SYSTEMATIC SELECTION OF VERY IMPORTANT POINTS (VIP) FROM DIGITAL TERRAIN MODEL FOR CONSTRUCTING TRIANGULAR IRREGULAR NETWORKS

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ABSTRACT

Selection of a set of significant points from a raster digital terrain model is important for constructing a triangular irregular network. The set of points should contain information of terrain surface as rich as possible.

INTRODUCTION

The most common form of digital terrain model is the raster data structure. Its dense grids represent terrain surface very well for some applications. However, another new data structure has obtained more and more attention recently.

For representation of terrain, an efficient alternative structure to dense raster grids is the Triangular Irregular Network (TIN), which represents a surface as a set of non-overlapping contiguous triangular facets, of irregular size and shape.

The TIN data structure shows a better solution to overcoming problems caused by the non-stationary property of the terrain surface. Also, for some applications, such as shading, cataloging, and visibility, TIN has a nice implementation.

TIN can be directly generated from random point data. However, for constructing TIN from raster DTM, it is not so simple. First, DTM usually has too many pixels which can not all be selected for constructing TIN. Second, if one uses all pixels to construct a TIN, some advantages of TIN, such as simplification and generalization, are lost. Only a subset of pixels from the total pixels can be used for the generation of TIN. Thus, a key question is raised: 'Which pixel should be selected ? ' and 'Which pixel can be ignored?'. The principle here is that, between two pixels, the more important point should be selected.

'VIP' PROCEDURE

Before answering the question of which are the more important points among all pixels, a significance of each pixel must be evaluated. Here the significance of a pixel means how great a contribution the pixel can make to the representation of the surface. Our goal is constructing a triangular irregular network (TIN) to represent the original terrain surface by using the least number of points. We have to select some pixels, while other points have to be thrown away. When we say a pixel P1 is more important than another pixel P2, we mean that a more precise triangular irregular network (TIN) can be constructed if we use the pixel P1 in the set instead of pixel P2. The function of the VIP procedure is to select a set of pixels. The set must have two properties:

(1) For certain precision, a TIN constructed from the set has the least number of points than any other set.

(2) Among all possible sets, with the same number of points selected from the DTM, the set can construct the most precise TIN than any other set.

In other words, any point belonging to the selected set should be more important than any point that does not belong to the set.

Evaluation of significance of a pixel

We have to know how important a pixel is before selection of pixels. The VIP procedure calculates the significant degree of each pixel. An improved spatial high-pass filter is used to produce this significant degree.

High-pass filtering

A picture or an image can be represented in either spatial domain or frequency domain. In frequency domain, low-frequency (long wavelength) components represent major features on the original picture, such as overall skelton, major spatial distribution, etc. High-frequency (short wavelength) components represent detail features, such as edges, peaks or pits. These properties of spatial filtering have been used in digital image processing widely. For example, high-pass filters can do edge enhancement for images to find features.

High-pass filters can also be used to select significant feature points from digital terrain surface models. A pixel should be selected only if we can not predict its value from its neighbor pixels. For example, if a pixel has an average value from its eight neighbors, this pixel is not important enough to be selected. In other words, the significance of a pixel can be evaluated by measuring its changing behavior from its neighbors. This measure can be done by high-pass filters, such as spatial differential or a Laplacian operator. For terrain surfaces, in our applications, an improved spatial differential high-pass filter is used.

In the one-dimension case, the second order differential of a function

$$Y=F(X)$$

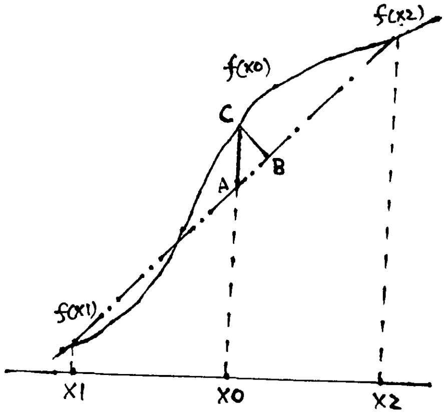
can be noted as:

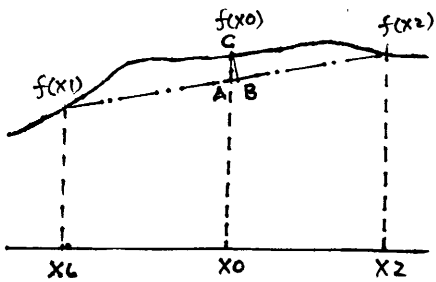
$$
\begin{aligned}
d^2Y/dX^2 &= F''(X) \\
&= 2 * [F(X0) - 0.5 * (F(X1) + F(X2))] \\
&= 2 * [F(X0) - A]
\end{aligned}
$$

The distance AC, shown in Figure 1, can be used to measure the behavior of change.

Improvements

The first improvement is an enhancement of the change measure. The change is measured by distance BC instead of distance AC. The consideration behind this improvement is an effort for better distribution of significant values of pixels. Comparing two examples in flat areas and steep slope areas, we can see why measuring BC is better than measuring AC. Distance BC is actually reflecting the real offset of change, especially in the steep slope area. At a given direction, a significance for the pixel is evaluated by measuring the distance BC

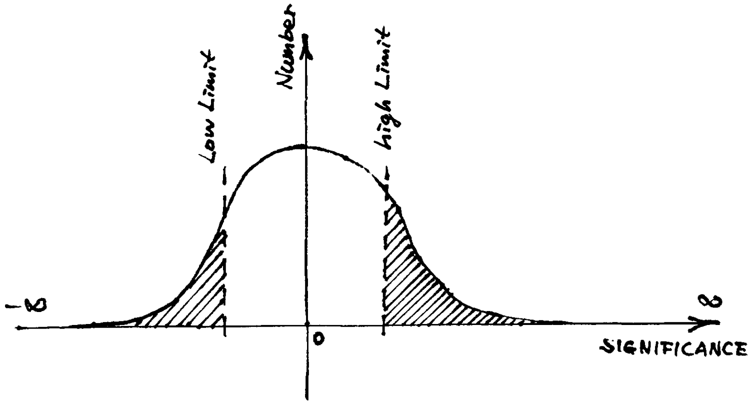




Another improvement is for considering all spatial directions. For simplifying computation, we only measure significances at four directions: up-down, left-right, upper left--lower right, and lower left--upper right. At each of the four spatial directions, a significant degree is measured and theabsolute values are added together to represent the significance of this pixel.

Histogram

After all pixels have been assigned their significance degree, the question of which pixel is more important can be answered. We assume that users will specify how many points are needed (or can be handled by their system). They can give this message by setting a ratio of the number of selection points over the total number of pixels. For selection, a histogram of distribution of significance of pixels is built. See Figure 2. The vertical axis is the number of pixels, while the horizontal axis is the significance value.



Based on this histogram, we now know the status of distribution of pixel significance. A typical distribution curve looks similar to normal distribution curves. More pixels have less significance. The number of points with higher significance values is less. The area under the distribution curve is 1.0 by normal units.

Determination of thresholds

Now, two thresholds can be found from the histogram.

$$\int_{\text{high limit}}^{\infty} \text{Number (significance) d significance} = 0.5 * \text{ratio} * \text{total pixels}$$

$$\int_{-\infty}^{\text{low limit}} \text{Number (significance) d significance} = 0.5 * \text{ratio} * \text{total pixels}$$

Any pixel with a significance value less than the low-limit or greater than the high-limit, should be selected. The sum of two areas beyond the two thresholds low and high-limits (shaded parts) is equal to the ratio the user specified.

Selection of VIP

A simple program scans all pixels and selects those pixels that have significances higher than the high-limit or lower than the low limit.

RESULTS ANALYSIS

There are two test data sets that represent mountainous and flat areas. For each data set, different ratio of VIP points over total pixels are set for selecting VIP points. Then their triangular irregular networks with different accuracies can be constructed, and each new terrain surface is compared with the original terrain surface to see how they match.

CONCLUSIONS

(1) The VIP algorithm can produce better significance distribution at both flat and mountainous areas.

(2) The VIP procedure provides a convenient way to select as many important points as the user needs. For any ratio of needed number of points, a set of points can be selected from all pixels. This set is always relatively more important than other unselected pixels.

(3) The VIP provides a better point set to construct TIN which fits the original terrain surface as faithfully as posible.

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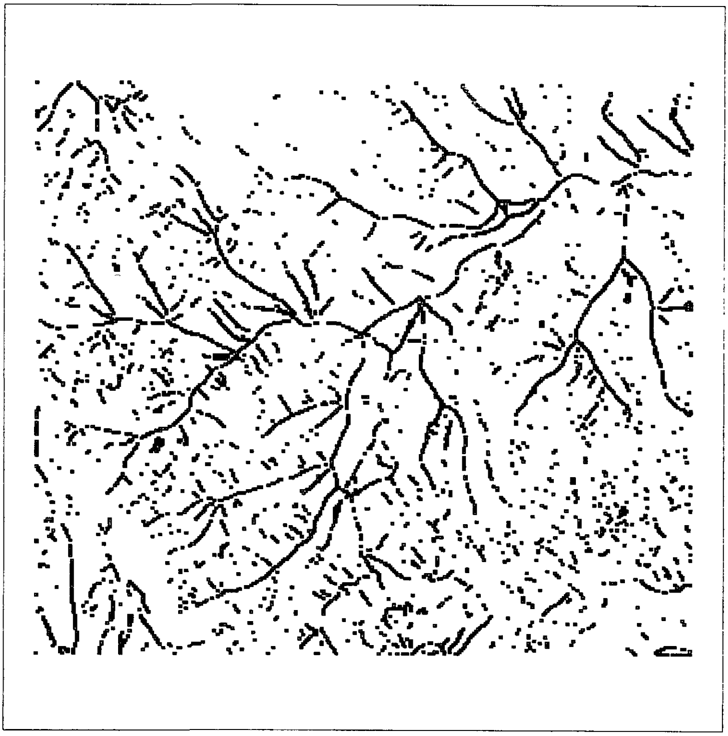

Figure 3. VIP points generated from raster DEM.
(The DEM is original from USGS file. Its size is 351*303.
VIP selected 4591 points. The ratio of VIP point number over pixel number is 4%.)

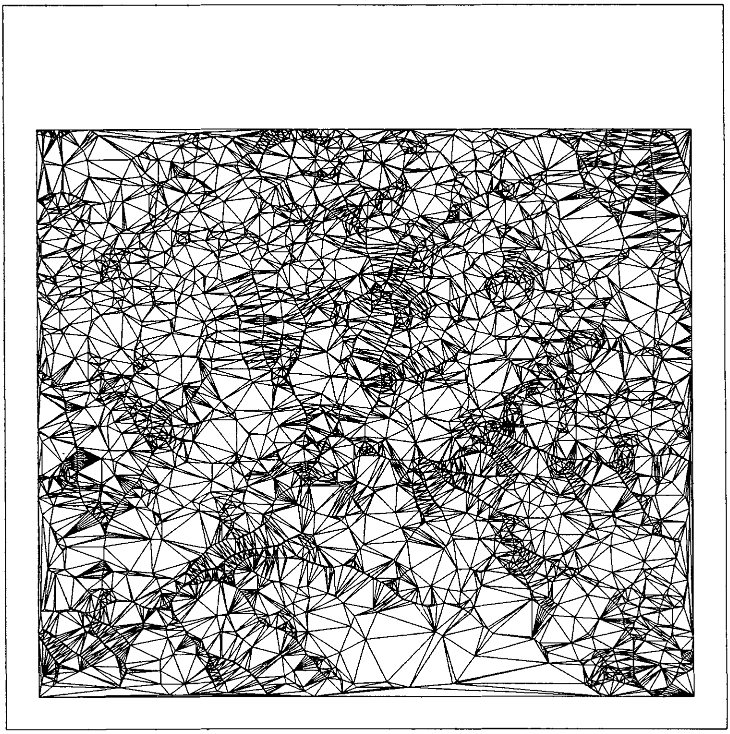

Figure 4. A TIN generated from VIP in Figure 3.
(The TIN has 4591 nodes, 9087 triangles.)