AN ENHANCED TIN GENERATION METHOD FOR USING CONTOUR LINE AS CONSTRAINTS

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Abstract

TIN (Triangulated Irregular Network) is a fundamental elevation model for analyzing data of 3 dimensional random points and break-lines. In the field of 3 dimensional GIS, where height data are usually sampled at random location together with 3 dimensional break-lines, elevation data are interpolated with TIN model, with break-line as constrains. When contour lines are used as break-line during TIN generation, flat triangles will be formed at the locations where contour line turns sharply and where there are no random points. Flat triangles formed under such conditions lead to unnatural presentation of the original elevation model, which will consequently cause incorrect analysis result when used in subsequent consulting activities.

While some researchers have proposed several algorithms to solve flat triangle problems in TIN generation, none of them gives a systematical way to generation natural TIN when using contour lines as constrains.

In this paper, we propose a series of methods which include identification of the flat TIN, modification of the input break-line data and finally generation TIN with the modified break-lines.

Experimental results with real world data show that the proposed method is easy to implement and generate more natural TIN.

Exceptions and solutions of our proposed methods are also discussed.

2. Description of the Proposed Method

The proposed method makes use of the result of popular TIN generation method with segment lines as constrains. It consists of the following phases:

a. Generation of TIN with contour lines as constrains by conventional method
b. Identification of the primal invalid triangle (flat TIN formed by the same contour line)
c. Tracing of the related invalid triangles
d. Generation of new break-lines
e. Regeneration of TIN with modified break-lines
f. Partial reconstruction of TIN

2.1 Identification of the primal invalid triangle

This phase locates the most fundamental triangle (hereafter called primal invalid triangle) that will always appear in the invalid triangles. With this primal invalid TIN, all the related invalid triangles can be efficiently located.

A primal invalid triangle is defined as a triangle that has two edges belonging to the same contour line. Since in real world data, a contour line is not always consisted of a consecutive point string, a preprocessing must be performed to connect polylines that belong to the same contour line but divided into different data group during data generation.

Fig.1 shows an example of primal invalid triangle.
Starting from the primal invalid TIN, all the invalid TIN can be traced by the following procedures:

Step 1: Initial set \( \text{InvalidTIN} \) with the primal invalid TIN as its only member.

Step 2: Initial set \( \text{InvalidTINEdge} \) with the edges of primal invalid TIN.

Step 3: Delete one edge \( E \) from the set \( \text{InvalidTINEdge} \).

Step 4: Find the triangle \( \text{T}_{\text{base}} \) that is non-planer and shares \( E \), if exists, take the vertex \( V_{\text{base}} \) that has different elevation value as the base point for regeneration of TIN.

Step 5: Find the triangle \( T \) that is planer, shares \( E \) and doest not belong to the set \( \text{InvalidTIN} \).

Step 6: It \( T \) exists, add it to the set \( \text{InvalidTIN} \).

Step 7: Repeat step 3 until \( \text{InvalidTINEdge} \) becomes empty.

2.3 Generation of new break-lines

This phase generates new break-lines to disable formation of most of flat TINs. According to the shapes of the boundaries formed by flat TINs, we prepare two approaches for generation new break-lines. The two approaches correspond to simple shape and complex shape respectively. When all the edges on the boundary are visible from the centroid of the shape, it is called a simple shape. Shapes that do not satisfy the above conditions are called complex shape. The procedures for generating new break-lines are as follows:

1. Boundary generation

   Sort the vertices of the flat TINs in their connection order to obtain the boundary of the flat TIN area. The vertex \( V_{\text{base}} \) belonging to the non-flat TIN obtained in 2.2 is included as the starting point of the boundary.

2. New break-line for simple shapes

   A new break-line for a simple shape is generated in the following procedures:

   Step 1: find the furthest point \( V_{\text{furthest}} \) from centroid \( C \).

   Step 2: calculate the horizontal distance \( D1 \) (from \( C \) to \( V_{\text{furthest}} \)) and \( D2 \) (from \( C \) to \( V_{\text{base}} \)) respectively.

   Step 3: let \( Z = Z_{\text{base}} + (Z - Z_{\text{f}}) \cdot D2 / (D1 + D2) \) be the height value of centroid \( C \).

   Step 4: Add the line segment \( L_{\text{base-centroid}} \) as new break-line.

Fig. 2 shows an example of simple shape and the derived new break-line.

3. New break-line for complex shapes

   A new break-line for a complex shape is generated in the following procedures:

   Step 1: Starting from \( V_{\text{base}} \), trace the connection tree of the flat TINs, which will have only two branches wherever exist.

   Step 2: Starting from \( V_{\text{base}} \), connect the middle point of shared edges to form a path tree, which will have only two branches wherever exist. The terminal point will be the common vertex shared by the two line segments belonging to the same contour line.

   Step 3: Calculate the height value of each branch node recursively. The height value of the first branch node is calculated by the same method as 2.2, with \( D2 \) being the distance from the node to the furthest terminal point in the tree. The rest will be calculated with the first node as starting point.

   Step 4: Calculate the height values of each intermediate vertex of a branch. The height value a vertex is determined by the proportion of its length to starting vertex against the total length.

   Step 5: Add each branch as new break-lines.

Fig. 3 shows an example of complex shape and the derived new break-lines.

2.4 Partial reconstruction of TIN

After generating new break-lines, we will generate the TIN once more with the new break-lines as added constrains. The new TIN set will not have any flat TIN area of complex shape, but there might still be flat triangles of simple shape. If there is any flat TIN area, we will then trace them by the same method stated in 2.2 to form flat TIN area. Then reconstruct the flat TIN area in the following procedures:

Step 1: Delete all the invalid triangles from the TIN result.

Step 2: Sort all vertices \( V \) of the invalid triangles by the connection order on the contour line.

Step 3: Form new triangles of \( V_{\text{base}} \) and \( V_{i}, V_{i+1} \) of \( \{V\} \) \( (i=1...N-1) \). where \( N \) is the number of elements in \( \{V\} \).

Fig. 4 shows an example of reconstructed TIN.
3. Experimental Results

In order to verify the effectiveness of our proposed methods, we have performed a lot of experiments with real world contour lines. For TIN generation we have used the one provided by Shewchuk[4]. To evaluate the result visually, we choose to generate contour lines of finer interval and compare the result with the original contour lines.

Fig. 5 shows partial contour result that is generated with TIN generated from real world contour lines that are also used as break-line constrains. Thicker lines are the original contour lines. The newly generated contour lines have smaller interval than the original ones. The result clearly shows that flat regions are formed at the locations where original contour lines turn sharply and the neighboring contour lines are not close enough.

Fig. 6 shows another processing result for the same original data. In this case, the methods stated in section 2 are applied. The unnatural contour lines in Fig. 5 become more natural ones that match their original neighboring contour lines.
4. Discussions and Future Works

4.1 Effectiveness of the break-line for simple shapes

In our methods, we only add a break-line from the centroid of a flat triangle area. This method aims at keeping the smoothness of the TIN at all points of the area. Fig. 7 (particularly at the middle lower part) shows an example of contour lines generated without new break-lines for simple shapes. The result at the far end from the non-flat TIN is smooth, but not so around the non-flat area. (The overlapped contours are caused by invisible shapes, which are not catered for in this result.)

Fig. 7 Contour line generated without new break-lines for simple shapes

4.2 Exceptions and solutions

The proposed method will not be valid when the contour line is broken, as shown in Fig.9 (a). In this case, the flat-TIN area cannot be traced properly and will consequently remain as it is. This problem can be solved by adding a line (shown in thick dashed line) as shown in Fig.9 (b), and then regrouping the contour lines connected to both end as the same contour line.

(a) An example of broken contour line

(b) solution

Fig. 9 The exceptional case and its solution

The contour lines connecting the broken ones can mostly be added automatically by considering the height value, uniqueness of the neighboring broken lines or the degree of connectivity. Here, the degree of connectivity of two adjacent broken contour lines can be determined by their relative angle, direction. One example of automatic connection can be found in Fig.6, where the broken contour lines are automatically connected, as a result, the flat triangles are correctly processed.

Even if the broken contour lines are connected improperly, the generated TIN will be the same as when they are not added, which means the same flat area will remain. If they needed to be corrected, such kind of area can be automatically identified from the location of broken contour lines and the flat TINs.

4.3 Future works

In general, the methods proposed can successfully solve the problem of flat triangles that will occur when using contour lines as constraints.

There are other ways of positioning the new break-lines, which are not discussed in detail here. For example, similar to the suggestion by Peng [2] for determining the position of newly added random points, the new break-lines can be drawn by connecting the centroid of flat triangles. There are also other ways for determining the break-lines for simple shapes, which still cause unnatural interpolation result in some cases. More experiments will be performed to compare the effectiveness of these options.

We will further apply the results obtained with the above-mentioned methods to analysis of topography. In this case, we will face the problem of continuous interpolation of contour lines. The contour lines shown in this paper are interpolated in linear method. As a result, the density (relative distance between new contour lines) is not continuous between different original contours. The ideal distance between interpolated contour lines should be in proportion to the gradient of adjacent height values.

References: