampled in a grid with a spacing differing from the data base but with the same orientation the old data can be rejected and the updated area will simply consist of the new grid data.

In any other case, an interpolation procedure has to be introduced to preserve the grid structure. A number of strategies are available for the updating:

- *New data can be interpolated to the data base grid and the old data rejected.*
- *New data can be interpolated to the data base grid and merged with old data.*

- *New data can be interpolated to a new grid spacing and old data rejected.*
- *New and old data can be interpolated to a new grid spacing and merged.*

Half of the above listed updating strategies include rejection of existing data from the data base and replacement with new sampled z-values. This may be a critical action since the old data still contain information on the terrain and can contribute to the data base. Of course, old data must be rejected if the elevation data base is updated in an area where any activity has changed the shape and the elevation of the terrain. However, an updating often takes place because new data of a higher quality or density are available in a limited area without any changes of the terrain surface.

The most general situation occurs when new and old data are interpolated to a new grid and merged. This involves 2 interpolations and a merging operation between the interpolated data and can be desribed as

$$z_{base} = a \cdot z_{o,int} + b \cdot z_{n,int} \qquad (1)$$

where z_{base} denotes z-values in the updated data base, $z_{o,int}$ are old z-values and $z_{n,int}$ new values interpolated to the same grid point. The factors a and b represent the merging operation.

MERGING OLD AND NEW DATA

It could be claimed that the interpolation and merging should be looked at as a single operation. On the other hand, it is obvious that the construction of a new grid from old grid data and new sampled z-values situated at other positions includes a distance dependent component which in this context is identified as the interpolation procedure. The interpolation of DEM data has been discussed extensively and in great detail by several authors. It should only be mentioned that interpolation in triangular networks (TIN) and least squares prediction seem to be the most popular interpolation methods when a simple linear approach is not sufficient. So, the following discussion will focus on the merging of old and new data, assuming that the z-values have the same position.

In the area to be updated, the merging can be realized by applying a weight function to the old and new data considering the individual accuracies of the data:

$$z_{base} = w_o \cdot z_o + w_n \cdot z_n \qquad (2)$$

A satisfactory solution is the weighted mean value introducing the variances of the two data sets.

$$z_{base} = \frac{\frac{1}{\sigma_o^2} z_o + \frac{1}{\sigma_n^2} z_n}{\frac{1}{\sigma_o^2} + \frac{1}{\sigma_n^2}} \qquad (3)$$

This approach requires information on the quality of the existing data base as well as the new data. It is assumed that the variances include contributions from the interpolation if such a procedure is applied.

The weight function works properly in the updating area, and in the case of the new data being significantly better than the existing data base, the new data will dominate the updated data base.

The result is probably a non-homogeneous data base as regards point density, but the quality of the data will also change suddenly when the border between old and new data is crossed. This is illustrated in figure 2 by the change in standard deviation.

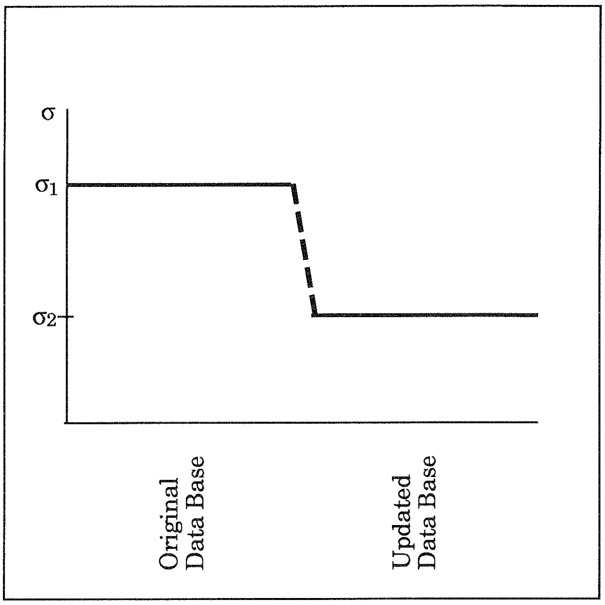

Figure 2.

In the updated elevation data base the variance is most likely to change suddenly from one area to another.

It is recommended that an overlap is created which can serve as a buffer zone between the existing data base and the updated area. In the buffer zone, a smooth transition between two areas with different variances can be established, while a change in grid spacing, of course, has to be accepted as a discontinuity. In case the old data in the updated area are completely replaced by new data, a "fidelity" measure can be estimated in the buffer zone, and possible discrepancies revealed. Small deviations can be eliminated by an adjustment.

Similar to the interpolation, a distance dependent weight function is introduced across the buffer zone in order to ensure a smooth variance function in the data base. A linear transition is obtained by

$$z_{buffer} = z_1 \cdot (1 - \frac{x}{b}) + z_2 \cdot (\frac{x}{b}) \qquad (4)$$

where $z_1 = z_{old}$ and $z_2 = z_{base}$ from expression (3). The distance from the outer border of the buffer zone is denoted x, and b is the width of the zone. The corresponding standard deviation function is illustrated in figure 4. Obviously, the shape has become smoother,

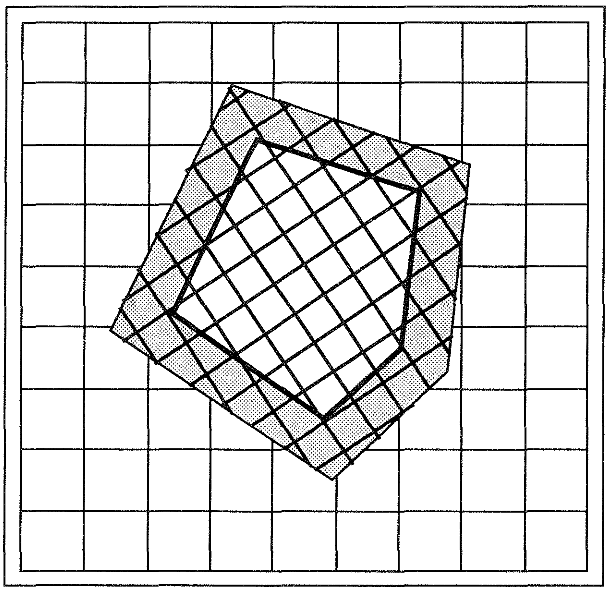

Figure 3.

A buffer zone is established as the transition between the old data base and the updated area.

but there are still break points at the borders of the buffer zone. A smoother transition is obtained by the weight function

$$z_{buffer} = z_1 \cdot \cos^2\left(\frac{\pi \cdot x}{2 \cdot b}\right) + z_2 \cdot \sin^2\left(\frac{\pi \cdot x}{2 \cdot b}\right) \qquad (5)$$

which is illustrated in figure 5.

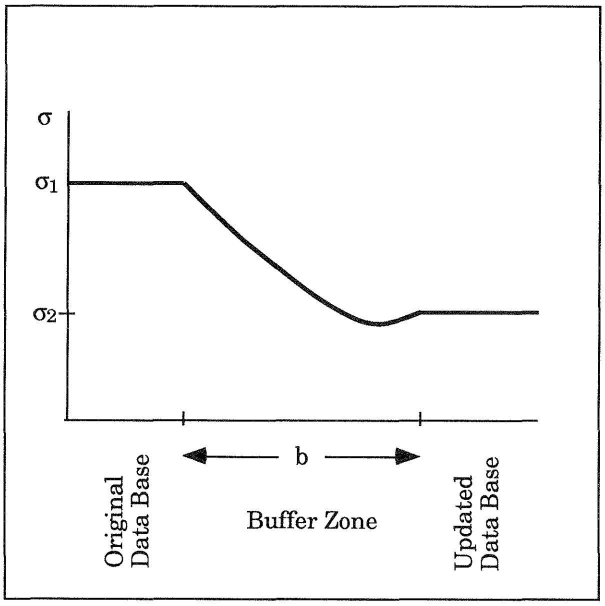

Figure 4.

The transition curve of the standard deviation as a result of the weights of equation 4.

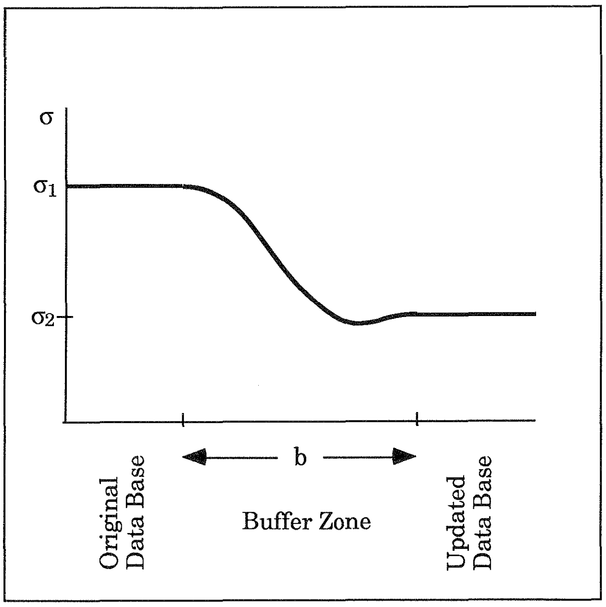

Figure 5.

A smooth transition curve is obtained by applying the weigths of equation 5.

USE OF THE UPDATED ELEVATION DATA BASE

The result of an updating procedure is in most cases a data base with varying grid spacing and accuracy. This will complicate the use of the data base and increase the risk of misuse. Therefore, it is necessary to communicate the non-homogeneity of the data base to the user. Special maps or illustrations attached to the data base can show these variations together with precise table information stored in the data base. In particular, transition zones between different grid sizes and accuracies are potential areas for misuse of the data base.

An automatic warning system could be created for future data bases. An example is the construction of contours where conventional rules for the relation between contour interval and point accuracy could be included in the data extraction module. An alarm should warn the user, if the contour interval required is less than that permitted by the quality of the elevation data. A more drastic solution would be to prevent the construction of contours until the requirements on the contour interval is in accordance with the data quality. It might be helpful for the skilled user and necessary for the unexperienced.

CONCLUSION

The updated elevation data base is almost always a data base with a more complex structure than the original data base. Point density, accuracy and even data structure may vary within the data base. This accentuates the need for additional information comprising historical data for any step in the creation of the data base. Such information is essential in future updating as well as to the regular user of the data base to prevent misinterpretation of data. The data base software should comprise warning systems or perhaps blockings which are activated if the data are called into use beyond the range of their application.

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