Simple Building Reconstruction from LIDAR Point Cloud

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Abstract

This paper presents a method for simple regular building reconstruction from LIDAR point cloud. At First, TIN model of the extracted building point from discrete LIDAR point cloud is built. Those points in triangle facet which having the similar normal vector value are clustered into the same plane point set. Then, every plane point set is fitted into plane using the least square method which boundary is decided by convex hull theory. The boundary of building top plane can be optimized based on regular building principle. From the optimized building top boundary and the height of ground, we can calculate the 3D coordinate of every corner point on building. The building model can be constructed based on 3D coordinates of these corner points. The experimental result shows that this method is able to construct effectively simple regular building.

1. Introduction

Airborne LIDAR (Light detection and ranging) is recently a new technology for earth observation. It can survey topographic information more detailed and accurately than those obtained by traditional photogrammetric methods. So, LIDAR technology becomes new means to research on 3D digital city. Because building is the main object in city region, building extraction and reconstruction is the main research problem in the field of 3D digital city.

With the development of detection techniques, there are many data resources used to research on building extraction and reconstruction in urban areas such as aerial photograph, satellite high-resolution image and LIDAR and so on. In these data resources, LIDAR data is the most important technology because not only LIDAR can detect the building and its outline, but also 3D information of building can be extracted from LIDAR.

In existing method of building reconstruction from LIDAR, many methods are fusing LIDAR data and other remote sensing image or ground plan. George Vosselman and Sander Dijkman (2001) [1] extracted the height and direction of building top surface to construct 3D building model by 3D Hough transform from LIDAR point cloud using ground plan for help. Rottensteiner and Briese (2003) [2] extracted the building top surface to construct polyhedron model using region growing and curvature-based segmentation technology from regulated DSM of LIDAR. In order to improve the geometrical precision, they integrated aerial images into the reconstruction process to increase the geometric quality of the reconstructed models. G. Sohn and I. Dowman (2003) [3] fused the IKONOS satellite image with 1m resolution and DEM from LIDAR data to detect building and construct building model. Haala, N. and C. Brenner (1997) [4] and Ellen Schwalbe (2005) [5] used 2D GIS data and LIDAR point cloud to generate the 3D building model by projection method. But in these methods, it is difficult to obtain the two types of data in the same area and the same time. Vosselman G. (1999) [6], Morgan, M. etc. (2001) [7] extracted the building top plane from the Delaunay triangulation network of discrete irregular LIDAR to reconstruct building. But the automatization and precision of building extraction and reconstruction need to be improved further.

In this paper, we only use the discrete LIDAR point cloud to research the method of simple regular building reconstruction. In order to avoid the interpolation error, we adopt the 3D TIN structure of LIDAR point cloud. Taking the simple sloped-top building as an example, the method is described in detail.

2. Methodology

The flowchart of simple regular building reconstruction from LIDAR point cloud is as figure1. This method includes four parts: building points clustering, building top planar fitting, building top boundary determining and building model reconstruction.

In this method, the discrete LIDAR point cloud data is adopted. At First, TIN model of the extracted building point cloud is built. Those points in triangle facet which having the similar normal vector value are clustered into the same plane point set. Then, each of these plane point sets is fitted into plane using the least square method, and plane's boundary is decided by convex hull theory. The boundary of building top plane can be optimized based on regular building principle. From the optimized building top boundary and the height of ground, we can calculate the 3D coordinate of every corner point on building. The building model can be constructed based on 3D coordinates of these corner points. Taking the sloped-top building as an example, the method of building reconstruction will be described in detail in the following text.

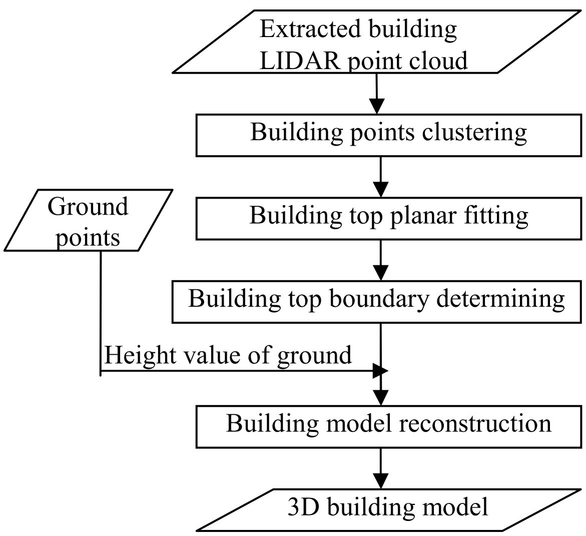
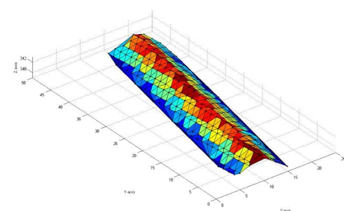


Figure 1. Flowchart of building reconstruction from LIDAR point cloud

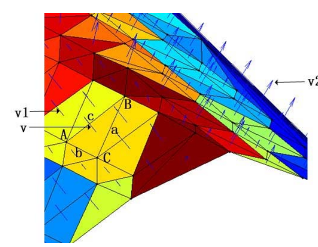
2.1 Building points clustering

Triangulated Irregular Network (TIN) is usually used for representing the DEM (digital elevation model) and neighboring relation of spatial discrete points. TIN model organizes the discrete points to triangulated network, and every discrete point is the vertex of triangle. In the constructing TIN model process, the planar Delaunay triangulation network should be constructed at first. The spatial sub-randomly distributed points can be projected as a disorder point set in the horizontal plane and then the planar Delaunay triangulation network is constructed based on Voronoi graph. Then, according to planar Delaunay triangulation network structure and every point's elevation value, the spatial TIN model for LIDAR point cloud can be constructed. The neighboring relation of spatial discrete points in the TIN model is same to that in Delaunay triangulation network. The TIN model of discrete building top points is as figure2 (a).

In figure2 (b), the triangle ΔABC is one triangle facet of TIN model that vertex A, B and C are LIDAR points having 3D coordinate values. The normal vector $\vec{v}$ of triangle facet ΔABC can be calculated by formula $\vec{v} = \vec{a} \times \vec{b}$. Figure2 (b) describes the normal vector $\vec{v}$ of triangle facet ΔABC from gravity center of ΔABC. From figure2 (b), the direction of normal vector on the same building top plane is similar, and that on different building top plane is different, such as v1 and v2. So we can divide the building top LIDAR points to different building top plane, based on the normal vector direction difference of every triangle facet.



(a)TIN model



(b) Normal vector of triangle facet

Figure 2. TIN model of building top point and normal vector of every triangle facet

In this paper, K-means clustering method is used to divide building top LIDAR points having similar normal vector into the same planar point set. The correlative coefficient is cosine of angle between normal vectors of triangle facet in K-means clustering method. The clustering result is as figure3. In this figure, the sign “ ” denotes planar point sets Ⅰ and the sign “•” denotes planar point sets Ⅱ. This method can divide effectively the sloped-top LIDAR points into two different planar point sets as figure3.

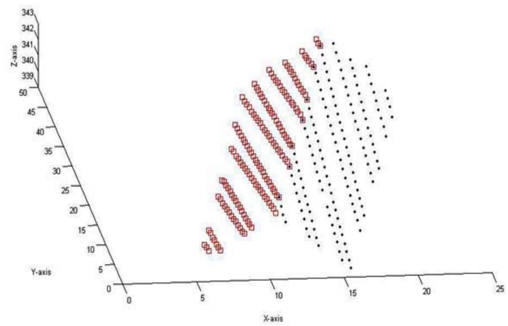


Figure 3. The clustering result of points

2.2 Building top planar fitting

The points in every planar point set need to be fitted into plane after LIDAR points are clustered into different planar point set. Planar fitting is seeking a most approximate plane comprised by given points. This plane can achieve that some points are on it and other are not on it but close to it. In this paper, the least square method is used to fit the plane. The least square fitting method tries to obtain the minimal square sum of difference between fitted value and observed value. The fitted plane Ⅰ and Ⅱ from planar point sets Ⅰ and Ⅱ are as figure4 using the least square fitting method. In every fitted plane, we can calculate the initial outline of building top plane using convex hull of points. The initial outline of building top plane is as figure 4 too.

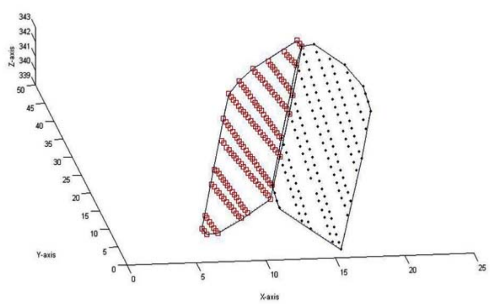


Figure 4. The fitted plane of building top

2.3 Boundary determining of building top plane

From figure 4, the initial outline of building top plane calculated by planar point set is the irregular polygon. But actually, simple building top is comprised by regular rectangle, trapezoid and triangle and so on. And in this paper, the top plane of sloped-top building is only comprised by regular rectangle. In order to calculate the boundary of building top plane, we calculate the intersecting line between top planes firstly. Then using this intersecting line and geometrical relationship we can obtain the minimal rectangle including convex hull of points outside of intersecting line. This rectangle line will be boundary of building top plane (as figure 5).

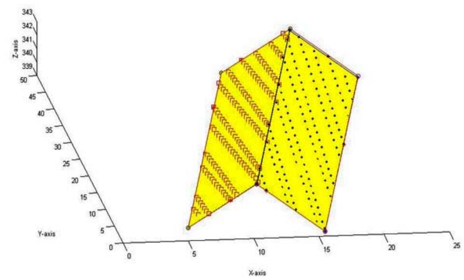


Figure 5. Determining of building top boundary

The two rectangles calculated by extending convex hull are incomplete symmetrical as figure 5. This asymmetrical result is contradiction with real simple regular building. So, the boundary of building top plane need to be further optimized. In order to avoid loss of LIDAR point, we adopt the maximal rectangle borderline to optimize the boundary of building top plane. As the figure 6, the inner boundary is calculated by extending convex hull, and the outer is the final boundary optimized by maximal rectangle borderline. This result satisfies symmetry principle of simple regular building.

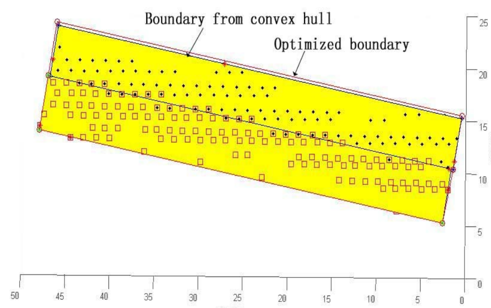


Figure 6. Optimizing of building top boundary

2.4 model construction

As the figure7, the regular sloped-top building has ten corner points (or vertexes). The building wall is vertical to ground and regular building is symmetry. So, vertex 1 and vertex 2 have the same height value, vertex 3, 4, 5 and 6 have the same height value, and vertex 7, 8, 9 and 10 have the same height value too. Vertex 3 and vertex 7 have the same x value and same y value. The same x value and same y value also exist in between vertex 4 and vertex 8, between 5 and 9, and between 6 and 10. Then coordinate of every vertex is (x1,y1,z1), (x2,y2,z1), (x3,y3,z3), (x4,y4,z3), (x5,y5,z3), (x6,y6,z3), (x3,y3,z7), (x4,y4,z7), (x5,y5,z7) and (x6,y6,z7) respectively. There are 15 parameters that z1 is the height value of building top, z3 is the height value of eave, and z7 is the height value of ground. In these parameters, the value from x1 to x6, y1 to y6, and z1, z3 can be obtained from above method of building top planar fitting and boundary determining. The value of z7 comes from the ground LIDAR point around building. 3D building model can be constructed by above 3D coordinates of vertexes.

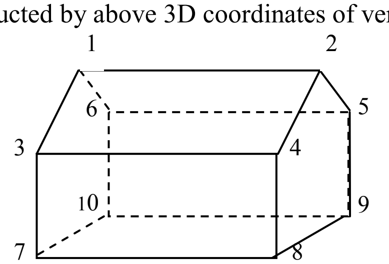


Figure 7. Building model of slope top

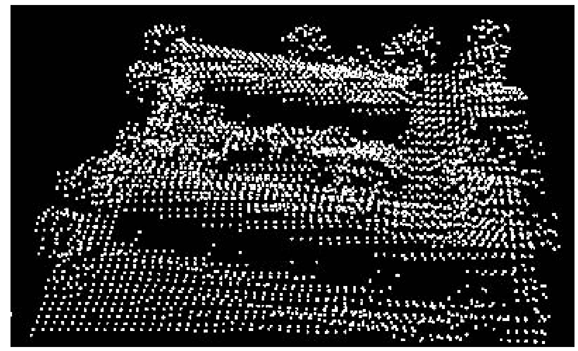
3. Tests and results analysis

The LIDAR point cloud data in this test is come from ISPRS opening data. This data is obtained with Optech ALTM1210 LIDAR system. It can retrieve the first echo, the last echo and reflected intensity from a given pulse. The average point density is about 0.67 points/m^2. The test region is comprised with some sloped-top buildings and sparse vegetation. ASCII data of LIDAR point cloud is as figure 8(a) and 3D figure is as figure 8(b).

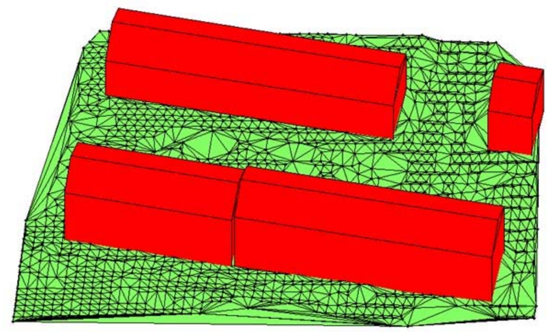
In order to reconstruct the building, LIDAR point cloud of building should be extracted from original irregular distributed discrete LIDAR point cloud. There are many filtering algorithms on LIDAR point cloud now. In this paper, TIN Filtering algorithm and Planar-fitting filtering algorithm are used to extract building LIDAR point cloud using the hierarchical filtering strategy [8][9]. Then 3D model of building is reconstructed using the above building reconstructing method. The result of 3D building model is as figure 8(c).

X	Y	Z	Intensity	X	Y	Z	Intensity
513054.59	5404020.31	336.49	53	513054.59	5404020.31	336.47	53
513054.63	5404021.79	336.43	147	513054.64	5404021.79	336.37	147
513054.67	5404023.28	336.36	71	513054.68	5404023.28	336.27	71
513054.71	5404024.67	336.30	91	513054.71	5404024.67	336.28	91
513054.75	5404026.25	336.22	126	513054.75	5404026.25	336.14	126
513054.79	5404027.64	336.14	143	513054.79	5404027.64	336.13	143
513054.83	5404029.13	336.07	155	513054.83	5404029.13	336.06	155
513054.87	5404030.62	335.99	148	513054.87	5404030.62	335.93	148
513054.91	5404032.10	335.91	144	513054.91	5404032.10	335.90	144
513054.95	5404033.59	335.84	173	513054.95	5404033.59	335.81	173
513054.98	5404034.98	335.80	157	513054.98	5404034.98	335.77	157
513055.02	5404036.47	335.76	348	513055.02	5404036.47	335.75	348
513055.06	5404037.86	335.67	110	513055.06	5404037.86	335.60	110
513055.10	5404039.45	335.68	145	513055.10	5404039.45	335.69	145
513054.99	5404040.84	339.60	51	513054.99	5404040.84	339.61	51
513055.02	5404042.32	339.77	130	513055.02	5404042.32	339.72	130
513055.08	5404043.72	338.91	162	513055.08	5404043.72	338.94	162
513055.25	5404045.41	335.45	45	513055.25	5404045.42	335.40	45
513055.29	5404046.81	335.45	45	513055.29	5404046.81	335.35	45
513055.32	5404048.30	335.42	43	513055.32	5404048.30	335.41	43

(a) ASCII data of LIDAR point cloud



(b) 3D figure of LIDAR point cloud



(c) 3D building model

Figure 8. Experiment data and result

4. Conclusions

The method of reconstructing building model in this paper can reconstruct rapidly automatically the simple regular building from LIDAR point cloud. This method considers adequately the spatial distributing structure of LIDAR point cloud. But complicated building need be researched further.

5. Acknowledgements

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