FACET SHIFT ALGORITHM BASED ON MINIMAL DISTANCE IN SIMPLIFICATION OF BUILDINGS WITH PARALLEL STRUCTURE

GE Lei, WU Fang, QIAN Haizhong, ZHAI Renjian
Institute of Surveying and Mapping
Information Engineering University
Zhengzhou 450052 China

About the author: GE Lei. Ph D candidate. His study interests are automatic generalization and 3D visualization. *Email:* chxy_gray@yahoo.com.cn

Abstract: Building with parallel structure is the most popular kind in modern city. As the widely used 3D City Model, more and more generalization methods of this kind of building have been developed. The paper begins with the structuring of 3D building data and then a data structure that benefits the generalization is provoked. Orthogonal of building, introduction of polygon and acquisition of feature information are used in building construction. According to the requirement of visualization, LOD of city buildings are divided into three levels, Based on which a simplification algorithm of shifting facet based on minimal distance is realized in simplification of the building with parallel structure. Experiment is done to prove the good efficiency and usability of the algorithm and the algorithm works well in simplification of buildings with parallel structure.

Keywords 3D building generalization, facet shift algorithm, simplification, LOD, minimal distance

1 Introduction

As the widely use of 3D city model, conflict between the requirement of vivid scene and limited software and hardware, manpower, material resource and other cost becomes more and more prominent. Using generalization of 3D city model to get different LoDs is an effective way to settle this problem.

Building is the most important part in 3D city. 3D city model is always consisted of all kinds of buildings such as residential buildings, church, tower etc. Among these building, parallel building is the most important type. So study on generalization of parallel building of great significance in establishment of model with different LoD[1].

Among all the methods in description of building, boundary representation model is an important one. Structure of vertex-edge-mesh is used in this model, which benefits the acquirement of topological information and BRep model is adopted in experiment of this paper. Based on discussion of 3D building data model, facet shift algorithm based on minimal distance is studied to simplify buildings with parallel structure.

2. Establishment of data model

2.1 Organization of 3D building data

3D studio is a widely used modeling tool and its exchange format file is data source in experiment.

Most data models of building are designed for storage and visualization, which have many disadvantages in generalization. Considering the change of topological relation in generalization, a new data structure based on triangle mesh is proposed, which benefits generalization of 3D building. In this structure, three arrays are separately used to store vertexes, normal of vertexes and texture coordinates, and the triangles are used as isolated units in executing some operators of simplification.

Compared with existed data structure of 3D building, the structure that benefits generalization has following characteristics:

(1) Triangle mesh is the primary graphic elements in operation. Point is lost as a level, so it's hard in interactive processing of points and lines and topological structure of different levels are not clear enough to realize the interoperation of different objects.
(2) As one vertex is stored in different triangles and the increase of corresponding normal, we need more space to store the building data. In visualization of building, one triangle mesh can be rendered just by fixing the index once and the visualization becomes faster.
(3) This structure has great advantages in generalization of 3D building model. In deleting of triangle meshes: change of vertex occurs just inside the triangle in this structure, so index of vertexes and corresponding normal keep still and it's easy to process operations such as shift facets and delete triangle meshes. In reconstruction of facets after simplification: in simplification of building with parallel structure, when a vertex is shifted, all its correlative facets are shifted at the same time, but it's hard to reconstruction the facet after shift and its neighboring facets are also effected. Use of this structure may avoid these problems in simplification.

2.2 Structuralization of building model

The data structure that benefits generalization provides base for simplification of building with parallel structure. But only the original geometry and texture information are not enough, so we have to structure the building to get more information for simplification. Structuralization of building includes orthogonalization, introduction of Polygon and acquiring of building feature information.

1. Orthogonalization of building with parallel structure

Orthogonalization of parallel structure is base of the algorithm, because little error may cause incline of the building. This affects little in visualization of building but can't fulfill the demand of simplification, so orthogonalization is needed. Orthogonalization of building aims at the facet. Judge normal of facet by three directions accordingly (x, y, z axis), if the normal is parallel with certain axis roughly (angle is little than threshold), adjust vertexes of the facet to make the building absolutely orthogonal.

2. Introduction of Polygon

In 3D building with parallel structure, Polygon is a plane contour that is composed of one or more polygons (holes inside outer polygon), each Polygon contains all the neighboring triangles on a same plane.

Polygon is an indispensable in structuralization of building model for the following two reasons:

(1) It is propitious to carry out the facet shift algorithm in simplification of building with parallel structure. Compared to direct shift of triangles, facet shift based on Polygon has its advantages. At least two disadvantages exist if we shift the triangles directly: shift of triangles of one facet may affect the triangles of its neighboring facet, and then the errors occur because coordinate change of the neighbor's triangles. When two opposite facets need to combined after shift, it's hard to represent the new facet without the use of Polygon. All the vertexes of a plane are shifted at the same time under the structure of Polygon, which makes it easy to realize the simplification.

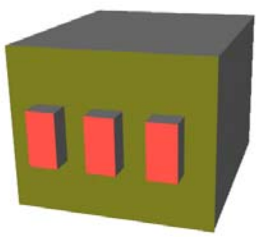


Figure 1. Polygon with several facets in it

(2) Polygon is the base to re-triangulation of the building after simplification. Generalization of building aims to reduce number of triangles and redundant triangles arise after simplification of building by facet shift algorithm, so we have to re-triangulation of new Polygons. Original building model always contains more triangles than the least needed number, so re-triangulation is also useful.

A traditional building is always consisted of many facets. For building with parallel structure, these facets are horizontal or orthogonal, so it’s easy to judge which facets are coplanar. If a polygon contains several facets, there are two cases (Fig 1): one is smaller facets included in big facet, holes in Polygon viz. (front building except balcony). The other is all the facets are isolated (several windows are on the sample plane). Based on the Polygon containing several isolated facet, these features are simplified just by shift once and the shape of building keeps well, except for the facets belongs to different features (as shown in Fig 2). In this case, we should treat these facets as Polygon separately to avoid errors.

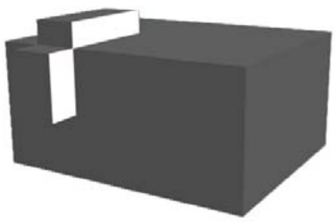


Figure 2. Two coplanar facets not belong to a same feature

3. Acquirement of feature information of building

Feature information of building is consisted of three main parts: circumscribed cuboid of building, area of each polygon, surface area and volume of building.

For a single building, circumscribed cuboid is useful in determination of its position in the scene and getting the center of building. When in generalization of building group, circumscribed cuboid helps to judge if two buildings are adjacent and provide important information in combination of building. Circumscribed cuboid is set by the minimal and max value in three directions.

Area of Polygon may be calculated directly and this method is of great usability. But when contour of Polygon has holes in it, we have to adjust order of its border, which waste lots of time. So areas of triangles inside a Polygon are added to get its area. After areas of all Polygons are calculated, they are summed up to get surface area.

Volume is the most important feature for a building, which determines the significance of the building in a certain degree and an important value to estimate the result of simplification. Volume of building with parallel structure is calculated by the following steps:

(1) Calculate areas of all the horizontal Polygons and note their normal, then the building is divided to N-1parts (number of Polygon is N).

(2) Calculation of basal area of each part. Order the Polygons by their height from lower to higher, and then get area of each Polygon marked as A_i. Basal area of each part is calculated accordingly by the following formula:

$$A_i = A_{i-1} \pm A_i \qquad (0 < i < n, A_0 = 0) \qquad (1)$$

Sign of the formula is determined by normal of Polygon, when the normal point downwards, the sign is +, otherwise it's -.

(3) Calculate altitude difference of neighboring Polygon marked as $H_i \ (0 < i < n)$.

(4) Volumes of all parts are sum up to get volume of the entire building, formula is as following:

$$Vol = \sum_{i=1}^{n-1} A_i H_i \qquad (2)$$

3. Design and realization of the algorithm

3.1 Data structure of the algorithm

By contrast of the two data structures above, the data structure that benefits generalization is used as base of the algorithm. Structure of Polygon and Object are the most important in organization of the data structure. Self-defined array vec3BorderArray store the border of Polygon by line segments, each segment is expressed by two neighboring points. Use of line segments makes it easy to construct the border and adjust it in simplification. Two parts are included in the structure of Object: one is array of triangles used in visualization and the other is array of Polygon used in simplification of building.

3.2 Determination of LoDs

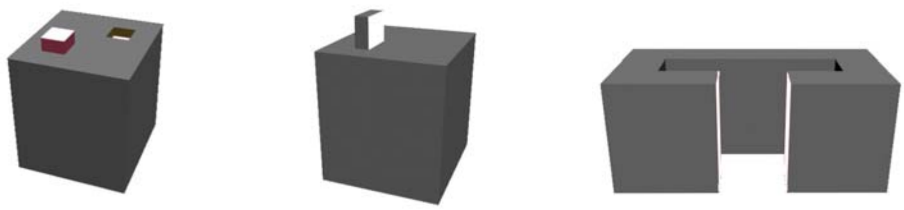
LoDs of building are divided by different criterions according to different use [3] [4] [12]. Based on the detail of feature, LoDs of building with parallel building are consisted of three levels: original model (LoD1), model with main feature (LoD2) and model only containing the most important feature. These LoDs are divided by the minimal distance between facets of building and the distance varies as change of building size. In simplification of isolated building, LoD2 is acquired by shifting of facets whose distance is smaller than 1/10 of the length of building in corresponding direction, and the threshold to get LoD3 is 1/4 of corresponding length.

3.3 Main operators used in the algorithm

(1) Shift of facets

Shift of facets is the key to this algorithm, including determination of shift distance and adjust of the neighboring facets. Several cases of shifting facets are shown in Fig 3. 3(a) is shift of facets with same orientation, which can process two features. 3(b) and 3(c) show the two different cases when the facets are with opposite orientations separately. When two facets are with opposite orientations, error occurs in the case shown in Fig 4. In this case, if the two facets are combined after shift, its normal is unable to determine, so we should avoid this case in execution of the algorithm. This case happens little in simplification of building from real world.

Shifting of facets aims to combine two facets to one, so the ideal distance to be shifted is according to the rate of their area, which can keep the volume of building well. But this method can’t keep the shape of building good and feature of small size may affect shape of building. So in the shift of facets, if area of the larger facets is greater than three times of the smaller one, shift smaller facet to the larger, otherwise the two facets are moved to the middle to form one facet. Experiments prove that this method of shifting facets may produce good result.



(a) (b) (c)

Figure 3. Three cases of facet shift

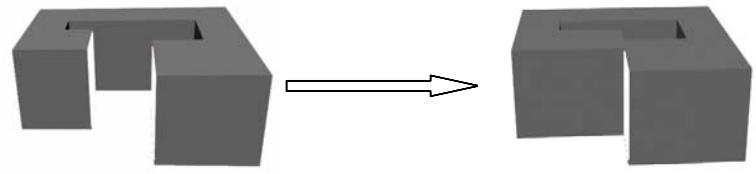


Figure 4. Error in facet shift

Neighbor of the shifted facet should be adjusted. Find out all the line segments that are some to the shifted facet and then change their coordinates according to the shifted distance of facet. Area of the neighboring facet can be calculated by multiplying length of line segments and shifted distance. When two facets are shifted, process their neighbor separately. We should process their neighbors before shifting facet; otherwise we can’t get the right line segments.

(2) Adjust of Polygon after shift

Each shift is a course of combining two Polygons to a new one. The new Polygon is used as a normal one in next step of the algorithm, so we must adjust it to have same structure with other ones. For a new Polygon and its neighbor, coincidence of points caused by facet shift is shown in Fig.5.

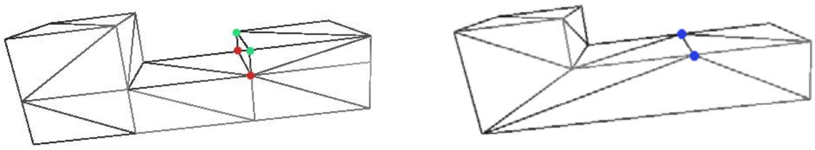


Figure 5. Coincidence of points caused by facet shift

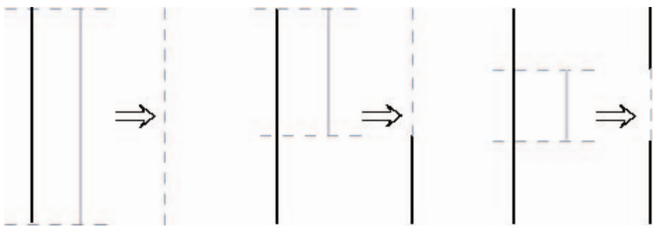
In this case, the coincident points should be combined; otherwise it will cause data redundancy and errors in the next steps (these points shift twice when the new Polygon is shifted). Adjustment of Polygon is executed by the following steps:

1) Traverse all the neighboring Polygons of the shifted one, for each Polygon, combine line segments of its border that are adjacent and collinear to one. In this course, the coincident points in Fig.5 can be eliminated as special line segment.
2) Add all neighbor indexes of the smaller Polygon to the neighbor index array of the larger one and then delete all the iterant indexes.
3) Index of the larger Polygon is marked as bIndex. Traverse neighbors of the larger Polygon; add bIndex to neighbor index array of the neighbor if it is not included in.

4) Contrast normal of the shifted Polygon, if they are same, their areas are added as area of the larger Polygon; otherwise area of the smaller Polygon is subtracted from the larger one.

5) Border arrays of the two shifted Polygons are added to form border array of the new Polygon. In the new Polygon, line segments are intersected completely or partly. In process with the intersection, delete the two complete intersected line segments as shown in Fig.6 (a); for the part intersected ones, subtract the shorter segment from the longer one as shown in Fig.6 (b). In the later case, one line segment may be cut to two, just as shown in Fig.6 (c). Adjust order of line segment and combine the ones that are collinear and adjacent.

6) Delete the Polygons of the PolyList that no longer existed after the shift, including the smaller shifted Polygon and neighboring Polygon whose area is 0. Adjust the neighbor index of deleted Polygon’s neighbors.



(a) (b) (c)

Figure 6. Three cases of merging lines

(3) Re-triangulation of Polygon

When a LoD of building model is achieved, all Polygons should be re-triangulated to fulfill the storage and visualization. Re-triangulation algorithm of arbitrary plane polygon base on constrained Delaunay triangulation.

3.4 Execution of the algorithm

Step 1: Construct of the building model and acquire the needed information.

Step 2: Delete all the original triangles of building model and re-triangulate the Polygons, then add these new triangles to the array pFaces and memorize number of the triangles.

Step 3: Note the level of LoD to be achieved and determine distance threshold of different orientations by circumscribed cuboid.

Step 4: Find out the two Polygons that with minimal distance. If the distance is smaller than threshold in this orientation, go to step 5; otherwise note the orientation and continue to execute step 4 in other orientations. If all the three orientations are processed and no more Polygons fulfill the terms to shift, the required level of LoD is achieved, go to step 7.

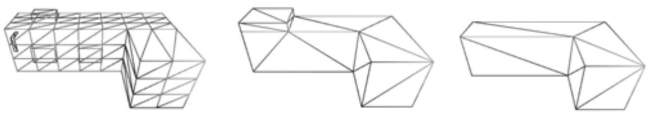
Step 5: Calculate ratio of the two shifted Polygons' area to determine which Polygon should be shifted and the distance to shift. Adjust corresponding line segments of its neighbor and then shift the Polygon. Calculate areas of the neighboring Polygons.

Step 6: Adjust the shifted Polygon by the method above and go back to step 4 after processing the referred Polygon.

Step 7: Delete all triangles of the original model and re-triangulate all Polygons. The new triangles are added to the array pFaces and its number is noted. Then the required LoD is achieved and the algorithm is finished.

3.5 Instances and analysis

Building model from 3ds file is used in the experiment. The chosen model is represented by an isolated external surface and texture of building is not considered here. Original building is consisted of 256 triangles with four clear features. It is simplified to LoD2 model with 28 triangles and three features are deleted and one is exaggerated. Then the model is future simplified to LoD3 with 20 triangles and the most important feature is maintained. Fig.7 shows simplification course of the building mode, (a) is original model, (b) is model of LoD2 and (c) is model of LoD3.



(a) (b) (c)

Figure 7. Building model simplified by the algorithm

4. **Conclusion**

Facet shift algorithm based on minimal distance in simplification of building with parallel structure is carried out and experimented in this paper. A new data structure that benefits generalization is proposed and the structure Polygon is introduced to construct the building with parallel structure. Experiments are done to prove that the algorithm is effective and produce good result in simplification.

Experiment in this paper is done based on simulated data and not all the complexities of 3D building model are considered. Keeping consistency of the geometry model and texture of building is important and hard work, which is the main content in the following research.

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