

Triangulated Irregular Network Model from Mass Points

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Abstract

Digital Terrain Modeling, the Triangulated Irregular Network (TIN) is a representation of a surface derived from irregularly spaced sample points and break line features. Paper deals with the basic concept of Delauney's triangulation method with its practical approach in ArcGIS. The next section describes the process to convert mass points to TIN model and explores some of the basics of TIN Model with their data structure. The last section gives clear idea about its advantages and disadvantages over grid based model.

Keywords

Geographic Information Systems, TIN, Delauney's Triangulation, TIN from mass points

1. Introduction

In Digital Terrain Modeling, the Triangulated Irregular Network (TIN) is a representation of a surface derived from irregularly spaced sample points and break line features.

TINs are made from a set of mass points, the vertices of contours or a combination of both. These mass points can be derived from their height values; A TIN is made by building tessellation of triangular polygons from the mass points, configured such that if a circle was passed through the three nodes of each triangle, no other node is included. This is called Delauney's triangulation [1][10].

TIN Model has a vector data structure. It partitions geographic space into contiguous, non overlapping triangles. In TIN Model vertices of each triangle are sample data points of (x,y,z) or (longitude, latitude, altitude) values. Mass points are carefully selected points to accurately model the surface.

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They can occur at any location but accuracy of TIN Model depends on the careful selection of mass points. If there is any major change in the shape of the surface like the peak of mountain, the floor of valley, top or bottom edge of cliff etc. then we must have to select those mass points for the TIN and those mass points are known as well-placed mass points.

Due to its simplicity and economy TIN Model is a significant alternative to regular raster or grid. The advantages of TIN Model are [11]

(i) It is suitable for regular and irregular distributed data points both, but grid model is only suitable for regular distributed data points

Mostly, the data points acquired from the field work are not distributed regularly. TIN model is a more flexible model than the grid model.

(ii) The earth's surface is rarely completely flat; the density of data is changing with the complexity of different terrain. In grid model regular square meshes are used to represent the earth's surface, while in TIN model, the irregular triangle meshes are used. TIN model can reduce the redundant data of Grid model and especially excel at the regions where the terrain is complicated and changes sharply.

(iii) TIN model have higher precision than any other models while representing the terrain. It gives better precision and efficiency of calculating the elevation than contours model.

This paper will discuss the possible practical solutions for creating TIN from mass points, including the TIN generation algorithms from mass points and the corresponding data structure.

2. Literature Review

X. Hanjianga et al. [11] proposed the technology of creating the Delaunay Triangulation with its data structure, integration, Storage, and update.

Lawson et al. [5] proposed that any triangulation T(s) can be transformed into Delauney's Triangles. It can be obtained by applying the empty circle test on all

Table 1: The Topology of a TIN

Triangle	Nodes	Neighbour
T1	p1,p2,p6	-,T2
T2	p2,p3,p6	T1,T3,-
T3	p3,p5,p6	-,T2,T4
T4	p3,p4,p5	-,T3

pairs of triangles. If the empty circle property is violated, then common edges of the two triangles are swapped. Delauney's Triangulation can be obtained by applying recursively process on all inner edges of the triangulation This procedure is known as a Lawson's local optimization (LOP).

Peucker et al.[10] proposed that the purpose of the digital terrain system is the digital representation of terrain so that "real world" problems may be approached accurately and efficiently. These features and the boundaries between them are seen to have higher "information content" than randomly located points on the surface.

Other researchers Like E. R. Vivoni et al. [3], G. E. Tucker et al. [4],L. Wang et al. [7],Peter Su et al. [8], R.Pajrola et al. [9] realized that by joining the surface as a sheet of triangular facets is simple means of meeting these specifications for 3D model. The implementation of this approach can be done by Triangulated Irregular Network or TIN.

3. Methodology

I. Components of TIN

Nodes, edges and triangle are Major components of a TIN, along with these components, it also have some other components like hulls, breaklines, faults etc. Here in this paper we are considering only the major components[6].

II. Topology and Data Structure of TIN

A TIN is a topological data structure that manages information about the nodes comprising each triangle and the neighbor of each triangle. Fig. 1 and table I shows the topology of a simple TIN. A TIN may be conveniently stored in a file or database table as with other topological data structures[6]. Data structure of TIN includes the triangle number, the numbers of each adjacent triangle, the three nodes defining the triangle, the x, y coordinates of each node, the surface z value of each node.

Efficiency of triangulation algorithm depends on the triangular mesh generator. The data structures of vertices, edges, and triangles are illustrated in the following section[11].

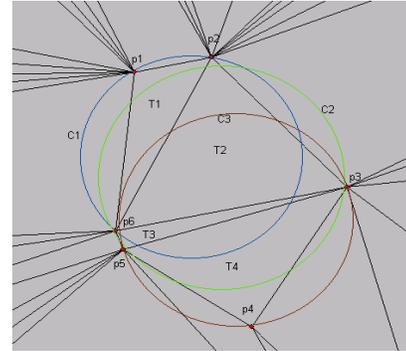


Figure 1: The topology of a TIN with Delauney's Triangulation

Structure of vertex:

```
struct Vertex
{
    double lat;
    double lon;
    double alt;
};
```

Structure of Edge:

```
struct Edge
{
    int edgeID;
    double stPoint;
    double endPoint;
};
```

Structure of Triangle:

```
struct Triangle
{
    int nTriangleID;
    struct Vertex *mPtriangle;
};
```

Storing the Vertices:

```
CTypedPtrList <Vertex> NewAddVertex;
//store the edges
CTypedPtrList <Edge> NewEdge;
//store the triangles
CTypedPtrList <Triangle> NewAddTriangle;
```

III. Delauney's Triangle Methods for Generating TIN's

There are two principle phases of the generation of TIN's:

- i. The selection of the data points (mass points) and their connection into triangular facets.

Manual selection of the points and links which creates the triangular network is one of the most obvious and accessible methods of creating a TIN.

- ii. Automated triangulation with manual point selection is an another technique which has been used.

A larger number of nodes are required to be stored in order to resolve uncertainties. This process is interpreted by the human operator. So there may be possibility of errors by the operator. Efficient algorithm for the triangulation makes it possible to get better results for automated triangulation.

The requirement for Delauney's triangulation is that a circle generated by the three nodes for the triangle will not contain any other node in the TIN network.

Let S be a set of non-collinear points in the plane. Triangulation $T(s)$ is the maximal division of a plane into a set of triangles with the restriction that each triangle edge, except those defining the convex hull of S , is shared by two adjacent triangles

Let S be a set of non-collinear points in the plane. Triangulation $T(s)$ is the maximal division of a plane into a set of triangles with the restriction that each triangle edge, except those defining the convex hull of S , is shared by two adjacent triangles [11].

Delauney's triangulation(s) is a unique triangulation constructed on S such that a circum circle of any triangle does not contain any other point from S . This condition, frequently also considered as an empty circle property, optimizes triangulation according to the minimal inner angle of the triangles. Triangles from Delauney's Triangulation(s) are considered as Delaunay Triangles (or legal triangles) and their circum circles as Delaunay circles. [11]

As shown in figure 1 In Triangle T1, nodes p1, p2, p6 are encircled by circle c1(blue circle) and no other nodes are inside that circle. Similarly, In Triangle T2, nodes p2, p3, p6 are encircled by circle c2(green circle) and no other nodes are inside that circle and In Triangle T3, nodes p3, p4, p5 are encircled by circle c3(brown circle) and no other nodes are inside that circle. Thus the condition for Delauney's triangle is satisfied.

4. Algorithm for TIN

Input : For each point v_i , we keep an ordered adjacency list of points $v_{i1} \dots, v_{ik}$, where $(v_i, v_{ij}), j = 1, \dots, k$, is a Delaunay edge. The list is doubly linked and circular. $PRED(v_i, v_{ij})$ denotes the point v_{iv} which appears clockwise (CW) of and immediately after the point v_{ij} . The counter-clockwise function $SUCC$ operates in a similar manner[2].

If the point v_i is on the convex hull $CONVEX_HULL(V)$, then the first entry on its adjacency list is the point denoted $FIRST(v_i)$, which appears after v_i if we traverse the boundary of $CONVEX_HULL(V)$ in a Counter clockwise (CCW) direction. Let $l(v_i, v_j)$ denote the line segment directed from v_i to v_j [2].

Function Delaunay_Triangulation()

- i. Sort the given set V of N points in lexicographically ascending order and rename the indices so that $v_1 < v_2 < \dots < v_n$, such that $(x_i, y_i) = v_i < v_j$ if and only if either $x_i < x_j$ or $x_i = x_j$ and $y_i < y_j$.
- ii. Divide V into two subsets V_L and V_R , such that $V_L = \{v_1, \dots, v_{N/2}\}$ and $V_R = \{v_{N/2+1}, v_n\}$.
- iii. Call $Delaunay_Triangulation(V_L)$ //recursive call
- iv. Call $Delaunay_Triangulation(V_R)$ //recursive call
- v. Merge $Delaunay_Triangulation(V_L)$ and $Delaunay_Triangulation(V_R)$
 - a. Calculate $VLU V_R$
 - b. Call $CONVEX_HULL(V_L \cup V_R)$

Forming the union of $CONVEX_HULL(V_L)$ and $CONVEX_HULL(V_R)$ will result in two new hull edges which are the lower and upper common tangents of $CONVEX_HULL(V_L)$ and $CONVEX_HULL(V_R)$. These two common tangents are known to be in the final Delaunay triangulation[2].

The following subroutine finds the lower common tangent of $CONVEX_HULL(V_L)$ and $CONVEX_HULL(V_R)$. For each convex hull $CONVEX_HULL(S)$, we maintain two points $LM(S)$ and $RM(S)$, which are the leftmost and rightmost points of S , respectively[2].

Subroutine HULL()

Input: two Convex Hulls
PROCEDURE $CONVEX_HULL(V_L, V_R)$

```

X ← RM(VL); Y ← LM(VR)
Z ← FIRST(Y); Z' ← FIRST(X);
Z'' ← PRED(X, Z')
A: IF (Z is-right-of I(X, Y))
Z ← SUCC(Z, Y); Y ← Z
    ELSE IF (Z'' is-right-of I(X, Y))
    Z'' ← PRED(Z'', X); X ← Z''
    ELSE
RETURN (X, Y)
    ENDIF
ENDIF
GO TO A
END CONVEX_HULL
    
```

5. Experiments and Results

i. Data Collection

Adaptive sampling method is used to collect elevation data for particular site. GML data format is used for this purpose to make the data interoperable. Longitude, latitude and elevation data are taken for this map from google earth.

ii. Import Data

Import the GML data in ArcGIS for creating TIN and plot the mass points on the map as given in the following figure 2.

iii. Height Values

Assign height values to the corresponding mass points in the table.



Figure 2: Data Collection (mass points)

iv. Creating TIN

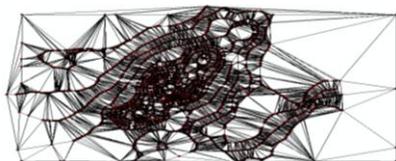


Figure 3: TIN Edges with mass points

Create TIN from the mass points (long, lat, altitude) using Delauney's Triangulation method. The

resulting TIN edges of the mass points are shown in fig. 3

If we want to see the mass points with TIN edges then also display those mass points with them as shown in fig. 4. Here black lines are TIN edges and red dots are mass points

v. Color Symbology

If we assign same to color to each face(default) then the output looks like in the fig. 5.



Figure 4: TIN face same symbol

vi. Symbology according to Elevation

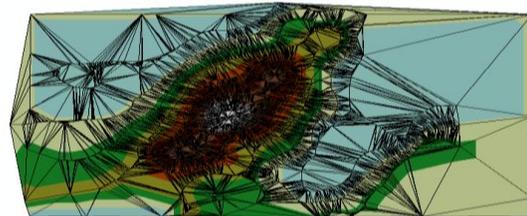


Figure 5: TIN face elevation with graduated color ramp

Now same symbol will not give a 3D Look on the paper so it will be better to change the symbology of TIN in such a way that color varies according to their elevation as shown in fig. 6 where low elevation faces are colored with light blue (water depth) and high elevation faces are with white color (showing mountains) in between them pale yellow, then green showing the greenery then mountain shades of brown color.

6. Conclusion and Future Work

In this study, we presented the basic concept of TIN Model with its . We focused on the generation of triangulated terrain models using the concept of Delauney's triangulation method. The advantages of TIN Model are that we can virtualize the terrain in 3D space. It is space efficient in comparison of other

grid based model DEM. A Delauney's TIN model expects units to be in feet or meters, not decimal degrees. Delaunay's triangulations are not valid when constructed using angular coordinates from geographic coordinate systems.

TIN models area unit less wide out there than formation surface models. TIN model is additionally costlier to make and method then formation model. the value of getting smart supply knowledge will be high, and process TINs tends to be less economical than process formation knowledge owing to the advanced arrangement.

TIN models are less widely available than raster surface models. TIN models are also costlier to create and process then raster models. The cost of obtaining good source data can be high than raster one and because of the complex data structure processing of TINs becomes less efficient than processing raster data.

TINs are typically used for high-precision modeling of smaller areas, such as in engineering, hydrology applications, where they are useful because they allow calculations of planimetric area, surface area, and volume.

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