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Research Article

Morphological recognition optimization of 3D building simplification by Delaunay algorithm

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Abstract: Focusing on the deficiencies in the application of standard Delaunay algorithm during three dimensional building simplification, based on morphological recognition, 3D building simplification model was proposed by searching optimization algorithm in this paper. First the Delaunay triangulation of constrained domain was converted to unconstrained domain, Delaunay net of discrete points was built by morphological recognition direction search method. Adopt the method of first pre-processing and then searching, insert two vertexes of the constrained edge into Delaunay triangulation using the mode of "point by point", then search the influence domain of the constrained edge. Finally, from the results of the simulation experiment, through the optimization of morphological recognition by standard Delaunay algorithm, improved algorithm had more excellent simplification effect compared to standard algorithm.

Keywords: three dimensional building simplification, Delaunay algorithm, shape recognition, triangulation, constrained edge optimization

INTRODUCTION

Along with the rapid development of national economic and constant adjustment of the economic structure, urbanization has become an unstoppable trend. In order to deal with the safety emergency issues effectively, prevent illegal construction emerging in the process of urbanization, avoid the disadvantages existing in the construction, and improve effectiveness of the expanding city management, the application of digital city technology becomes essential. The basis of this technology is computer graphics, multimedia, large-scale cluster computing and storage technology, and it takes network as the bond, apply a combination of techniques such as remote sensing, geographical information system, global positioning, and virtual simulation, thus achieving multi spatial, multi-scale, multiresolution three-dimension description of the city.

As for the researches concerning three dimensional construction, Chinese researchers mostly focus on the data acquisition and modeling of the buildings. Tan Renchun et al.[1] mainly studied the data acquisition of three dimensional buildings, they analyzed from three aspects: plane data, altitude data and texture data of the buildings, in addition , they also carried out research on geometric model of three dimensional building. Based on the building structure, Shao Zhen feng et al. [2] discussed a strategy about semi-automatic extraction of simple buildings, they targeted complex buildings and proposed a modeling model 3D in relation to topological structure, the validity and high efficiency has been proved by examples. Cui Qingsheng and Fei Jihong[3] built an object-oriented 3D data model, and related experiment was conducted on basis of the model. Zhou et al. [4]presented and implemented three-dimensional building design component based on OpenGL, in the meantime, they completed the building modeling and motion simulation of virtual environment. As for overseas studies, correlation experiments were conducted by Poggio[5] based on 3D building recognition system of artificial neural networks, this system is not only applicable to simple buildings but also to complex buildings. Besides, Laurent D.Cohen and Samuel Vinson [6] put forward a method to extract buildings from air photo, they realized fast reconstruction of 3D buildings by aerial images, and the time required is reduced. Depending on user assistance, S.C. Lee et al. [7] presented a method of complex 3D building modeling, related experiments were performed as well, and this method showed higher superiority than the others. The premise of 3D building integration is data acquisition of 3D buildings and modeling technology, high-quality data and excellent 3D building models can accelerate comprehensive experiment and application implementing, thus, better results could be achieved. So, it is essential to carry out research in this area. Focusing on the issues in the application of 3D building model simplification algorithm, Wang et al. [8]discussed and analyzed the thought of 3D building surface model simplification.

Base on point pair contraction method, generation of multi-resolution building meshes and display algorithm were discussed by Sun et al [9], and the merit of this algorithm is that it can realize real time display of multi-resolution building meshes. Sheffer et [10] al. discussed 3D meshes synthesis method based on energy minimization technology, this method can be applied to three dimensional buildings and other three dimensional elements. A new synthesis method of 3D building vector data was proposed by Andrea Forberg[11], this method showed the advantages of both the scale-space data morphology and the curvature space, and it simplifies the synthesizing process.

Focusing on the issues in the application of standard Delaunay algorithm during three dimensional building simplification, in this paper, 3D building simplification model was built by searching optimization algorithm based on morphological recognition. The simulation experiment was also carried out, and validity of the model was verified.

3D modeling algorithm based on Delaunay

Delaunay triangulation is the geometric dual graph of Voronoi, the so-called Delaunay triangulation refers to the triangulation composed by connecting various points in adjacent region of Voronoi polygon.

Let finite point set in two-dimensional real number field be set P, represent the close line segment composed by the points in the point set as e, E represents for the set of e.

Triangulation $T=(P,E)$ is a planar graph G of point set P, and the following conditions should be met: First, no intersection edges; Secondly, except for the endpoints, no other points from the point set should be included in the edges of the planar graph; Thirdly, all the surfaces in the planar graph should be triangle, and the set of all these triangle surfaces composes the convex hull of the point set.

If a side e in the collection E is used as a side.（ a , b represent the end points）When a combination of the following conditions is obtained, e can be called Delaunay edge: there will be a circle passing the end points a and b simultaneously, and no points in set point V are included in the circle, and this can be summarized as empty circle characteristic, the detail is shown in fig-1.

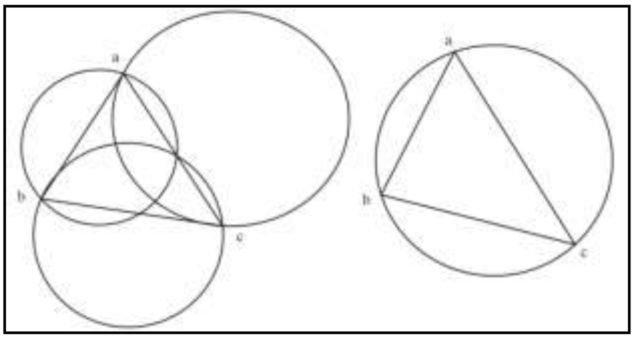

Fig-1: Delaunay edge

If all the edges in triangulation T of point set P are Delaunay edges, then we can call this triangulation Delaunay triangulation.

Triangulation of the point set composed by three points in different lines is the triangle surface formed by these end points connecting one by one. It's obvious that each edge of it is Delaunay edge.

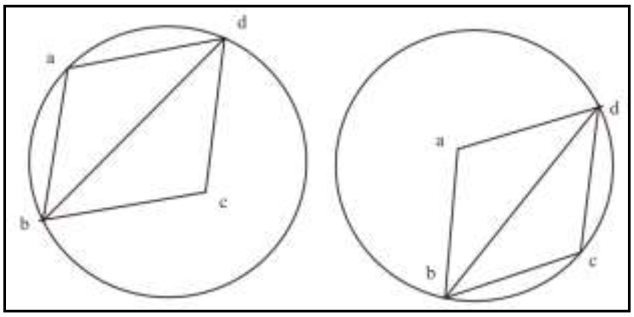

Fig-2: A triangulation composed by four points

Figure 2 shows a triangulation in a point set formed by four points. In this case, because the circle passing point b and d includes either point a or point c, edge bd is not Delaunay edge. Briefly speaking, if point c or point a is not located on or inside the circumscribed circle of triangle abd or bcd, bd is Delaunayedge. In fact, under the condition that the circumscribed circles of all the triangle surfaces do not include any point in the point set, the triangulation is exactly the Delaunay triangulation. Also, it is another definition of Delaunay triangulation.

Base on 3D modeling, we can come to the basic thoughts: first build a triangulation in relation to the point set of given points $S \in R^2$, then switch process the formed triangular meshes, stop processing until all the edges are Delaunay edges. In this way, 3D model based on Delaunay triangulation is formed.

Delaunay algorithm optimization based on morphological recognition

Delaunay algorithm based on morphological recognition

Let $V_1, V_2, V_3, V_4 = V_1$ be a triangle. Calculate four poles of triangle $V_1, V_2, V_3, V_4 = V_1$, the formula is shown as follows:

$$\begin{cases} a = \min(V_i, x) \\ b = \max(V_i, x) \\ c = \min(V_i, y) \\ d = \max(V_i, y) \end{cases} \quad (1)$$

As for the relation between point M and $\Delta V_1V_2V_3$, if it goes along anticlockwise(clockwise) direction, point M locates in the left(right)side of V_iV_{i+1} all the time. If $\Delta V_iV_{i+1}M$ is anticlockwise(clockwise), point M will locate inside $\Delta V_1V_2V_3$. There is a special situation, when we judge the direction of a certain $\Delta V_iV_{i+1}M$, if the triangle has two pairs of same poles and it's unable to judge the direction, put the coordinate value of point M into formula(2) (3). If the requirements of formula (2) (3) are met at the same time, M is on edge V_iV_{i+1} of $\Delta V_1V_2V_3$. Hereinafter, $\Delta V_iV_{i+1}M$ in this case is called that this kind of triangle is directionless.

$$\min(V_i, x, V_{i+1}, x) < M.x < \max(V_i, x, V_{i+1}, x) \quad (2)$$
$$\min(V_i, y, V_{i+1}, y) < M.y < \max(V_i, y, V_{i+1}, y) \quad (3)$$

The direction of $\Delta V_1V_2V_3$ is anticlockwise, and $V_iV_{i+1}M$ is also always anticlockwise, so we can come to a conclusion that M is inside $\Delta V_1V_2V_3$.

On this basis, location method based on direction search of triangle morphological recognition is discussed in this paper. Let $V_1, V_2, V_3, V_4 = V_1$ be a triangle, set M as an unpositioning point, under the condition that $\Delta V_1V_2V_3$ and $\Delta V_iV_{i+1}M$ are in the same direction, point M is an internal point of $\Delta V_1V_2V_3$. When a certain $\Delta V_iV_{i+1}M$ is unidirectional, point M is on V_iV_{i+1}. And when $\Delta V_iV_{i+1}M$ and $\Delta V_1V_2V_3$ have different directions, M is an external point of $\Delta V_1V_2V_3$, search direction is the triangle adjacent to edge V_iV_{i+1}, that is to say, the search direction is hidden from direction of $\Delta V_iV_{i+1}M$.

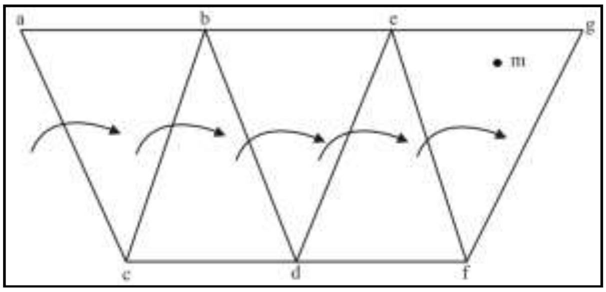

Fig-3: Schematic of the triangle in which fast positioning insertion points are located

In figure 3, m represents the point to be inserted, ΔT_i is a triangle in Delaunay triangulation network. The localization of the triangle where point m is located should cover the following process: judge the direction of the triangle, the direction of Δabc and Δabm is clockwise, the direction of Δbcm is anticlockwise, Δcam has a clockwise direction. Because the direction of Δbcm and Δabc is opposite, search ΔT_2 which is adjacent to edge bc along the direction of edge bc, then judge Δbdc, Δbed, Δefd, Δegf with the same method. Afterwords, we can position Δegf in which point m is located.

Three dimensional building simplification model on the base of improved Delaunay algorithm

Adopt the method of first pre-processing and then searching. Insert two vertexes of the constrained edge into Delaunay triangulation using the mode of "point by point", then search the influence domain of constrained edge. After improvement of the algorithm, all the constrained edges are in the condition of figure4, vertexes of all the constrained edges coincides with the discrete points of Delaunay triangulation network.

As a result, when searching the triangle where the vertexes of the constrained edges are located, we only need to compare the vertexes of the constrained edges and the triangle vertexes in the triangulation network, then we can search the triangle which includes this point. If multiple triangles are found during the search process, we can judge by the relation between the constrained edges and the triangles.

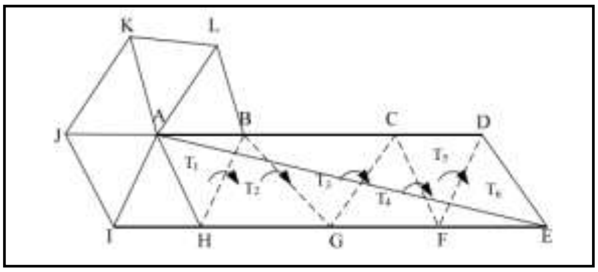

Fig-4: Searching method for influence domain

As shown in figure 4, when searching the influence domain of constrained edge AE, ΔT_1 and ΔT_6 should be searched first, and starting point A and ending point E of AE belong to ΔT_1 and ΔT_6, edge AE and edge BH of ΔABH are intersecting, then ΔT_2 adjacent to edge BH belongs to the influence domain, keep searching until ΔT_6 is obtained, union $Q = \bigcup_{i=1}^{5} \Delta T_i$ of all the triangles which meet the conditions is the influence domain of edge AE.

In the process of searching the triangle which A belongs, because six triangles which include point A exist simultaneously, we have to find out ΔT_1 satisfying the requirements. The six triangles form polygon $BHIJKL$, AE intersects with edge BH of polygon $BHIJKL$, thus ΔT_1 is found. As for point E , the same method is adopted. After the influence domain is searched, the influence domain of all the constrained edges can be reconstructed through diagonal exchanging method.

Based on the above discussion, three dimensional building simplification modeling based on improved Delaunay algorithm comprises the following steps:

The first step, change all the line segments into discrete points by the method of valuing each point.

The second step, triangulate the discrete points by virtue of triangle expanding method, then triangular surface array P is obtained.

The third step, traverse all the triangular surfaces of P , judge whether the edge of triangular surface intersects with the polygonal boundary. If intersection happens, adjust the two triangular surfaces sharing the edge, then swap diagonals of the quadrangle formed by two triangular surfaces, and replace the original triangular surface with the freshly generated two surfaces. When the entire traverse is completed, if there is no more line segment intersecting with the boundary, then we can come to the fourth step.

The fourth step, traverse the triangular surfaces, judge the relationship between the midpoint of any center line in each surface and the polygon contour. If the point lies outside of the polygon, triangular surface can be deleted from P .

The fifth step, calculate all the normal vectors of the triangular surfaces. Under the condition that the normal vectors on the same surface are opposite, interchange the first edge and the third edge of this triangle, and change the normal vector of triangle face to the normal vector of a plane.

The sixth step, calculate the normal vectors of all the vertexes, if the visualization requirements are met, the algorithm ends.

Algorithm performance simulation

In order to test the performance of the improved algorithm, standard Delaunay algorithm and improved algorithm is used respectively to simplify two three-dimensional buildings, comparison result of three-dimensional point cloud number is shown in the figure below:

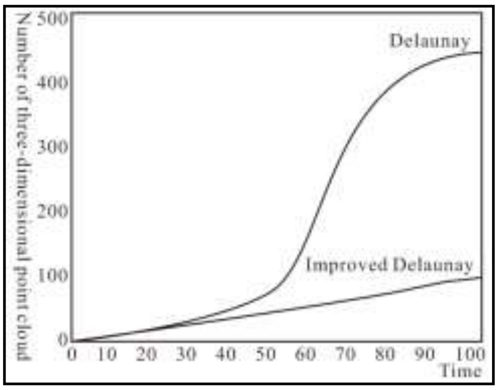

Fig-5: Three-dimensional point cloud number comparison result of building A

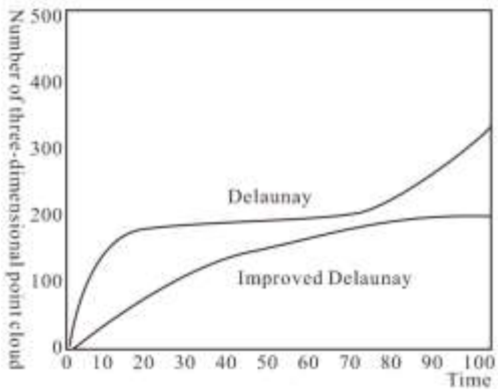

Fig-6: Three-dimensional point cloud number comparison result of building B

Simplify the three-dimensional buildings by the improved algorithm presented in this paper, we can get the simplification effect in the following figure.

Fig-7: 3D building simplification effect figure

From the results mentioned above, through the morphological recognition optimization of standard Delaunay algorithm, simplification effect is more pronounced.

CONCLUSIONS

Along with the rapid development of cartographic technique and the introduction of 3D visualization technique, 3D digital city is becoming an important research direction for cartography. As the most important component of 3D digital city, researches relevant to integrated area of 3D building are conducive to development of 3D digital city modeling and visualization. This paper focused on the issues in the application of standard Delaunay algorithm during three dimensional building simplification, 3D building simplification model was built by searching optimization algorithm based on morphological recognition. The simulation experiment was also carried out, and the results showed that improved algorithm had more excellent simplification effect compared to standard algorithm.

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