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A Resizing Method for 3D Visualization of Digital Elevation Models

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Abstract

The diversity and versatility of display devices today imposes new demands on digital elevation models (DEMs). This paper proposes a resizing method for 3D visualization of DEMs based on topographic feature. The proposed method improves seaming carving algorithm to resize DEMs instead of images according to the characterristics of DEMs. The proposed resizing method considers not only geometric constraints but also the characteristics of DEMs. Being different from the traditional reduction and expansion methods, the method not only resizes DEMs, but also preserves the characteristics of Digital Elevation Model. The method is implemented and experiments are carried out on actual DEM data. It can be seen from the comparison with scaling method that the proposed method is efficient and provides better 3D visualization of DEMs.

Keywords*: 3D terrain, 3D visualization, display device, reduction algorithm, expansion algorithm*

1. Introduction

In recent years, with the rapid development of computer technology, especially computer graphics, 3D visualization technique and virtual reality technique, the intuitive and vivid 3D terrain visualization system has become the focus of researches. Compared to 2D plane terrain which is characterized with singularity and lack of intuitiveness, 3D terrain can transform the geographic data and its analysis results into direct visible information, and enable geographic information visualization and space analysis [1-4]. Digital Elevation Models (DEMs) is a digital expression of landform surface and one of the basic data to describe terrains, and is of great advantage to 3D visualization and statistical analysis of terrains.

Nowadays more and more display devices appear in our life, digital cameras, PDAs, PADs, cell phones, computers and so on. Meanwhile we want to see 3D terrains on different display devices. Different display devices have different resolutions, but column and row of DEM are fixed. The resolution of the DEM should be changed (reduced or expanded) in order to fit into different display devices. Numerous methods have been developed in recent years.

Vertex clustering algorithm [5-8] divides the vertexes into some vertex clusters through spatial partitioning, and then merge the vertexes within the same cluster into one vertex. Vertex clustering algorithm does not depend on topological information of the model (adjacency relations), and depends on geometric information (vertex coordinates). However, vertex clustering algorithm can not keep the characteristic of the models and control errors.

Region Merging algorithm [9-14] merges some surface regions to form a surperface. Based on coplanar criterion, superface algorithm partitions the vertexes into some connected regions and uses polygonal patch instead of each region respectively. Finally, the algorithm simplifies the boundary of polygonal patch and triangulates polygonal patch again. The algorithm always consume too much time.

Stepwise refinement algorithm [15-19] provides an approximation model of the original model, and increases the details gradually. Then, the algorithm triangulates the local regions and does not stop until the approximation model achieve the user-specified accuracy. The

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algorithm includes greed insertion method and hierarchical segmentation method. Computational time of the algorithm is very high.

Vertex Decimation algorithm [20-21] removes some details and decreases the complexity of the model by deleting the vertexes. Firstly, the algorithm classifies the vertexes according to local topological structures and geometry information (simple point, complex point, boundary point, interior point and corner point). Then, the algorithm selects the vertex which will be deleted and deleted all the adjacent facets of the selected vertex and triangulates the holes generated during the processing procedure. The algorithm can not keep the smoothness of the models.

Edge Collapse algorithm [22-24] sorts the edges according to the error when the edges are deleted. The edge with the minimum error will be deleted firstly. If an edge is deleted, the two ends of the edge will be merged into one point and the related edges will be degraded into triangles. However, the algorithm has a high time complexity.

Triangle Collapse algorithm [25-27] merges the three vertexes of the triangle into one vertex and deletes the degraded adjacent triangles and the original triangle. The time complexity of the algorithm is very high.

Wavelet [28] Decomposition method provides a perfect mathematical expression. The method was proposed by Lounsbery and DeRose in 1994. The main principle of the method is decomposing the 3D model into low resolution parts and details by wavelet. The low resolution parts are subsets of the original models and the vertexes are weighted average of the corresponding vertexes' neighborhoods. Low pass filter is used to realize and it shows low frequency signals. The details include abstract wavelet coefficients. High pass filter is used to realize and it shows high frequency signals. The algorithm only works for triangle network with subdivision connectivity.

The simplest and most popular method for resizing the DEM is scaling method [29-33].

The methods mentioned above could be used to resize the DEM, but these methods are not always very effective to preserve the characteristics of DEMs. More effective resizing can only be achieved by considering the characteristics of DEMs and not only geometric constraints.

Avidan and Shamir published "seam carving" algorithm in 2007 [34]. A simple image operator called seam carving that considers the image content (content-aware image) resizing for both reduction and expansion is presented. A seam is an optimal 8-connected path of pixels on a single image from top to bottom, or left to right, where optimality is defined by an image energy function. By repeatedly carving out or inserting seams in one direction the algorithm can change the aspect ratio of an image.

In this paper, we propose a new method for resizing DEMs which is based on topographic feature (mountainous region, hill, plain, high land, basin). Seam carving algorithm is not oblivious to the image content, so we aim to improve seaming carving algorithm to resize DEMs instead of images according to the characteristics of DEMs. The proposed method uses an energy function defining the importantcance of point in DEMs. A enery path is a connected path of low energy points crossing the DEM from top to bottom, or from left to right. By successively removing or inserting enery path, we can resize the DEMs in both directions.

2. Methodology

2.1. Computation of DEM Parameters

A DEM is a digital simulation of terrain surface through limited elevation data. Elevation data often use absolute height or altitude. In a mathematical sense, DEM is defined as a two-dimensional continuous function [35-38]:

$$H = D(x, y) \tag{1}$$

Where (x, y) is the plane position of terrain point and H is elevation of the corresponding point. The gradient of $D(x, y)$ at point (x, y) is the following vector:

$$\nabla D = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial D}{\partial x} \\ \frac{\partial D}{\partial y} \end{bmatrix} \quad (2)$$

The gradient is the direction in which the function increases the most quickly at point (x, y):

$$|\nabla D| = mag(\nabla D) = \left[G_x^2 + G_y^2\right]^{1/2} \quad (3)$$

Where $|\nabla D|$ is the maximum value of $D(x, y)$ as per unit of distance increases. The topographic features is more and more obvious with the increasing $|\nabla D|$. For convenience of calculations, we calculate point-to-point partial derivatives of DEMs ($\partial D/\partial x$ and $\partial D/\partial y$) to detect edges of obvious topographic features. This leads to the following energy function:

$$E(D) = \left|\frac{\partial}{\partial x} D\right| + \left|\frac{\partial}{\partial y} D\right| \quad (4)$$

2.2. Reduction Algorithm

The key problem of reduction algorithm is how to select the points to be removed. Our goal is removing the background points which are independent of topographic feature with low energy. Topographic feature points are with high energy [34]. Energy function defining the importance of pixels, since an optimal strategy to preserve energy would be to remove the points with lowest energy in ascending order. if we remove a different number of points from each row or each column, the visual coherence of the DEM will be destroyed and visual artifacts will be introduced [39].

Therefore, we need a resizing operator that can preserve the continuity of DEMs. This leads to the improved seam carving algorithm and the definition of energy paths.

Because we want to resize the DEMs (remove or insert some points from each row and each column), we firstly remove or insert one point from each row and column.

Formally, let *D* be a $n \times m$ DEM and define a vertical energy path based on the x direction and a horizontal energy path based on y direction to be:

$$P^X = \{p_i^x\}_{i=1}^n = \{x(i), i\}_{i=1}^n, s.t. \forall i, |x(i) - x(i-1)| \le 1 \quad (5)$$

$$P^Y = \{p_j^y\}_{j=1}^m = \{(j, y(j))\}_{j=1}^m, s.t. \forall j, |y(j) - y(j-1)| \le 1 \quad (6)$$

Where x is a mapping of $x: [1, \cdots, n] \to [1, \cdots, m]$ and P^X is a vertical energy path in DEM from top to bottom (the first row to the last row), containing one, and only one, point in each row of the DEM. Similarly, y is a mapping of $y: [1, \cdots, m] \to [1, \cdots, n]$ and P^Y is a horizontal energy path in DEM from left to right (the first column to the last column).

The definitions of P^X and P^Y lead to the following optimal energy path (OEP, the path to be removed or inserted) P^* that minimizes this path cost:

$$P^* = \min_P E(P) = \min_P \sum_{i=1}^n E(D(p_i)) \quad (9)$$

The optimal energy path can be found using dynamic programming [40]. First compute the cumulative minimum enery for all possible connected paths for each point in the DEM. Then backtrack to find the path of the optimal energy path.

The proposed reduction algorithm is an iterative process by repeatedly removing OEP as follows:

Step 1, Calculate REM, which is the number of columns (rows) which will be removed.
Setp 2, Calculate EnergyMatrix, which stores the enery of each point in the DEM.
Step 3, Loop, step is 1, from 1 to REM DO
Step 3.1, Find a OEP.
Step 3.2, Remove the OEP.

3.3. Expansion Algorithm

The proposed expansion algorithm is also an iterative process by repeatedly inserting energy path as follows:

Step 1, Calculate ADD, which is the number of columns (rows) which will be added.
Setp 2, Calculate EnergyMatrix, which stores the enery of each point in the DEM.
Step 3, Loop, step is 1, from 1 to ADD DO
Step 3.1, Find the ADD OEPs.
Step 3.2, Compute the average of the left neighbors and right neighbors of the ADD OEPs and store the average values in ADD average OEPs (AOEPs, top and bottom in the horizontal case).
Step 3.3, Add the ADD AOEPs into the raw DEM.

3. Results and Discussions

We selected GTOPO30 DEM for our study. GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds. GTOPO30 was derived from several raster and vector sources of topographic information. For easier distribution, GTOPO30 has been divided into tiles [41]. The study area (Figure 1), between east longitude 20° to 60° and south latitude 10° to 60°, is located in southeast Africa. There are 750 rows by 600 columns in the raw DEM matrix.

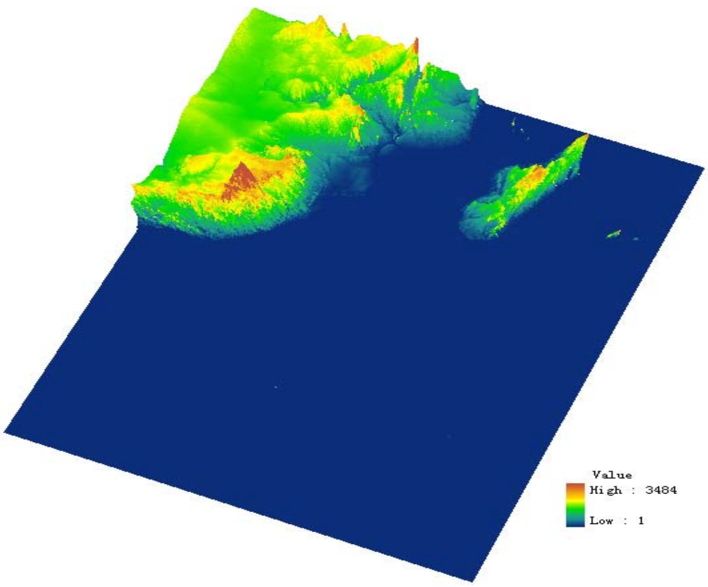

Figure 1. The GTOPO30 DEM of the Study Area

In order to examine the suitability and performance of the proposed method, it was implemented on the study area. We compare the proposed reduction method to the standard scaling method which is simplest and most popular. Figure 2 and 3 show the DEM resized using the scaling and proposed methods respectively. There are 375 rows by 300 columns in the resized DEM. Based on the comparison of the two figures, it can be seen that the proposed method is able to preserve the characteristics of DEM. It can be concluded from the comparison that the proposed method is efficient and provides better 3D visualization of DEM. Contrary to the scaling method, the proposed method will not alter important topographic feature of the DEM (as defined by the energy function), and preserve the characteristics of the DEM.

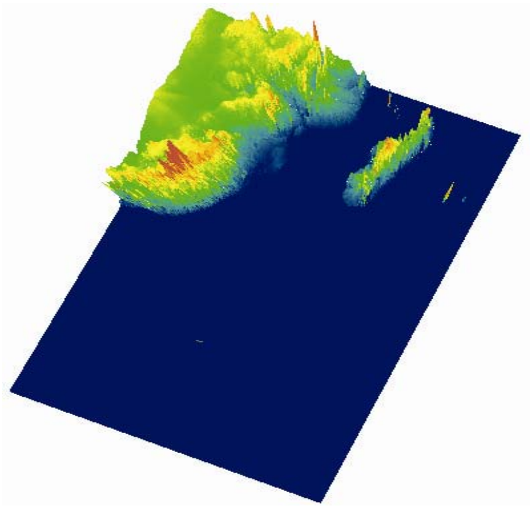

Figure 2. The DEM Resized using the Scaling Method

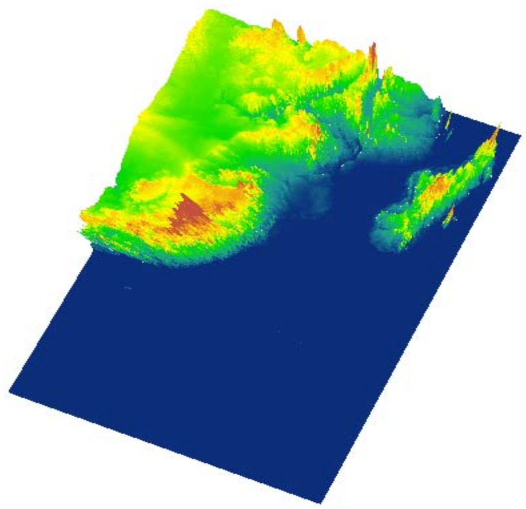

Figure 3. The DEM Resized using the Proposed Reduction Method

4. Conclusion

In this paper, we present a method for DEM resizing. The proposed method improves seaming carving algorithm to resize DEMs instead of images according to the characterristics of DEMs. The proposed resizing method considers not only geometric constraints but also the characteristics of DEMs. We would like to extend the proposed method to other domains, 4D GIS would be the first.

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