BUILDING BOUNDARY EXTRACTION FROM LIDAR DATA

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Abstract: Three-dimensional (3D) city modeling has been rapidly increasing the importance due to the need for accurate 3D spatial information for urban planning and management. Building modeling is one of the major tasks in city modeling. Traditionally, building modelsare mainly reconstructedusing aerial images with photogrammetric mappingtechnique. Because manual measurement of building boundary is required, the photogrammetry approachis time-consuming. Airborne LiDAR data directly provide 3D spatial information and make the reconstruction process of building models to be straightforward and possibly to be very automatic.Focused on the extraction of building boundaries fromLiDARpoint-cloud data, this paper proposes an algorithm to detect building outlines and to simplify and regulate the outlines to form the structures of building roofs.The algorithmis mainly composed of two parts.The first part is to extract the structure lines of buildings, which can be obtained by calculating the intersections of adjacent planes formed by coplanar point cloud.The second part focuses onthe detection of the building boundaries by using aboundary tracing algorithm. Our preliminary experimental results show the possibility of extracting structure lines and boundaries of buildings. Further study will be continue to refine the algorithm.

1. INTRODCUTION

The most common man-made objects in real world are buildings, so the building model plays the most important role in model reconstruction. There has been a lot of research about how to reconstruct three dimensional building modeling manually, semi-automatically, or even automatically. There are many kinds of data sources for three dimensional building modeling, for example, vector map data, images, LiDAR data, etc. (Tsai andChen, 2010) Two dimensional vector map data which contains accurate horizontal locations of building boundaries and the number of floor can be used to construct three dimensional building model in block form rapidly, but the result is short of height information and the details of roof. The z-coordinates can be obtained by stereo- measuring aerial images. Although accurate building models can be reconstructed using aerial images with photogrammetry technique, the procedure highly relies on manual measurement of stereo images and is labor-intensive and time-consuming. Some papers proposed aerial image matching automatically could extract three dimensional features for reconstruction to increase the degree of automation (Tsai, 2009). However, the rate of overlap of images may cause occlusion of building outlines, and the accuracy of image matching is worse than manual measurement.

Airborne laser systems or light detecting and ranging systems are active sensor capable of capturing threedimensional spatial data of objects. Such data usually called point clouds are typically three dimensional coordinates and laser intensities of scanned points, which are densely and irregularly distributed on scanned object surfaces. In general, the accuracy of z-coordinate can meet cm-level (Ackermann,1999), which provides accurate height information for model reconstruction. Point clouds imply abundant spatial information, in other words, object boundaries are not explicitly expressed in LiDAR point clouds. It becomes the top priority to extract out the structure features of buildings, for example, the roof boundaries before building reconstruction. This paper proposes a new algorithm for building reconstruction from airborne LiDAR point cloud data. Thisalgorithm aims to extract the roof edges and feature points obtained by the intersection of two or more adjacent planes, which are extracted using octree-based split-and-merge segmentation (Wang and Tseng, 2012). Also, this paper introduces an important concept of retrieving boundaries, which have not been extracted in the plane-intersection process. Such concept is usually called generalization. A generalization algorithm is proposed to retrieve roof outlines which are traced with boundaries tracing algorithm.

There are four sections in this paper: the first section is introduction part inclusive of motivation and the following paper review. The second section will explain some details about methods. The third section shows a simple experiment and some discussion on result. The last section gives some brief conclusion.

Because raw airborne LiDAR point clouds contain information of all scanned objects, for example, ground surface, buildings, trees, and other man-made objects, it is necessary to filter points of building out (Maas and Vosselman, 1999; Verma et al., 2006; Wang et al., 2006; Sampath and Shan, 2007; Neidhart and Sester, 2008; Lee et al., 2011).(Maas and Vosselman, 1999) estimated the parameters of roofs and generated initial model, combined with known location of buildings which came from two dimensional vector map data, and then adjusted model by the structure features and outlines of roof planes. (Verma et al., 2006) analyzed the topology relationship between adjacent planes, decided planar parameters, and then fitted initial model with these planes to reconstruct building model. (Wang et al., 2006) extracted footprints of building with planar roof from airborne LiDARdata ,and traced the building boundaries. (Sampath and Shan, 2007) traced course building outlines by convex-hull algorithm, and added some geometric constraints to integrate these segments which belonged to the same outlines into one group. In addition to convex-hull algorithm for building boundary extraction, some papers proposed Doulas-Peucker algorithm to simplify the fragmented segments, and adjusted the line formulas by using RANSAC algorithm and least squares adjustment (Neidhart and Sester, 2008). (Lee et al., 2011) gave an appropriate threshold of sleeve-fitting algorithm to group the points on building boundaries so that the corner points of building could be founded.

We can induce two key points of building reconstruction from the aforementioned research. One is to extract the roof plane by turning point clouds into grid or applying TIN (triangle irregular networks), and then obtain the point, line feature of roof by intersecting adjacent plane. However, some important information may lose during converting point data to two dimensional grid data, and the TIN is usually implemented in region with small area. Therefore, this study adopts octree-based split-and-merge algorithm as plane extraction method, which do not need clustering or interpolation and can be applied in region with big area. Second, tracingthe building outlines directly on LiDAR point clouds to get line segments, and then modify or adjust these course line segments by different algorithm. The discrete and irregular distribution of point clouds impacts the accuracy and efficiency of result and the buildings are man-made objects which satisfy vertical or parallel conditions , so it is necessary to do generalization which means a tradeoff between “simplicity” of description anddistance from the original data (Brenner, 2005).

2. METHODS

This study aims to develop an automatic algorithm for extracting structural features of roof and building boundary tracing and generalization for reconstruction using airborne LiDAR point clouds.Figure 1shows a simple flow chart of this algorithm. The input data is airborne point clouds which are classified into building and non-building. First, octree-based split-and-merge segmentation is implemented to extract coplanar points, and the parameters of planes are also generated. Then, we geta numberof planes which belongs to the same roof. To get better tracing result, it is necessary to inspect whether the roof has parapets. If yes, these planes needs to be grouped at first and go through tracing, generalization process to obtain thecomplete outlines of this building.If no, boundaries of individual planes are traced, simplified, and regularized directly from point clouds.

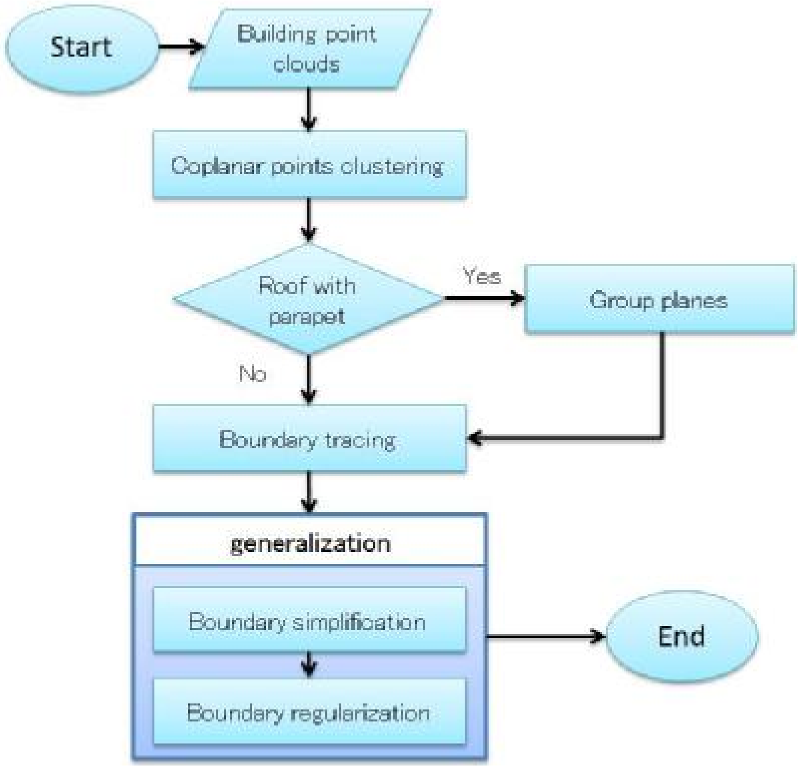


Figure 1: Flow chart of proposed algorithm

2.1 Coplanar points clustering

In this stage, the coplanar points from classified airborne LiDAR data are extracted out using octree-based split-and-merge algorithm. This algorithm is based on anoctree structure which serves as a spatial index of subdividedpoint sets. Connection of point sets are represented by noderelationship of the octree (Wang and Tseng, 2012).In the split process, point clouds are continuouslydivided into octree subspaces until each subspace containsonly coplanar points, and the planar parameters are also generated.In the merge process, planes of neighboring nodes are combinedin the octree formed through the split process if the pointswithin the combined subspace pass the coplanar test.The process recursively finds two neighboring nodes inthe octree, and merges corresponding subspaces to generatea combined plane.After the split process, roof of buildingare separated into many clusterswith points in the same class. The relationships between these clusters can be obtained by spatial geometric analysis, namely the structure lines will be extracted by intersecting adjacent planes.In 3D Euclidean space, two planes always intersectstraight line if they are not parallel or coincide (figure 2). There are many possible results of three-plane intersection (figure 3), and the most common case isa unique intersected point.Therefore, structure features such as bridges, step-edges, and feature points of roofs can be received. The points combined by the merge process can represent the roof planes which belong to the same building.

Figure 2: Geometric relationships of two planes

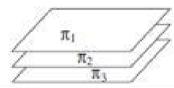
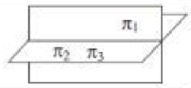
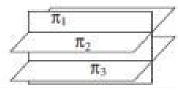
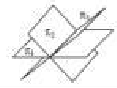
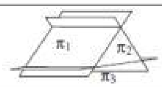
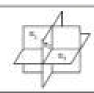
Geometric Relation		Intersection	Algebraic Condition		Illustration
All 3 planes are parallel	Coincide	1 plane	$\bar{n}_j \times \bar{n}_k = \bar{0}$ for $j \neq k$	$d_1 = d_2 = d_3$	
	Disjoint	None		$d_1 \neq d_2 \neq d_3 \neq d_1$	
Two planes are parallel and the 3rd plane cuts each in a line	Parallel planes coincide	1 line	Only one $\bar{n}_j \times \bar{n}_k = \bar{0}$ for $j \neq k$		
	Parallel planes disjoint	2 parallel lines			
No parallel planes	Intersection lines coincide	1 line	$\bar{n}_j \times \bar{n}_k \neq \bar{0}$ for all $j \neq k$	$\bar{n}_1 \cdot (\bar{n}_2 \times \bar{n}_3) = 0$ test a point from one line	
	Intersection lines parallel and disjoint	3 parallel lines		$\bar{n}_1 \cdot (\bar{n}_2 \times \bar{n}_3) = 0$	
	No parallel intersection lines	1 unique point		$\bar{n}_1 \cdot (\bar{n}_2 \times \bar{n}_3) \neq 0$	

Figure 3: Geometric relationships of three planes (Wang and Tseng, 2012)

The boundaries detected from aerial images usually depend on the location of parapets. However, the boundaries extracted from LiDAR data rely on the completeness and correctness of segmentation. To gain the result which is correspondent with that from images, we integrate clusters into one group according to height information. At first, the main height is chosen if area of the plane is the largest or the number of points in the plane is the most (the plane pointed in figure 4). The points located within a height difference threshold are added into the group. Then, the boundary tracing algorithm is carried out for this group to receive the out boundary of the roof. What's more, outlines of the other planes are also found by boundary tracing algorithm respectively.

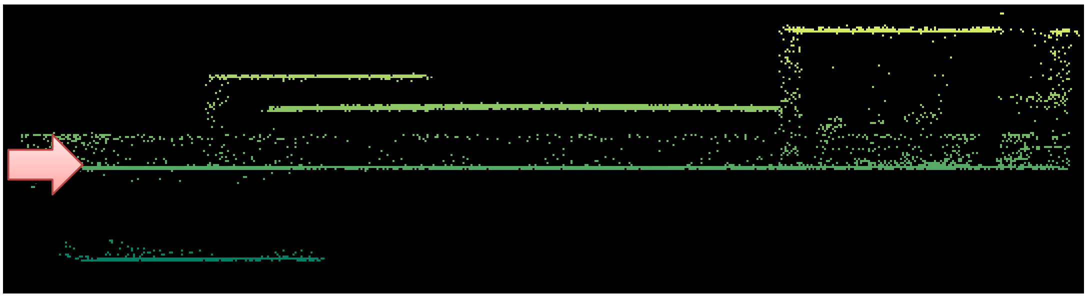


Figure 4: The side view of building roof of LiDAR data

2.2 Boundary Tracing

The course outline of each planeis traced by modified convex hull algorithm, also called concave hull algorithm in this study. Figure 5 shows a basic concept of original convex hull algorithm. We select the point (P) with its location is the left and out as starting point. Next, linesegments are formed between P and the other points. These points are then sorted in increasingorder of the clockwise angle from the vertical axis. Thepoint which corresponds to the least angle is chosen as thenext point (A). In the second step, line segments areformed between the point A and the rest of points. Then, thepoints are sorted in order of their angles between the linesegment AP and allother line segments. Thisalgorithmwill not stopuntil the end pointcoincides on the starting point P.

The outline traced by convex hull algorithm sometimes cause not ideal result, like the left polygon in figure 6. To gain the right polygon which is similar with the boundary of roof in real world, we add length condition. If the distance between points surpasses the given length, this line segment will be ignored even though the angle between this line and the previous line is the smallest.

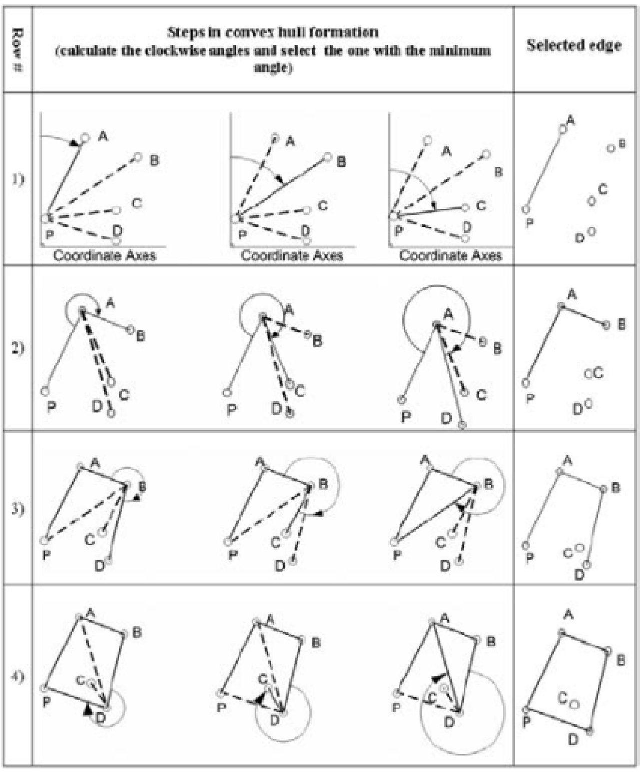


Figure 5: An example of convex hull algorithm (Sampath and Shan, 2007)

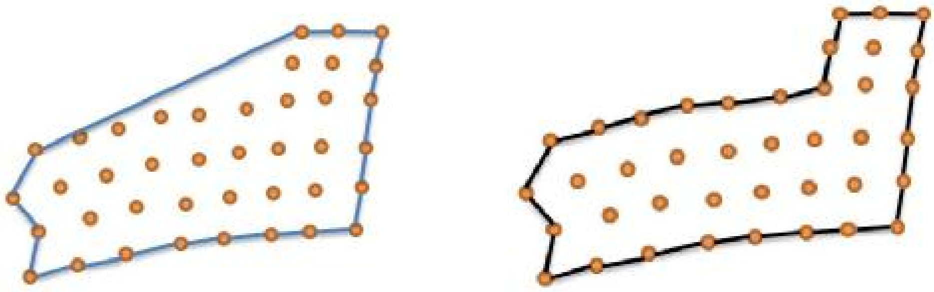


Figure 6: Comparison between convex hull algorithm and concave hull algorithm

2.3 Generalization

The definition of generalization is the tradeoff between "simplicity" of description anddistance from the original data (Brenner, 2005).Forinstance, a dense triangulated irregular network(TIN) of 3D points on a roof is generated, the"best polyhedral reconstruction" of the roof is thecomplete TIN —because it is the surface of a polyhedronand has a minimum distance to the original TIN,namely, zero. Meanwhile, what we want actually isa more simple (generalized) description of the roof,which preservesimportant representations of a building model. However, this kind of conceptwas seldom mentioned in previous studies.In this paper, we try to integrate some basic or essential rules in generalization process which is composed of simplicity and regularization. Due to the irregular distribution of pointsaround the area with large difference of height, the course outlines traced by concave hull algorithm cannot truly stand for regular building boundaries. Therefore, the key vertices are founded by simplify process, and the number of fragmented line segments will be decreased. Then, the formulasof boundaries coincided with geometric conditions, e.g. vertical or parallel are decided by regularize process using least squares adjustment.

3. EXPERIMENT

3.1 Data

The input data forthis experiment is airborne LiDAR point clouds of department of systems and naval mechatronic engineering of National Cheng Kung University (NCKU)in Taiwan, scanned by ALTM 30/70, Optech(table 1).Figure 7 shows the unclassified point clouds colored according to z-coordinate, and figure 8 is the orthogonal image of the study area.This roof is planar with parapets on it and more than two clusters with different height, so the split distance and merge distance should be considered carefully for the purpose to get ideal segmentation result. One of the most important thresholds is voxel size which depends on the average density of LiDAR data, and it causes over-segmentation or under-segmentation of point clouds. Over-segmentation can be improved by merge process, but under-segmentation leads to not ideal result. In this test, the voxel size is 1m. In order to obtain a better segmentation result, thevalue of split distance may be a little smaller than that of merge distance, which are 1.0 and 1.5 m respectively.

Table 1: Basic information of airborne LiDAR dataset

Flight height	About**500m**
Field of view	36°
Number of strips	3
Number of points	23812
Average density	8 pts/m^2

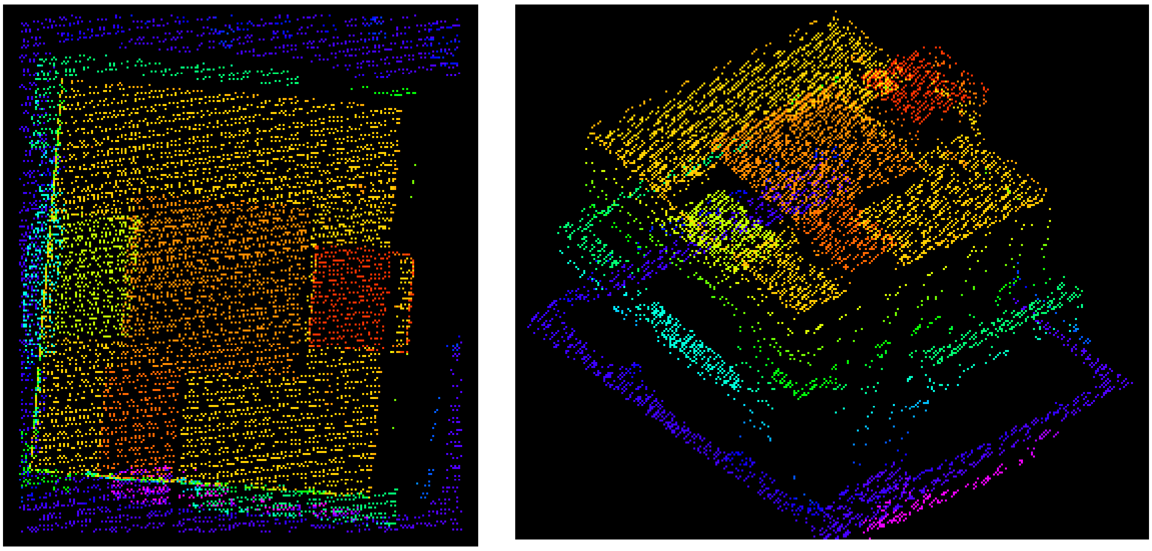


Figure 7: Airborne LiDAR data of department of systems and naval mechatronic engineering of NCKU

Figure 8: Orthogonal image of department of systems and naval mechatronic engineering of NCKU

3.2 Result

After segmentation, coplanar points which belong to the plane display in the same color (figure 9). The parapets are classified into the main plane in which number of points is the most, so the out outline of the main plane looks fragmented but complete and similar with the boundary of LiDAR data(the left picture in figure 10). There are four plans up the main plane, and the course outline of each plane also generated during concave hull algorithm. However, the splines do not close.The simplification process reduces the number of line segments, butitmay cause the corners of polygons cut.

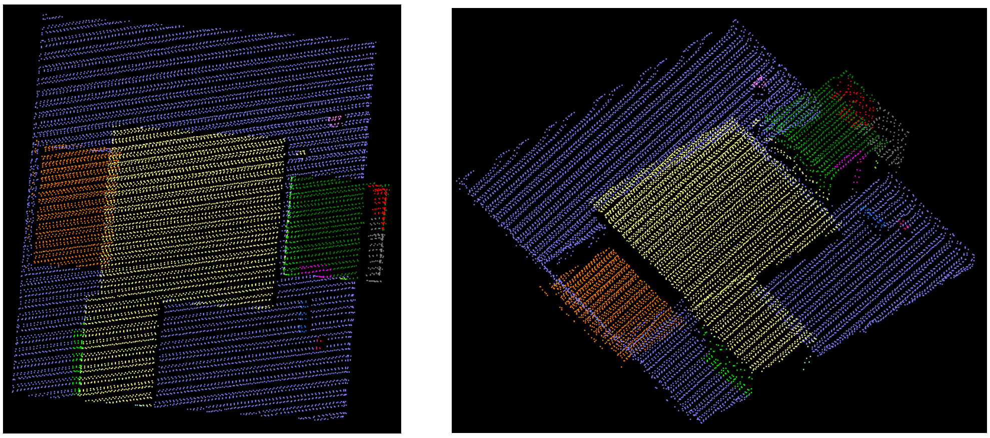


Figure 9: Coplanar pointscolored by class (left: top view; right: perspective view)

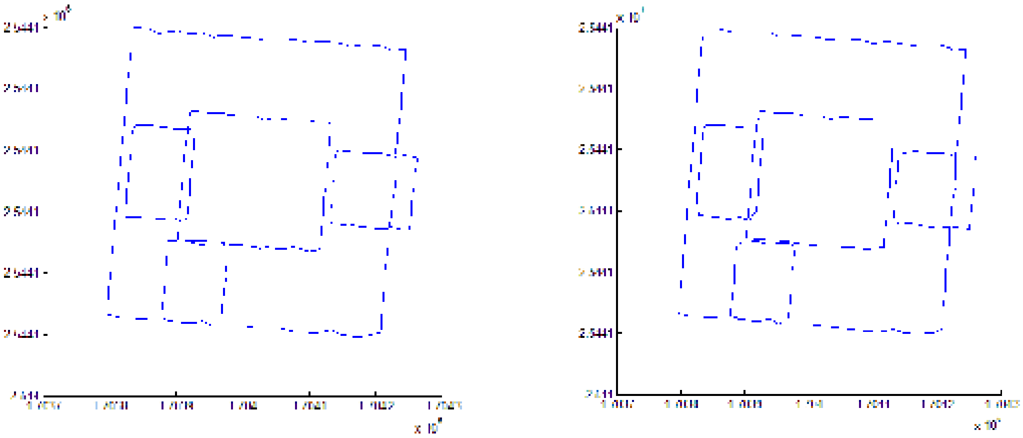


Figure 10: The outline of roof (left: after concave hull algorithm; right: after simplify process)

4. CONCLUSION

This study extracts roof planes by using octree-based split-and-merge segmentation. The concave hull algorithm can trace the course outlines of planes completely, and simplification algorithm can automatically simplify the boundaries of roofs. Somepreliminary experimental results demonstrate the feasibility of the proposed algorithm. Although the current version of the proposed method can only deal with buildings of simple structures, it is possible to sophisticate the algorithm in order to handle complex buildings. In the future, we will come up with some geometric regulations in the generalization process.

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