Research on the fine DEM of the open-pit establishment method considering the steps character

Sui Xin, Song Wei-dong, Xu Ai-gong, Li Lan-yong*

Liaoning Technical University, No.47 Zhonghua Road, Fuxin 123000, China

Abstract

At present, triangulated irregular net is the best method for landform expression, so we discusses the method of applying triangulated irregular net to establish the DEM of open-pit in this paper. Because of the complicated landform characteristic of open-pit, corresponding constraint condition should be considered in the process of building model, otherwise it will appear a phenomenon that the flight of the step is cut. The method of triangulated irregular net establishment includes three kinds of algorithm, that is, divide and conquer algorithm, piecemeal intervene in algorithm and triangle net growth algorithm. Each algorithm has its own advantage and disadvantage. Combined with the actual situation of the mining area, this paper adopts the constrained triangulated irregular net of one-time algorithm, through spatial data extraction, topological relations generation and spatial indexing generation, then finally builds up constrained triangulated irregular net within boundary line.

Keywords: open-pit; constrained triangulated irregular net; spatial index

1. Introduction

In the process of the digital landform modeling, triangulated irregular net approaches the surface of landform through consecutive triangular surface generated by irregular distributing data point. In terms of expressing the information of landform, the advantage of TIN (triangulated irregular net) is that it can use different levels of resolution to describe landform expression. Compared with the model of grid data, TIN can use less space and time to express more complicated surface accurately at a particular resolution, so we can deem that TIN is the best method of landform expression at present, so this paper aims to apply TIN to establish the DEM of open-pit. Because of the complicated landform characteristic of open-pit, complicated landform should be considered in establishing DEM of open-pit, which means most of the form in the earth's surface is showed as ladders, otherwise it will be in error, DEM will be different from the practical landform, and appear a phenomenon that the flight of the step is cut, so corresponding constraint condition should be considered in the process of model building.

At present, the method of constraint triangulated irregular net establishment approximately includes three kinds of algorithm, that is, divide and conquer algorithm, piecemeal intervene in algorithm and triangle net growth

* Corresponding author. Tel.: +86-418-3351992; fax: +86-418-3350145.
E-mail address: survey_suixin@163.com.
algorithm [1, 2]. Each algorithm has its own advantage and disadvantages. As to the divide and conquer algorithm, because of adopting recursion and divide algorithm, it makes the complexity close to $O(n)$, but the disadvantage is that it needs lots of memory to save midway data in recursion process and that it still adopts connectible algorithm to put both sides of the boundaries into together from bottom to top while fitting pieces together, which needs a large number of complicated judgments, it increases the probability of floating-point error inaccurate [3]; As to the piecemeal intervene in algorithm, it is legible, simple and easy to program, but while building constrained model it will divide unconstrained TIN up, which makes the algorithm unstable, highly complicated and slow [4]; As to the triangle net growth algorithm, it adopts the method of gradual expansion in model building, which makes the stability of algorithm be good, but all the spatial data should be search every time during expanding, so the speed of modeling building is not high, but the speed of spatial data searching could be improved through the method of spatial indexing generation. Combined with the actual situation of the mining area and the aforementioned analysis, this paper adopts constrained triangulated irregular net of one-time algorithm.

2. Delaunay triangulation data structure

In order to improve the efficiency of field work collection, while in the fieldwork of the open-pit, usually collecting data along the bench crest and the bench toe rim, and collecting some feature points of the terrain on the flat plate aptly. We can obtain the boundary line, the bench crest, the bench toe rim and the flat plate point after preconditioning the above data. The boundary line, the bench crest and the bench toe rim are all the triangle edges in the progress of establishing CDT (constrained triangulated irregular net), so we should show them with edge data structure in unity (using the attribute of “property” to divide the class of line), the bench crest and the bench toe rim are called internal constrained lines and the boundary line is called boundary constrained line according to the different effect in the progress of network creation. The points on the boundary line, the bench crest and the bench toe rim and the flat plate point all use the discrete point data structure to express (using the attribute of “property” to divide the class of point). Edge and the discrete point data structure use C# to express as follows:

```csharp
//Discrete point data structure
public class ElvPoint
{
    public int note;   // The ID of point
    public double x;  // X coordinate
    public double y;  // Y coordinate
    public double z;  // Z coordinate
    public int gridnote;  // The grid number of this point
    public byte property;  // The attribute of the point : 1 indicates the point on the bench toe rim, 2 indicates the point on the bench crest, 3 indicates the point on the boundary line
    public bool isCollectPoint;  // Whether be a collected point or not
}
// Edge data structure
public class Edge
{
    public int note;  // The ID of edge
    public int startpnt;  // Save in anti-clockwise direction, the ID of the originate point of the edge
    public int endpnt;  // Save in anti-clockwise direction, the ID of the final point of the edge
    public byte property;  // The attribute of the edge : 1 indicates the boundary constrained line, 2 indicates the internal constrained line, 3 indicates the new generated triangle edge
    public LinkedList<int> circumGrids;  // The external grid linked list of edge
}
Triangle network data structure use C# to express as follows:
public class Triangle
{
    public int[] pntIndex;  // Save the index ID of the three triangle vertices one by one (anti-clockwise direction)
}
```
The establishment method of fine DEM in this paper is based on the triangle net growth algorithm, considering the disadvantage of inefficiency of the triangle net growth algorithm, we should build spatial index of point and edge. The specific method is in Part Three of this paper. The class of the spatial index use C# to express as follows:

```csharp
public class Index
{
    public LinkedList<int>[] pointGridList; // The spatial index linked list of point ID
    public LinkedList<int>[] edgeGridList; // The spatial index linked lists of edges ID
}
```

3. The constrained triangulated irregular net of onet-ime algorithm

3.1. The design concept of algorithm

At present, the main method of establishing CDT is the two-step process which firstly generates unconstrained TIN, and then embeds constrained lines to adjust TIN. Because the process of embedding constrained lines demands to judge the affected region of constrained lines, then to divide the corresponding affected region up and to establish net again, which make the efficiency of the algorithm low [5]. In this algorithm, firstly takes the constrained lines directly as triangle edge on growth: boundary constrained line to generate inwardly and internal constrained line to generate outwardly. And make the new generation of triangle edges continue to generate inwardly or outwardly, until the inward generation of triangle and the outward generation of triangle are both intersected , and now the CDT has been established within boundary line.

3.2. Concrete steps

Step 1: Extracting constrained lines and discrete point data. Constrained lines contain internal constrained lines and boundary constrained lines, and internal constrained lines can be divided into the bench crest and the bench toe rim; Discrete point refers to the flat plate point, not including the discrete points on the constrained lines. In the process of extraction, the boundary constrained lines are the extraction conditions, the points and lines in its inner will be extracted.

Step 2: Establishing the topological relation between points and lines. First, according to the coordinate equal principle, establish the topological relation between line and point in line, and save every line section in linked list of edge, at the same time, save the point in line in the linked list of discrete point without reapeating. In order to avoid long and narrow triangle in the process of model building, we should carry on a corresponding process: If the length of the constrained line is bigger than certain threshold value, it should insert equidistance points, and divide the line section up, at the same time, save the new inserted points and new generated line sections, after dealing with the constrained line, save the discrete point that extracted in the step 1 in the discrete point linked list.

Step 3: Creating grid index of the discrete points and the edges. According to the minimum and the maximum values of X and Y of all the discrete points, we can obtain the minimum circum-rectangle of discrete points; According to the minimum circum-rectangle and the given step length, the area of the discrete points can be divided into grids, and the grids will be numbered; And extract every discrete point successively, then based on the discrete point’s coordinate to calculate the grid where the point locates, and store the ID of the point in the linked list that the grid contains, until all the discrete points are extracted; And extract every edge successively, then according to the grids where the originate point and the final point of the edge locate, determine the minimum circumscribed grid group of the edge, and store the ID of this edge in the linked list of edge ID that every grid in the grid group contains, until all the edges are extracted.

Step 4: Establishing CDT. Extract every edge in the linked list of edge successively, and determine the minimum circumscribed grid group of this line section according to the two endpoints of the line; Extract all discrete points and edges in the grid group according to the index, and take the discrete points which are extracted as the candidate point set, and take all edges that are extracted as edge set to be judged; Then judge whether the line is the constrained line: if the line is the boundary constrained line, extract the left points of this line segment from the candidate point set; If the line is the internal constrained line, extract both the left and the right points of this line segment; If the line is the non-constrained line (the new generated triangle edge), extract the right points of this line.
section, and then based on visual conditions (the connection between two points doesn’t intersect with any other line sections) and the angle maximum principle to select the third point of the triangle; According to the baseline and the selected third point, establish triangle, and then store the information of triangle in the linked list of the triangle; Judge that whether the two new generated triangle edges exist in the edge set to be judged, if they exist, don’t store and delete the existed edges (at this time, have created triangles on both sides of the edge, and the edge is not likely to continue to generate, so delete), if they don’t exist, store the information of the edge in the linked list of edge, and delete the baseline; Repeat the above process until the nodes in the linked list of the edge become zero.

In the Fig. 1 describe the process of generating CDT by the constrained triangulated irregular net of one-time algorithm.

Fig. 1. (a) Prepare the basic data of modelling; (b) Modeling by taking constrained lines as triangle’s edges; (c) Add other discrete points to the model to finish modeling; (d) Three-dimensional display of the DEM model

3.3. Time-consuming analysis

The biggest weakness of triangle net growth algorithm is its low-efficiency, in the worst case time complexity can achieve $O(n^2)$, with the increase of the number of discrete points, the time-consuming of the algorithm increases exponentially. In this paper, the proposed algorithm is based on the triangle net growth algorithm, but considering this disadvantage, by establishing the spatial index for the discrete points and the triangle edges, make the hunting zone of the optimization points controlled in a small grid interval, although time-consuming of the search in the grid interval increases with the number of points increasing exponentially, when there is a great amount of data, then the average time complexity of the algorithm is close to $O(n)$. For the purpose of verifying the above opinions, there’s a corresponding experiment: take eight groups with different number of discrete points respectively, and link the discrete points on the edge forming the boundary constrained lines, and link the part of the discrete points in the inner of the boundary constrained lines forming internal constrained lines, and then establish nets respectively, and record the corresponding operation time.
See the relationship between the number of discrete points and the time-consuming of establishing net on the Fig. 2.

From Fig. 2 we can know that time-consuming curve is close to linear, and it is accordance with above analysis that the time complexity of the proposed algorithm in this paper is close to $O(n)$.

4. Conclusion

In this paper, the one-time constrained triangulated irregular net algorithm can only generate CDT once, which avoids the unstable stability in the progress of dissection in the two-step process, and the establishment of a spatial index of discrete point and triangle edges makes the time complexity of the algorithm be close to $O(n)$. Moreover, due to the use of the boundary constrained line, all the new generated TIN are within the scope of the boundary constrained line, which makes the judgement of the spatial relationship between the triangle and the boundary constrained line unnecessary and facilitates the combination of the new-generated TIN and other TIN at the same time. The fine DEM of open-pit generated through this algorithm can be applied in exploitation volume calculation in check-and-acceptance measurement, browsing the three-dimensional graph of the mining area and establishing the spatio-temporal database of the mining area, which is an important data source of digital mine.

Acknowledgements

Our research project is supported by Ph. D. Program Research Foundation from MOE of China (20060147004), Projects of Liaoning Province University Innovation Team (2008T085, 2007T072), Project of Liaoning Province University Key Laboratory (2009S049) and Higher Education Research Program of Liaoning (2008276, 2007T077).

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