CONTOUR CLUSTERING ANALYSIS FOR BUILDING RECONSTRUCTION FROM LIDAR DATA

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ABSTRACT:

Automatic building reconstruction from LIDAR data has become a hot topic for several years. Many methods and algorithms have been put forward to reconstruct the building models, such as of flat roof, gable roof, or other rectangular shapes. Among which, contour based method is an innovative one to simplify the focusing, detection and reconstruction of buildings. In this paper, the contour clustering is investigated deeply for the construction of complex buildings. At first, the contour based reconstruction method is reviewed. Then the contour cluster is defined with topology relationship and shape similarity. The experiments show the clustering technique can capture the structure of the building, providing a sound base for reconstructing buildings of multiple layers, curved surface and other complex shapes.

1. INTRODUCTION

3D model reconstruction of building is one of the most important research works in the 3D Cyber City. With the development of airborne LIDAR technology, the advantages of LIDAR data cause expectations in the field of building reconstruction and city modelling. But the reconstruction of building model from LIDAR data is a challenging problem. It can be divided into two major steps: building detection and model reconstruction. At the building detection step, the major work is detecting the position and extent of buildings. At the model reconstruction step, the major work is creating appropriate building models. There have been a large volume of researches on the two topics.

The existing methods can be divided into two groups. One group extends methods for image information extraction to LIDAR data. Such as edge detection is used to extract building edges, then the fragmented edge segments are connected to form building boundaries (Huber, et al., 2003; Oda, et al., 2004). All methods in this group have to face the difficulty of edge organization. To overcome this difficulty, Vosselman et al. (Vosselman and Dijkman 2001) apply ground plans of the buildings to determine the building outlines and to support for the 3D reconstruction.

Another group adopts a unique way to circumvent the problem of edge organization. This kind of methods exploit closeness of contours (Ping Yan, Wanshou Jiang, 2005; Tee-Ann Teo, Liang-Chien Chen, 2006) or height slices(Zhan, Molenaar and Tempfli, 2002). Zhan uses a certain height slices to cut DSM. By comparing the size and gravity center, slices can be classified as building or not. Ping Yan and Tee-Ann adopt contours to detect and extract 3D building models from the dense DSM. Firstly, contour tracing is applied to get building footprint. Then the building’s closed boundary is acquired from contours. Finally, the closed boundaries are adjusted by least square refining to constitute the buildings of multi right angles and multi layers and the parametric building models are constructed.

All of the above methods try to find out a way to reconstruct building models more accurately and automatically. But at the present, automatic reconstruction algorithms are only applicable for simple buildings, such as flat roof, gable roof, and so on. In regard to buildings with complex structure, manual editing is still the last choice. The multilayer of building structures, the multifarious of building shapes, the influence of noise and vegetation all make complex building reconstruction difficult to be automated.

After deeply analyzing the problem of complex building reconstruction, we believe contour clustering is a promising way. Contours have many advantages. They contain the shape information of object boundary, and they are closed, complete, having explicit topological relationships among each other. Generally, buildings in urban area are composed of complex structures and mixed shapes. Contours of a building in different parts may have different shapes. The measurement of similarity can be used to classify contours into different cluster. Each cluster reflects the structure and the shape feature of a certain part of buildings.

The concept of contour cluster and the idea of building reconstruction based on contour clustering are given in section 2. Section 3 gives the algorithms of contour clustering. Section 4 gives the experiments and comments.

2. BUILDING RECONSTRUCTION BASED ON CONTOUR CLUSTERING

2.1 Contour clustering

Contour clustering is based on the following observations: The contours of a building are usually very similar to each other in every part of the building; the nested similar contours are defined as a cluster of similar contour. The contour cluster reflects the detailed feature of the corresponding object.

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For different objects, their contours are usually different in their characteristics of clustering.

(1) The contours of a building are generally dense, their shape are regular and similar enough to form a cluster;

(2) The contours of terrain are generally sparse, their shape is smooth, the length of which are usually longer, the area of which are larger, and shapes between them are usually different. The reason for this phenomenon is that the elevation difference of terrain is insignificant. For example, in the urban region, the ground is unusually flat.

(3) The contours of trees may be also dense, but their shape is less regular than that of buildings, they are less similar to each other, and the length and the area of a closed contour is usually smaller than that of buildings.

With the measurement of similarity, contours can be clustered. With area, length and other factors of shape, the regions of contour cluster can be classified into roof, layer of building, terrain, vegetation, etc.

In addition, the contour cluster can reflect the structure information of the building. In fact, clusters represent layers of a whole building, and the multi-layer building reconstruction can be achieved by each cluster. Each contour is one closed outline of a building. It provides a basic unit of processing. The closeness of contours can effectively solve the difficulty of edges grouping.

2.2 The idea of building reconstruction based on contour clustering

The idea of our approach can be illustrated in Figure 1. Figure 1a is point cloud of a building of two layers. Figure 1b shows the contour generated from the data set. Figure 1c and Figure 1d show two clusters of contours representing the two layers of the building. Figure 1e and Figure 1f show the model reconstructed from the two clusters. Figure 1g shows the whole model merged from the models of two layers.

From the analysis above, it can be found that many problems in building reconstruction from LIDAR data can be solved with contour clustering analysis, including the focusing of ROI, closeness of the building boundary, layer separation, etc. The processing steps are shown in Figure 2.

(1) filtering the points of multi return

In our approach, contours are the base of the whole processing procedure of building reconstruction. The pre-processing is necessary for filtering out some LIDAR points.

Presently, most LIDAR systems can record multi-return signals. It is useful to eliminate vegetation from other objects. Multiple echoes will cause large varieties in height direction in some areas, such as vegetation region. In this region, the length and areas of contours are very small, making it difficult to be analyzed. So before triangulation, multi return points need to be filtered out, so that only the last return points are kept. Meanwhile, vegetation area with multi-return information can also be recognized and removed.

(2) Delaunay triangulation

After point filtering, the Delaunay triangulation can be made to generate a triangle mesh. An open source triangulation software can be used to construct the mesh (Shewchuk, 2005).

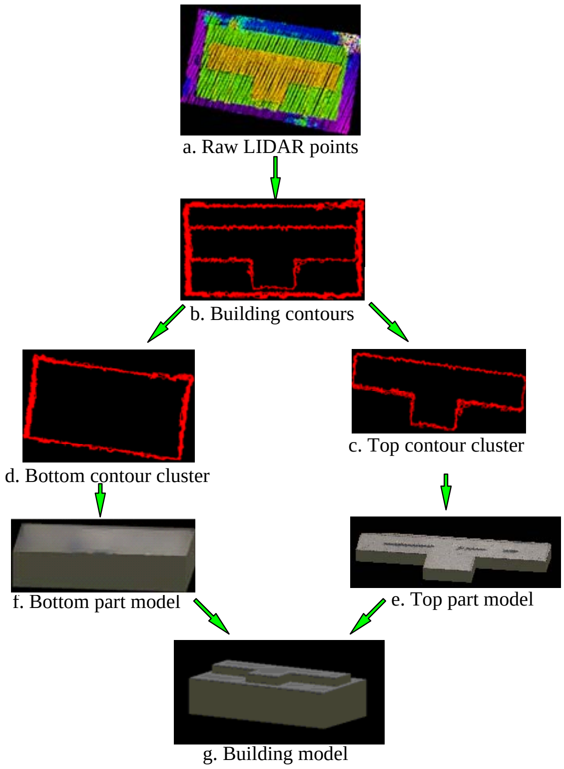


Figure 1. The procedure of building reconstruction based on contour clustering analysis

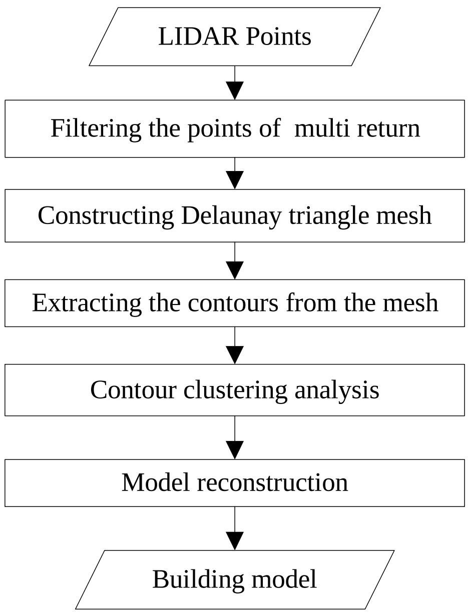


Figure 2. Building reconstruction based on contour clustering

(3) contour extraction

With the triangle mesh generated from points cloud, contours can be traced. With thresholds of contour length and area, some contours of vegetation can be removed.

(4) contour clustering analysis

Contour clustering analysis includes topological relationship analysis and similarity analysis. With the determination of topological relationship and similarity of contours, the contours can be grouped into clusters. The details of the algorithms are given in section 2.

(5) Model reconstruction

Model reconstruction is based on the clusters of contour. The key problem is to recognize the shape of the cluster and form a model. For example, the research work is to split the point chain of the contour into segments (such as lines, arcs, ellipses, circles, curves, etc). Then the relations, such as parallelism, perpendicularity, between these segments are to be determined. A constrained least square adjusting can be adopted to refine the model parameters. Using clusters of contour, we can detect the detailed structure of objects.

3. CONTOUR CLUSTERING ANALYSIS

As defined in section 2, contour cluster is a set of contours with inter-nested topologic relationship and similar shape. In our approach of building reconstruction, contour clustering is a key step, output of which is the based subsequent processing. The flow chart of the algorithm can be illustrated in figure 3.

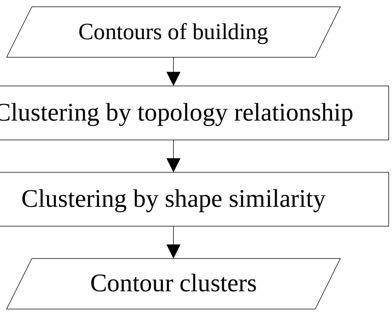


Figure 3. The flow of contour clustering analysis

First of all, contours are clustered by their topological relationship, and then a shape matching algorithm is applied to do clustering according to shape similarity.

3.1 Clustering by topological relationship

Between two contours, there are only two kinds of topological relationships, namely nesting or separation. In Qiao and Zhao' work (Qiao Chaofei, Zhao Renliang, et al., 2005), a tree structure is used to describe the topological relationship between contours. In figure 4, a complex building model is shown, in which the contours are coloured in red. For the convenience of analysis, each contour is labelled with a unique ID. The building is consisted of four parts --- a foundation, two towers, and a spire on a tower, which are rendered in different colours. As the contours are all closed and free of intersection, a simple algorithm can be applied to construct the relationships between these contours. For any two neighbour contours, the process is as following:

(a) Select a point of one contour, if the point is inside another contour, then the first contours is nested by the second contour;

(b) If both the two contours is not nested by each other, then relation of two contours is separation;

(c) If every contour is regarded as a node of a tree, then the contours can be put into nodes of a contour tree. The contour not nested by any contour is the father node, and the contours nested by a father node are children nodes.

The tree of contours in figure 4 is shown in figure 5. The nodes of the tree are corresponding to the contours with the uniform ID. And the colours of the nodes are identical to the colours of the corresponding building parts. A root node is appended to complete the tree structure. In the tree structure, if a contour is nested by another one, they are connected by a line.

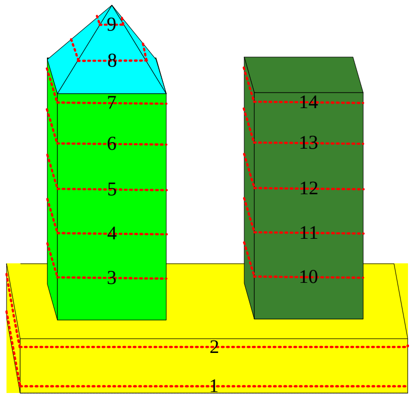
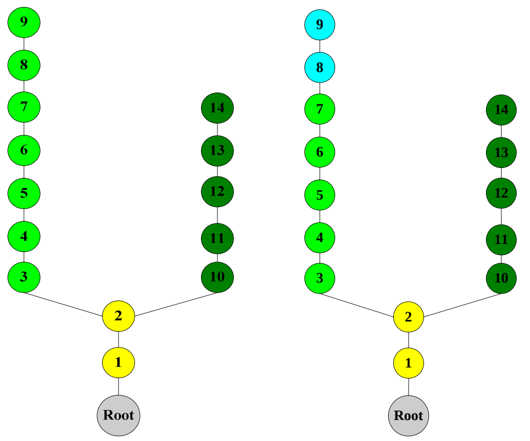


Figure 4. A model of a building and its contours



a. Result of topological clustering b. Result of shape clustering

Figure 5. The tree of contours

It is obvious that the contours of a cluster can only be of a group of contours which are nested each other. So the relationships of tree nodes can be used to group contours into clusters. Figure 5a shows a group of interconnected nodes without branch forms a cluster. Connecting to each other without branch, node 3, node 4 … and node 9 form the cluster of left tower; node 10, node 11 … node 14 form cluster of right tower. At last, node 1 and node 2 simply form the cluster of the building foundation.

3.2 Clustering by shape matching

The method of clustering by topological relationship is good for separating certain buildings parts, which are composed of several branches in vertical direction. But it is not applicable to this situation that building has different structures in the same branch. See the example in figure 4, the left tower is consisted of two parts, the main part rendered in light green and the spire roof rendered in dark green. The contours from 3–9 are clustered together by topological relationship. It is not accurate in reflacting actual building model. In figure 6, we can see that in the left cluster, contour 3–7 are more similar in shape and the distances among them are nearly equal, so they form cluster of the main part of the tower; while contour 7, 8, 9 have the similar shape, but the distance between each other are much more longer than which among contour 3 to 7. So contour 7, 8, 9 are formed a new cluster, which reflects the roof structure of building model.

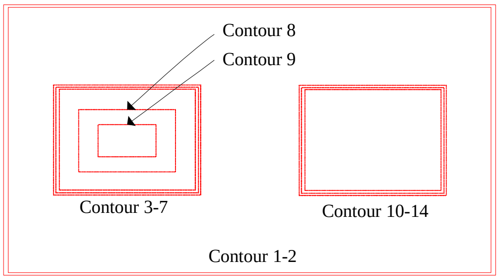


Figure 6. The vertical view of ideal building contour model

The similarity of shape and interval between contours can be another measurement of the cluster contours. Using this measure, the building contours such as left tower part in Figure 4 can be separated into two clusters. Contour 3-7 with similar shape and small interval can form one cluster. Contour 8-9 can be fitted well by a scale transformation with a larger interval, so they form another cluster. The shape is the essential character to distinguish the contours in different clusters. A shape matching is applied to enhance the accuracy of clustering.

A shape matching algorithm is adopted to analyse the shape similarity between contours. As shown in figure 7, if through a certain transformation, contour a fits contour b, the two contours are accepted as matched (Besl & Mckay, 1992).

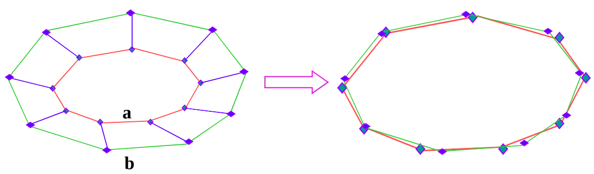


Figure 7. Matching of two contours

Suppose the corresponding points in different contours are given:

$$\begin{aligned} p_a &= \{(x_{a1}, y_{a1}), (x_{a2}, y_{a2}), \cdots (x_{an}, y_{an})\} \\ p_b &= \{(x_{b1}, y_{b1}), (x_{b2}, y_{b2}), \cdots (x_{bn}, y_{bn})\} \end{aligned} \quad (1)$$

The transformation of shape matching of two contours can be expressed by formula (1).

$$\begin{cases} x_b = \lambda x_a + \Delta X \\ y_b = \lambda y_a + \Delta Y \end{cases} \quad (2)$$

Where, λ is the scale parameter, ΔX, ΔY is the offset parameter. With a threshold of fitting error and a threshold of scale difference, the residual error of least square adjustment and scale difference are used to refine the clustering result by topological relationship.

The clustered result by shape similarity is shown in Fig 5b.

4. EXPERIMENT RESULT

To test the approach presented above, 2 experiment of contour clustering is applied to the LIDAR Raw points.

4.1 Experiment 1

The first experiment area is at the Toronto City Hall. The LIDAR data (Figure 8a) is collected by Optech scanner. The image (Figure 8b) and 3D model (Figure 8c) are downloaded from Google Earth. Shown in Figure 8b, this building is consisted of 4 parts, two bicorn towers locating on both sides, a dome hall in the middle, and two small parts connects towers and the dome hall. The connective parts are relatively small and usually lost in reconstruction. Apparently, 3D model from Google Earth omits the connective parts.

The contour extracted from the LIDAR data is shown in Figure 8d, the contour interval is 3 metres. The clustering results are shown in Figure 8e. Comparing Figure 8b and Figure 8e, it can be seen that the contours are correctly divided into four clusters: the left and right tower, the round roof of the dome and the base part of the whole building, especially keeping the connecting part.

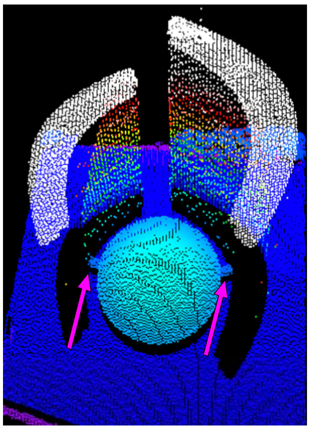
From this experiment, we can conclude that the contour based method can correctly express the detail of the building and the clustering method can extract key components of building.

4.2 Experiment 2

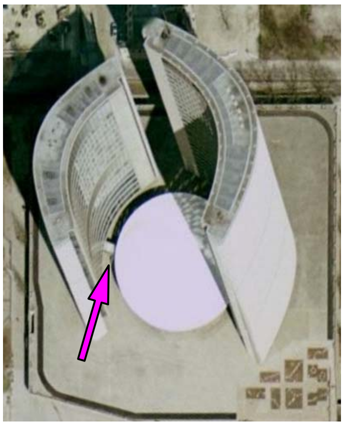
The second experiment is applied to the demo data ‘Hut200’ of Terrasolid software, which can be downloaded freely from Terrasolid’s website. The data set includes the LIDAR data, the aviation image and the manual edited 3D model. The test area locates 20 km west from Helsinki. A complex building region is chosen to test the feasibility of clustering and model reconstruction.

This building has multiple layers, and the shape of each layer is complex. The outlines consist of line segments and arc segments together. The generated contours are shown in figure 9d, the interval 5m.

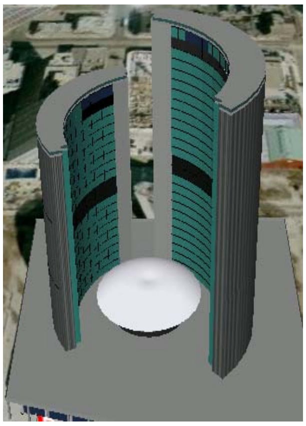
In figure 9e, the contours of the building are correctly clustered into 3 layers, 5 parts. Figure 9f shows polygon extracted from the contours. The key points are successfully captured, but the arc parts are not precise, which has to be improved in the future.



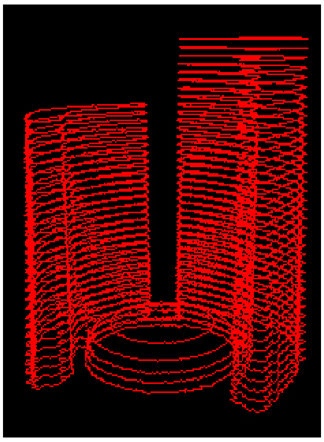
a. LIDAR data



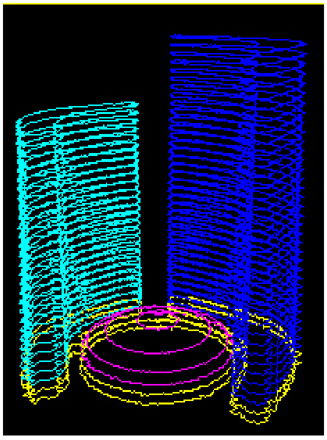
b. Image from Google Earth



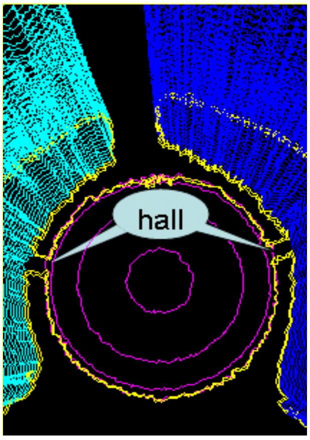
c. model from Google Earth



d. Contours generated from LIDAR point

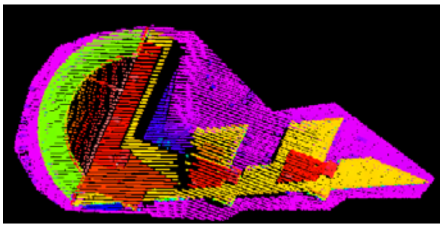


e. The result of contour clustering



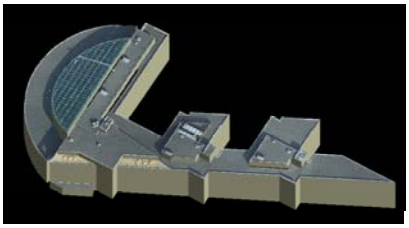
f. The detail of the base cluster

Figure 8. The contour clustering result of the Toronto City Hall

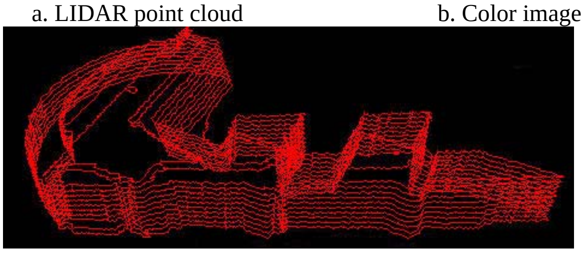


a. LIDAR point cloud

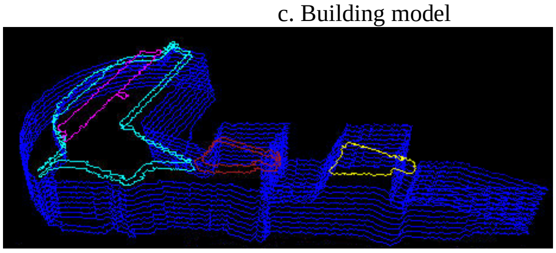
b. Color image



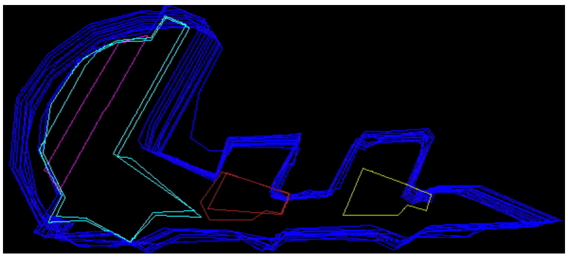
c. Building model



d. Building contours



e. Contour clusters



f. extracted building model

Figure 9. The contour clustering and building extraction result of Terrasolid's demo data

5. CONCLUSION

In this paper, the advantages of contours are discussed and the outline of contour clustering for building reconstruction method is given. The experiments show the clustering technique can capture the structure of the building, providing a sound base for the 3D building reconstruction. To achieve the whole process, there is still much work to do, such as:

(1) The separation of building contour and vegetation contour more exactly,
(2) Segmentation of contour cluster,
(3) Roof model reconstruction.

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