RESEARCH ON A CORRECTION METHOD TO EXISTING GRID-BASED DEM

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ABSTRACT:

The existing grid-based DEM has several disadvantages in representing the features of real terrain surface, such as peak clipping, channel filling, etc. And abrupt changes in elevation cannot be handled easily and precisely. The inherent size of grid mesh affects the DEM computing, analysis and results. Through the discussion of DEM terrain distortion, the representative types of distortion were analyzed and the possible reasons of distortion were given in this paper. A brief review of the existing DEM data structures was showed and a technique for correcting the existing grid-based DEM was presented to try to solve the problem mentioned above and improve the precision of the terrain surface represented by the DEM. The method developed a new and simple data structure of DEM. It is based on the raster structure and integrated terrain features to the grid cell of existing DEM. Experiment was also made to test the results of correction method.

1. INTRODUCTION

The digital elevation model (DEM) is widely used in remote sensing, geographical information system (GIS), virtual reality (VR) and so on. So far, Triangulated Irregular Network (TIN-based DEM) and digital contours (Contour-based DEM), the grid-based DEM has been developed for the terrain representation, of these data structures, grid-based DEM has been the most commonly used data source for its own advantages, such as the implicit definition of point topology and the relatively compact storage, etc. (Alias A. et al, 1994; John P. W. et al., 2000; Li Z. et al., 2005). On the other hand, the disadvantages of grid-based DEM are also obvious that it cannot handle abrupt changes in elevation and the size of grid mesh affects the obtained results and the computational efficiency (Carter 1988; Collins et al. 1981; Moore I. D. et al., 1991; Zevenbergen L. W. et al., 1987).

Some methods are tried to overcome these drawbacks:

- TIN offers a relatively easy way of incorporating break lines, fault lines, drainage lines, thus tailored to the terrain variations and it can easily incorporate discontinuities and may constitute efficient data structures because the density of the triangles can be varied to match the roughness of the terrain. (Peucker et al., 1978; Peuquet 1990; Weibel et al., 1991; Lee, 1991; Kumler, 1994)
- A hybrid structure was developed to represent terrain by a relatively dense regular grid in smooth surface regions and TINs describing structures at a finer resolution such as topographically complex or interesting terrain parts (such as the area containing break lines and spot heights, etc.). This framework can integrate different multi-resolution modelling techniques operating on different types of data sets such as TINs, regular grids, and non-regular grids. (Amor M. et al., 2004; Karl K. et al., 2005; Amor M. et al., 2007; M. Bóo et al., 2007)

However, it is known that TIN is always applicable in small areas while large scale terrain regions, so many problems may arise in storage, transmission and visualization in a large area of rough terrain.

The hybrid DTM uses different structures to represent the terrain in different areas, but the related works emphasized particularly on the representation and visualization of the terrain, extremely, they lay particular stress on the hardware supporting of the method. Not much attention was paid to the description and improvement of the structure.

A good implementation of the hybrid structure is the SCOP++ program. It achieved considerable results of the interpolation and the visualization. But it only gave a compendious introduction of the data structure and a mass of pointers were used to model the topology of the hybrid DTM. The pointers will cause additional storage space. So in fact, this structure is complex and can result in the complexity of data management and reduce the data retrieval efficiency. Then it is difficult to be realized and widely used.

Grid-based DEM may clip the peaks or fill the pits which are exited in the real terrain, and the linear features like ridges and channels are often depicted in one grid cell width. This phenomenon is called as terrain representative distortion of grid-based DEM. The inherent grid structure is the major cause of distortion.

So, the aim of this paper is to provide a method to solve the problems mentioned above and improve the precision of the terrain surface represented by the DEM. Inspired by the SCOP++ program, a new DEM structure was developed and a correction method to existing grid-based DEM by embedding the terrain features was presented.

In this paper, firstly the terrain representative distortion that cause by grid DEM was discussed, then the existing DEM structure and the new one that combined terrain features and grid DEM were introduced, and lastly a correction method was presented based on the paper's new structure. Visual

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experiment was done to compare the results of the existing method and its correction.

2. TERRAIN REPRESENTATIVE DISTORTION

The SCOP approach mentioned that the quality, the level of detail and the demand of a complete model of the 3D world of DTMs still required to be improved. It gives the suggestion that the existing DEM cannot meet the needs of the representation of the real terrain.

As part 1 mentioned, for the inherent grid structure and other reasons, grid-based DEM cannot describe the real terrain surface accurately, so terrain representative distortion occurs. Representing both external characteristics and internal causes, terrain distortion of the existing DEM is especially obvious in complex landform. However, it should be distinguished from DEM's error and DEM's uncertainty. DEM's error is the difference between the observed value and the true value of the terrain surface and DEM's uncertainty is the degree of the difference. Because of the existing of the terrain distortion, grid DEM cannot meet the applied demand of the high quality project.

The terrain representative distortion in grid DEM was analyzed in detail and classified into four types, which are spatial position distortion, spatial relationship distortion, spatial structure distortion and terrain morphology distortion. All those distortions were owing to three reasons:

- *Inherent grid structure of DEM;*
- *Terrain features lose in collection;*
- *Incomplete technique to create DEM.*

Some representative terrain distortion is showed in the following pictures (from Figure 1 to Figure 5):

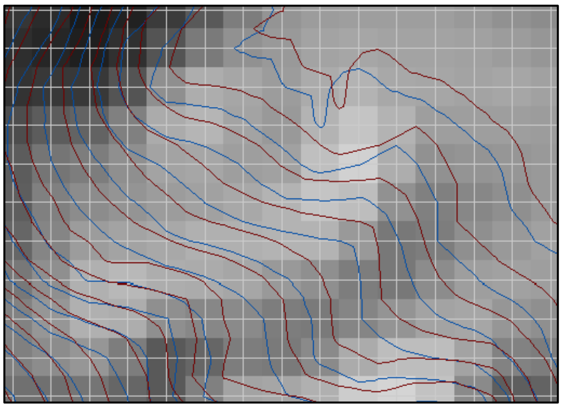

Figure 1. Elevation matching warp of DEM

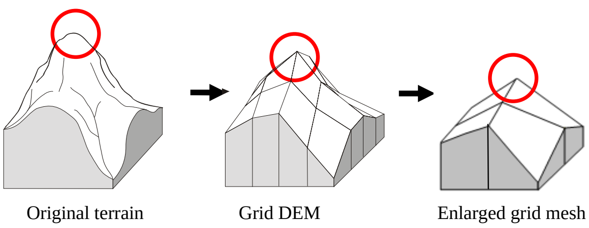

Figure 2. Sketch map of the peak point distortion

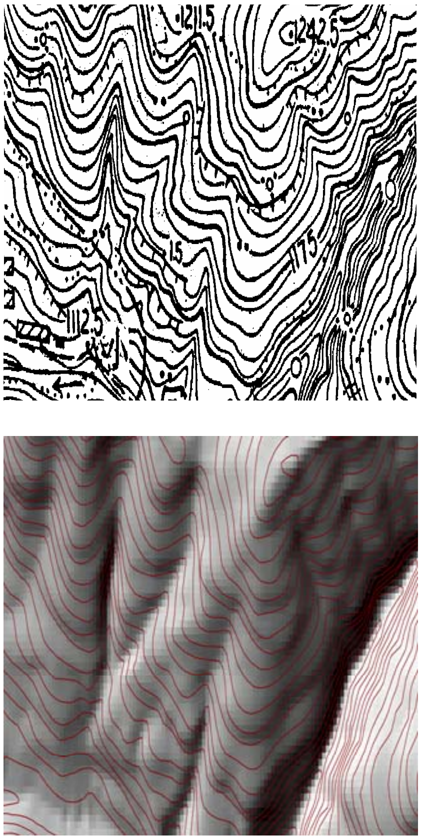

Figure 3. Loss of cliff lines in DEM

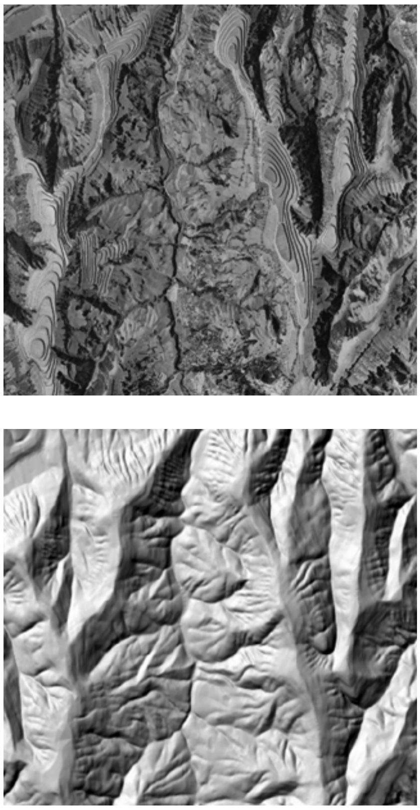

Figure 4. Loss of terrace in DEM

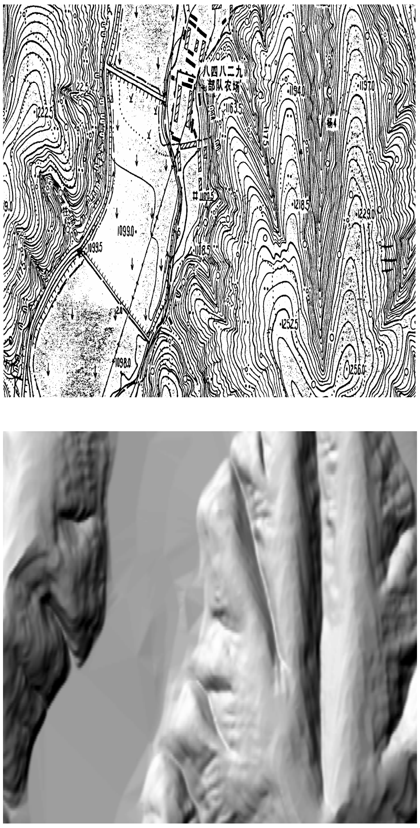

Figure 5. Loss of dams in DEM

As above, five figures are displayed to give a visual show of terrain representation distortion.

Figure 1 shows the spatial position distortion. Two different construction methods are used for the same DEM data, one is point-based surface modelling, the other is grid-based surface modelling. Owing to the DEM benchmark is not definite, the contours generated by the two modelling methods cannot match each other.

In figure 2, there are 3 pictures which can describe the peak point distortion, which is a typical type of terrain morphology distortion. When grid DEM is constructed, some details of the real terrain cannot be represented, the peak point is not very obvious, and when the grid mesh is enlarged, the peak point is almost disappeared.

Figure 3 & figure 4 are also terrain morphology distortion. Cliff lines can be clearly seen in the topographic maps, while in grid DEM, the terrain surface is described smoothly in figure 3. And in figure 4, there are many terraces in the DOM image (left picture), but they are not visible in the DEM (right picture). So this kind of DEM may result in the incorrect landform classification and terrain morphology, etc.

Figure 5 compares the topographic map and DEM of dam representations. The river in the DEM is continuous but it is divided into three parts in the topographic map. So when the DEM is used to flood routing and simulation, there will be a large additional area to be inundated.

3. CORRECTION METHOD

3.1 Existing grid-based DEM structure

Traditionally, the grid / raster structure is the most widely used data structure. The points (xyz coordinates) are normally arranged in a series of rows and columns or in xy Cartesian system.

The cell values of each grid interpolated by the sampling points, are recorded in the DEM file. These values constitute the main part of DEM file. They are formed in row-major order (just as a matrix). Besides, there must consist of header information containing a set of keywords, such as NCOLS, XLLCORNER, etc. The file structure is displayed as the following picture (Figure 6).

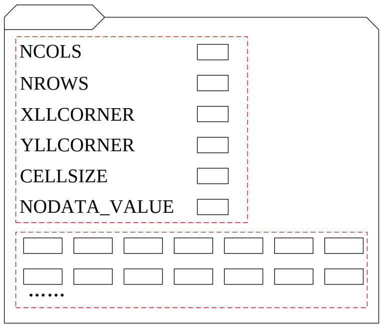

Figure 6. Arcview ASCII file structure of grid DEM (here □ is a number, and the keyword nodata_value is optional and defaults to -9999)

- *Header information:* include the coordinate southwest, size of grid mesh, number of columns / rows, nodata_value, etc. The nodata_value is the value in the ASCII file to be assigned to those cells whose true value is unknown. In the raster, they will be assigned to NoData. The number of columns in the header is used to determine when a new row begins.
- *Cell values:* cell values in row-major order. (Matrix of the elevation values) The number of cell values is equal to the number of rows times the number of columns in the header information.

3.2 Correction method to grid DEM

3.2.1 Data structure:

The existing grid-based DEM is a grid/raster data model while the terrain features, such as peaks, pits, ridge lines and channels, are of vector character. Although the hybrid data structure like SCOP++ can integrate grid and TIN, the structure is not easy to apply and cannot be compatible with the existing DEM.

Taking the above issues into account, the new structure uses the existing grid based-DEM and feature information to model the terrain. The new structure of DEM integrates the feature information to the grid cell, while feature information contains feature points, feature lines and feature polygons. Feature information is divided up by the grid cells (Figure 1).

Additionally, the intersection point of the grid mesh and the features should be computed, it is interpolated by sampling points of the features (Figure 7).

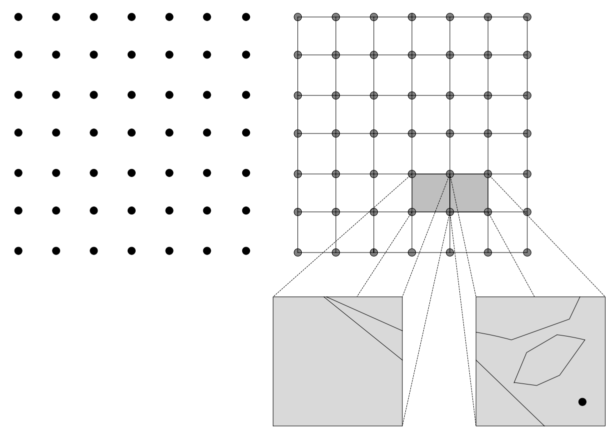

Figure 7. Grid (left) and mesh-divided features (right)

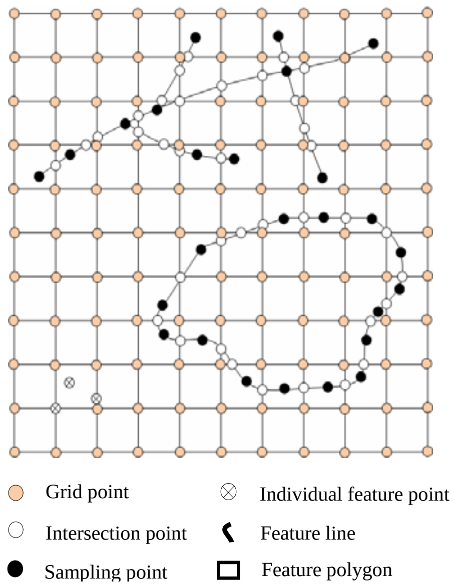

Figure 8. Grid DEM integrated features

As figure 8 shows, there are 3 different features, points, lines and polygon, which are integrated to the grid mesh. They are all divided up by the grid cells, and the intersection points are marked up in the figure and recorded.

3.2.2 File structure:

The new structure of DEM include two parts: one is grid file, which is the existing grid DEM file, but the elevation of any grid cell that contains terrain features is replaced by a pointer. The other one is the terrain feature file which records the feature points, lines or polygons of the relevant DEM. The two parts was associated with the pointer which is recorded in grid file.

- *Grid file:* The structure is almost the same as the above structure in 4.1, the only difference is that the elevation data of the grid cell that contains terrain features is replaced by a pointer. And the pointer locates to the place where terrain features are stored and collected relatively precisely in the feature file. Then the two parts was associated. (Figure 9)

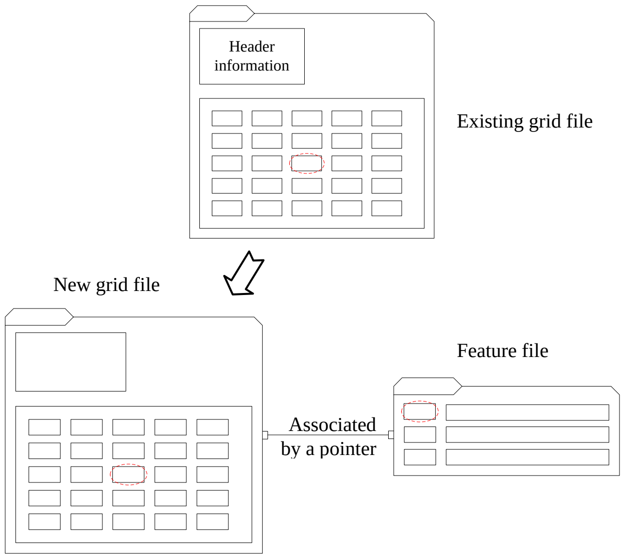

Figure 9. New file structure

- *Feature file:* All the feature information and the intersection points of features and grid mesh in a grid cell are stored as an item (in one row) in the feature file. The features are stored by a series ordered points in the file, feature codes are used to distinguish different feature types. So the feature information is stored as figure 10.

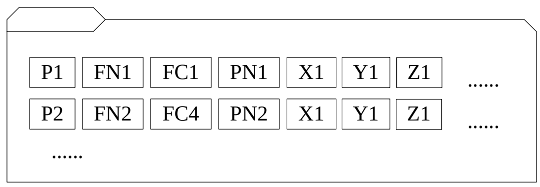

Figure 10. Feature file structure (here P1, P2… represent the pointer; FN1, FN2…represent the number of feature types in a grid mesh; FC1, FC2…represent the feature code; and PN1, PN2…are the number of points in a grid mesh; while at last, X1, Y1, Z1…are the coordinates of the points.)

Comparing the two methods, the new grid structure is a little difference from the existing one, it retains the original structure integrally and only replaces some cell values by a pointer. And the feature structure gives a detailed description of the DEM features. The pointers associate the two parts, so this new structure is not only compatible with existing grid DEM, but also integrates the terrain features.

4. VISUAL TEST AND EXPERIMENT

4.1 Experiment of the correction method

Using the above new data structure of DEM, experiments are made to test the effect of integrating terrain features in grid cell,

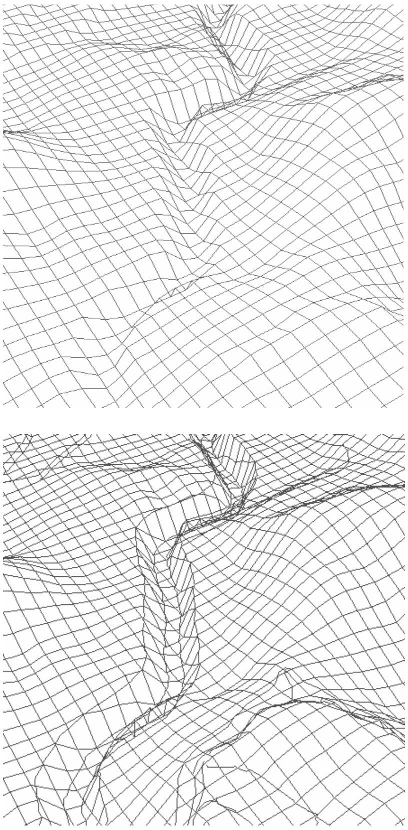

Figure 11. Representation of the channel with the grid-base DEM and the corrected DEM

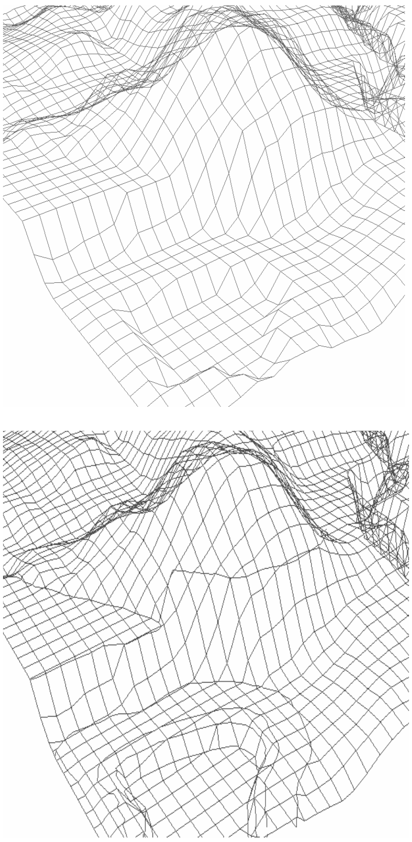

Figure 12. Representation of the cliff and pond with the grid-base DEM and the corrected DEM

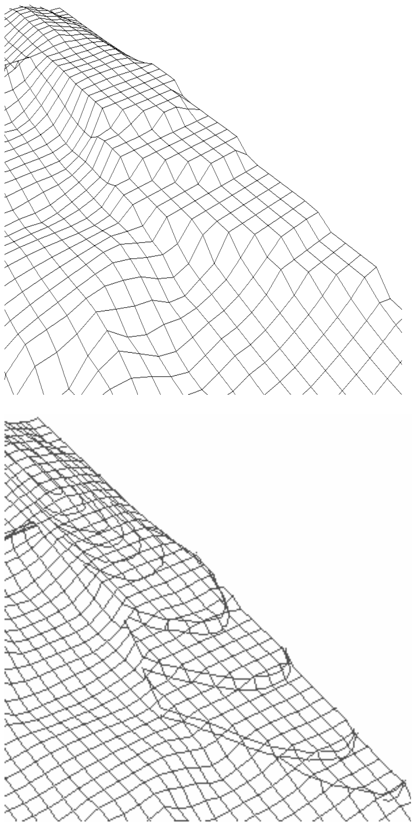

Figure 13. Representation of the terraces with the grid-base DEM and the corrected DEM

all the programs are running on the Windows XP platform, based on Visual C++ 2005 and OpenGL 2.0.

The above pictures (from Figure 11 to Figure 14) show the results of the experiment.

The above 3 couples of pictures give an obvious contrast of the existing grid-based DEM (top) and the corrected DEM (bottom).

As mentioned above that grid-based DEM cannot handle abrupt changes in elevation, each left picture of the three figures shows a relative smooth terrain surface. Many terrain morphology features, such as shoulder lines, ridges, valleys, cliffs, etc., cannot be accurately or clearly described. Due to the inherent structure of grid DEM, when there are abrupt changes or terrain features inside the grid mesh, the peak will be clipped, the channel will be filled and the cliff will be smoothed, etc. (left picture of each figure). Then terrain representation distortion occurs. This can lead to incorrect result of hydrological modeling, geomorphology application, ecology application and other digital terrain analysis.

When the terrain feature information is integrated to the grid, the terrain representation has taken great changes (right picture of each figure). In figure 11, the channel is obvious and its bottom and edges are described by feature lines. And similarly, in figure 12, there is a cliff and a pond, using a feature line, the cliff can be easily handled and a feature polygon represents the pond. At last, in figure 13, there are many terraces in this area, which are not obvious in the left picture, when the feature lines are embedded, the terraces can be seen clearly, which is important to the land use classification and control of soil and water loss, etc.

As a whole, the visual test and experimental results show that the correction method can integrate the feature information with grid DEM and describe the terrain more closely to the reality, especially in the abrupt changing areas.

5. CONCLUSIONS

As the existing grid-based DEM plays an important role in GIS and it's widely used to modelling the terrain surface, the disadvantages should be made up. With the analysis of terrain representation distortion, this paper provides a new structure of DEM using the embedded terrain features, and gives a correction method to the existing grid-based DEM. From the visual test, terrain features are integrated with the grid mesh and DEM representation is improved. With the findings of this study, the following conclusions can be draw as follows:

- Terrain representation distortion is inevitably existed in grid-based DEM, and it goes against with terrain analysis and DEM application.
- The new structure is simple and easy to realize, what's more, it's still a raster structure. It makes good use of the existing grid structure.
- The correction method improves the representation precision of DEM, then the digital terrain analysis can be improved. It also gives some suggestions to DEM sampling. With the method, high quality demanded DEM can be produced and DEM will be more widely used.

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