A Novel Method for Extracting Building from LIDAR Data----------Fc-S method

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ABSTRACT:

Automated techniques and tools for data acquisition of building are urgently needed because building information is extremely important for many applications such as urban planning, telecommunication, or environment monitoring etc. For the traditional manually building extraction from raw imagery is highly labor-intensive, time-consuming and very expensive, the generation of Three-dimensional building models from point clouds provided by airborne laser scanning, also known as LIDAR (Light Detection And Ranging), is gaining importance. Several methods have been presented for building extraction from LIDAR data during last decades. Based on data source involved, those methods can be divided into two classes; the one is only using LIDAR data and general knowledge about buildings, geometric characteristics such as size, height and shape information to separate buildings from other objects. Another is using LIDAR data fashioned another source data, such as aerial imagery, multispectral images, and so on, to extract building. For the acquisition of multi-source data and the fusion of them still have some difficulties, more researchers pay attention to the former class. This article presented a novel method for extracting building solely based on LIDAR data. For the proposed method consists mainly of two processes: filtering and segment, and in the first process, we used the properties of contours of digital surface models to distinguish the cloud of LIDAR points into on-terrain points and off-terrain points which is different from previous filtering method such as mathematical morphological filter, we named this method as Fc-S method. The main purpose of filtering process in Fc-S method is to generate DTM from LIDAR data. There are four steps: Firstly, digital surface model is generated from original LIDAR point data by a nearest neighbor interpolation method which can preserve the sharp difference between buildings and their surrounding ground. Secondly, contours are derived from digital surface models and are separated into on-terrain contours and off-terrain contours according to some properties of contours, including its closing, distance from the starting point to the last one, length of contour. Thirdly, an initial DTM is generated by interpolating on-terrain contours and refined by iterative method. And lastly, the normalized digital surface models, which can describe those objects(buildings, trees, etc), is generated after the ground information and low objects, e.g. cars, are removed by the height difference between DSM and DTM. To ensure there are no on-terrain points in the normalized digital surface models, the edge information is considered. Those areas with less edge information are delete because building area should has more edge information. Edge information can be easily obtained by sobel edge extraction method. In the second process, the main purpose is to distinguish buildings from vegetation. Because we extract buildings solely from DSM, the criteria must be geometric ones. Based on general knowledge about buildings and vegetation, we try to use size and shape characteristics to achieve this purpose. In the previous segment methods, the size threshold usually is used firstly to remove some smaller objects such as single trees. Thus a tough problem is left: the larger vegetation area or vegetation mixed with buildings cannot be removed using size criterion. In our method, we try to use shape information to reduce the size of large vegetation or separate vegetation from buildings before using size threshold. Observing the building and the vegetation, we can discover a fact that the shape of their top is very different; the one is roughly smooth whether its roof is lever or oblique, and the one is rather undulate. So we select quadratic gradient parameter to distinguish them. After deleting the points which quadratic gradient is bigger than the threshold, the vegetation area remaining become smaller and can be removed by size threshold almost. At last, the fine building is extracted by iteration technique. The article describe the algorithms involved, giving examples for a test site in Fairfield, and the extracted building by the proposed method are evaluated by comparing with the high-resolution aerial photograph acquired in the same area. The results show that the proposed method can extract building relatively accurate in the region with undulatory surface and even can extract building which is adjacent to vegetation.

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1. INTRODUCTION

Application as city planning and environmental investigation is crying for acquiring and updating 3D city, especially the building, information[1]. Traditional 3D building information was in general manually acquired from stereopair, which took much time, manpower and money. So, many scholars have being endeavored in researching automatic or self-automatic extraction of building and gained much for the past 20 years[2].

During the last few years, LIDAR, direct acquiring 3D ground information, has become a very attractive alternative of traditional technique for its high accuracy and lower cost. According to different data source, there are basically two types of LIDAR. One is incorporating LIDAR with the building's geometry [1, 3-6] or directly depending on the layer feedback signal [7] to extract buildings. Among which, sole application of signal is still somewhat difficult while that incorporating with buildings geometry is easier. The other way is combining the LIDAR data and other data [8~10], such as aerial image and multispectral images, to extract buildings. But, just because of independently acquiring of different data, it is a little difficult either to match them and hard to recognize the borders so as to make it somehow difficult in application.

A typical step of combining geometry features to extract building is[5], firstly to filter the DTM from LIDAR data, then divide the DSM data into ground points and non-ground points(including vegetation and building) by height difference, finally use the segmentation method to extract buildings away from vegetation in non-ground points group by some geometric parameter as area threshold, gradient and surface undulation. Although this filter-segment method having achieved much in real application, the existing filtering methods, for instance the morphological filtering [11-13] and surface prediction [14-15], also has obvious deficiency [13] which is especially hard to be applied for the undulate area. No mater how to select the segment parameter, there is a typical problem of mis-dividing vegetation and buildings into a same classification for those undulate regions with higher vegetation or vegetation much close to building so as to affect the segmenting accuracy.

Since not all city landforms are flat, for which the existing filter-segment method is hard to be applied, in this paper we discussed the filtering, selecting geometric parameter and the parameter sequence, and raised a new and high-accuracy filter-segment method to extract buildings in the undulate region. We have verified the new method by a testing area in Virginia. Buildings were extracted out and the aerial photographs were used to evaluate the result.

2. EXTRACTING BUIDINGS BY PROPOSED METHOD

2.1 Filtering

The original LIDAR cloud data is discrete and irregular, which needs effectively post-processing. It is firstly to classify effectively and exactly the ground points from non-ground points, which we called filtering.

1）Extracting DTM

In order to extract exact DTM in fluctuant regions, this paper proposed a new filtering method called contour-based surface estimation. For such a truth that vegetation and building points are much higher than the ground points around them in some areas, and its contour lines (hereinafter referred to as Object Counter Line, OCL) are obviously close (1 and 2 in Fig.1), while contour line formed by ground points (hereinafter referred to as Ground Counter Line, GCL) are always unclose (3 in Fig.1). Thus we can easily differentiate OCL from GCL according to their closing status. However, the closed OCL at image edge is easy to be manually cut off while cutting images (4 in Fig.1). In this case, we can use the parameter as the distance from start to end of the contour line and the curve length to distinguish them.

From the already out extracted GCL, we can get DTM which is not exact enough at this stage. It is mainly because few GCLs of downfold and hill were also removed while judging the closing of contour lines thus leads to the phenomena of hill cutting or downfold refilling in DTM. To resume the ground points, we can use the iterative approaching method to refine it as follows:

3. Take the DTM that interpolated from the GCL as the initial DTM,
4. Compare the elevation between DSM points and the initial DTM, take any DSM with the point elevation difference less than the threshold Δh_1(e.g. Δh_1=0.1m) as a new DTM data; contrarily the new DTM of this point shall be set as blank,
5. Count the points increment (Δn) with elevation difference less than the threshold, if Δn less than 100, interpolate those points without data in new DTM from all the points with data, get the final DTM and output. Otherwise execute the next step,
6. Interpolate those points without data in new DTM from all the points with data, and replace the initial DTM by the new DTM, return （2）.

2) Normalized DSM

So-called normalized DSM is actually DSM-DTM. Since buildings are higher than ground, if we set a elevation difference threshold Δh_2 (e.g. a general Δh_2=2.5m), using this we can remove the lower objects as ground points and cars and get a initial building segmentation surface including vegetation information but excluding ground information.

Because it is impossible to get a completely accurate DTM extraction, the initial building segmentation surface gained only by elevation difference contains possibly some ground points, moreover, the geometrical parameter (e.g. acreage and quadratic gradient) of those points is quite similar to those of the building roof, which is hard to be removed in the following process hence to affect the precision of extracting buildings. Necessary measures have to be adopted to remove them. Considering the elevation of buildings and ground have the following features: building surface is relative regular but the elevation difference at the edge changes evidently with strong
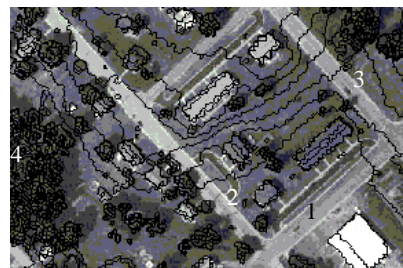

Fig.1 Contoured aerial photograph

edge information, however the elevation difference of ground is continuous without clear edge, meaning weak edge information, therefore, this paper selected edge information to refine the initial segmentation surface. First of all, the standard edge extracting method (e.g. Sobel method) was adopted to extract the edge of DSM, afterwards overlaid the edge image and the initial segmentation surface of buildings, and counted the total edge points of each overlaid segment at last. If the total edge points are less than the preset threshold n (e.g. n=10, determined by test), this segment is asserted as ground and removed from the initial building segmentation surface.

2.2 Segmentation

The purpose of segmentation is removing the vegetation and preserving building information. The existing methods usually use area threshold to remove small and separated vegetation, then based on the gradient or extent of surface undulation to remove those larger or building-closed vegetation[5]. Because vegetation almost grows together or near building, there is little small and separated vegetation. You may face two problems when adopt the existing segmentation sequence. One is the area threshold method can only remove small quantity of vegetation, the other is using gradient and the extent of surface undulation can not remove vegetation completely. For this, this paper proposed a different method of changing segmentation sequence as, firstly using gradient to remove vegetation or to separate vegetation from building, then using area threshold to remove the rest vegetation, finally processing segmentation result by neighbor iterative approaching to resume the removed edge information.

1) Gradient segmentation

From geometrical points, the roof shape of building and vegetation is completely different, that of building is usually plane or bevel but of vegetation is normally flexural. If not considering noise, the second derivative value of each point on building roof except for edge should be zero while that of point on vegetation surface is not zero. Moreover, either of vegetation or building edge, the second derivative value is very big. Therefore, we can use second derivative value to remove vegetation or separate vegetation from building. In processing of digital images, gradient is usually applied to replace derivative with the quadratic gradient being defined as follows:

$$\nabla^2 f = \left|\frac{\partial^2 f}{\partial x^2}\right| + \left|\frac{\partial^2 f}{\partial y^2}\right| = \left|\frac{\nabla^2 f}{\partial x^2}\right| + \left|\frac{\nabla^2 f}{\partial y^2}\right|$$

Taking noise into account, we almost choose a smaller but non-zero value of quadratic gradient threshold, such as 0.03.

2）Area Segmentation

Because the quadratic gradient of most vegetation surface is big, after gradient segmenting, most vegetation information was removed leaving only a little but building information was

better preserved. In this case, we can use area threshold to remove the residual vegetation information.

3) Refining buildings

As the building roof is not smooth enough, and the quadratic gradient is bigger at the edge, so, gradient segmenting will result in some absence on building roof or mis-removing edge information, which requires further refining. The absence can be refilled by local filling method of morphology and neighbor iterative method can be used to resume the edge information. The steps are,

(1) Adopting the existing graph traversal method to judge neighbor of all points on the building segmentation,

(2) Neighbor judgment: Comparing the absolute elevation difference Δh between the point and its eight neighboring points not in the segment. If Δh is less than the elevation difference threshold (such as Δh_3=0.6m), it shall be added into the segment. The elevation difference threshold is equal to grid cellsize, and its selection was based on the assumption of the max. building roof slope is 45°.

(3) Count the increased points after graph traversal, if it is less than the assumed threshold (such as 10), then terminate iterating otherwise return to (1).

3. TEST AND RESULTS

3.1 Test data

The LIDAR data used in this paper is an aerial image covering about $1200\times420m^2$ obtained by Optech 1210 LIDAR system in October 2000, which represents a large area of $3065\times538m^2$ in Wytheville, Virginia, U.S.A. The data resolution is 0.6m. All algorithms following were executed by Matlab.

3.2 Results

Fig.2a shows the DSM generated by nearest distance interpolation with grid space of 0.6m. Fig.2b is the sectional view of DSM. The section lies on the red line in Fig.2a from which we can see fewer buildings but more vegetation at the left, and several big buildings and complex ground surface but less vegetation at the right. From the sectional view we can see that this region is undulate.

Fig.3a shows the DTM extracted by contour-line-based filtering method. Fig.3b is the sectional view of DTM with the same sectional position as that in Fig.2a. Comparing with the DSM, it is clear that most non-ground points as vegetation and building have been removed and have similar undulation, which indicates the DTM extracting is accurate. This filtering method can be applied on the undulate region.
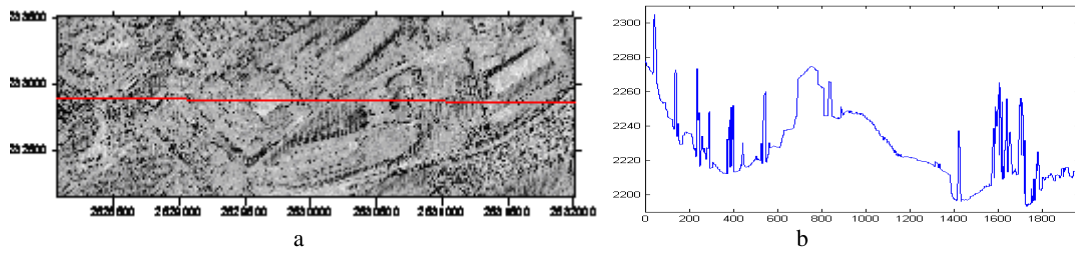
<div align="center">a   b</div>

<div align="center">Fig.2   Surface and section-view of DSM</div>

<div align="center">a   b</div>
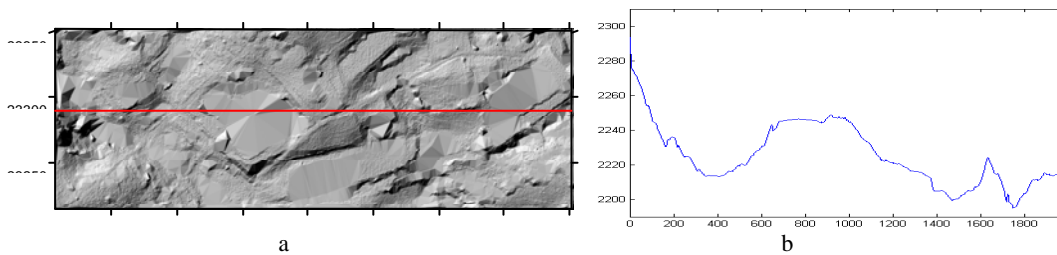
<div align="center">Fig.3   Surface and section-view of DTM</div>

Fig.4 is a binary image of initial segmented surface S_0 acquired by height difference. Fig.5 is a binary image of refined initial segmented surface S_0' being added with edge information. The white represents building while black represents other objects. Comparing Fig.4 with aerial image data (in Fig-9), we can see that the ground points are easy to be segmented from non-ground points through height difference threshold only few left (such as the red region in Fig.4). These points could be removed after adding edge information (Fig.5).
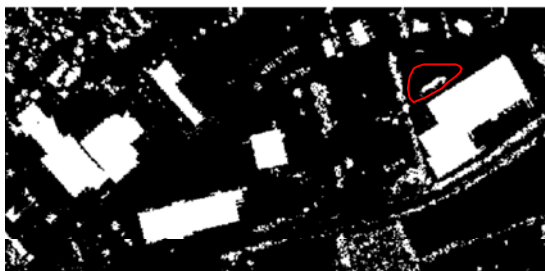

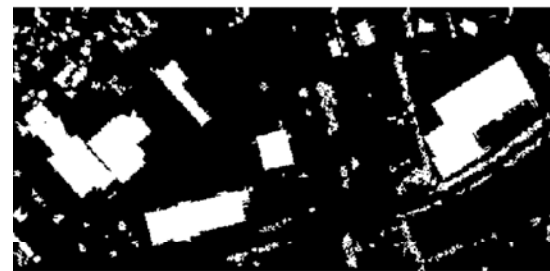<div align="center">Fig.4   Initial building segment S_0 Fig.5   Initial building segment S_0'</div>

Fig.6 and 7 are segmentation respectively by quadratic gradient and area. We set the quadratic gradient threshold 0.03 and area threshold 9m^2. In Fig.6, most vegetation was removed by quadratic gradient threshold except few vegetation points which were easily removed by area threshold. It shows that combinative applying the two parameters by this order can accurately segment building from vegetation. But there have some absence on building roof and incomplete edge information which needs further refining.
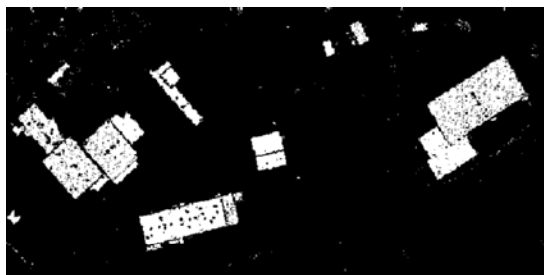

<div align="center">Fig.6. Building segment by quadratic gradient threshold   Fig.7. Building segment by area threshold</div>

Fig.8 is the accurate building information acquired by local refilling and iterative processing, in which a means binary image and b represents 3D model. From the two images we can see that, by neighbor iterative approaching, it is better to

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resume the building edge information and make its outline clearer and complete.

3.3 Analysis of Results

Because lacking of practical and accurate building layout map, we can not analyze the accuracy of segmentation results quantitatively but to qualitatively judging by eyes. Comparing the extracting results with aerial image data (Fig.9) we find that all the larger buildings in this area have been extracted out except for few parts of smaller ones, and no ground points and vegetation were mis-judged as buildings. The extracting accuracy is very high.
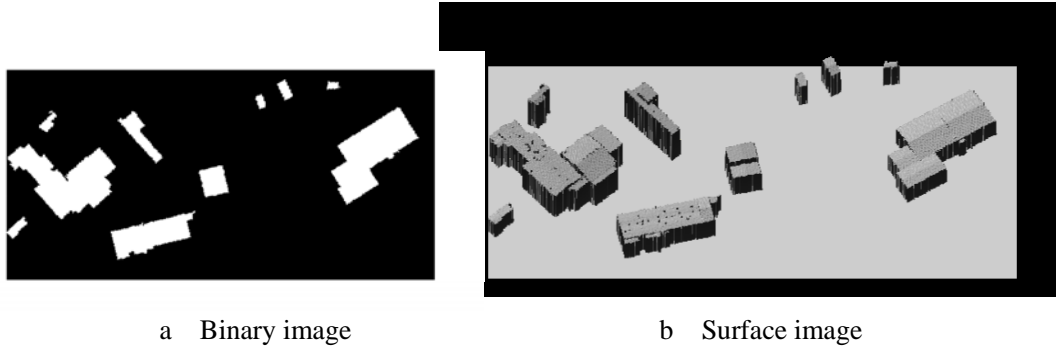

a　Binary image　　　　　　b　Surface image

Fig.8 Refined buildings

4.　CONCLUSIONS

This paper has improved the existing filter-segment method so to make it applicable even on the city buildings in undulatory regions. It is firstly, by means of a new contour-line-based surface prediction filtering method, to easily and quickly extract DTM and then normalize the DSM. During segmenting, it not only added some geometrical parameters, but also changed the segmentation sequence and extracted out more accurate building geometry by neighbor iterative approaching method. Test results show that although contour-line-based surface prediction filtering method is not absolutely accurate, yet it is very easy to do and can satisfy the majority requirements of extracting building in the undulatory region. Changing of segmentation sequence did make the segmentation parameter more effective. However, this method still has some

Fig.9　Aerial image

deficiency like it can not extract out some very small building information. Further improving and updating is still necessary.

REFERENCES

1.　Weidner U. An Approach To Building Extraction From Digital Surface Models(A). in Internatioanl Archives of Photogrammetry and Remote Sensing(C). Vienna. 1996. 31(B3): 924～929.

2.　Mayer H, Automatic object extraction from aerial imagery: a survey focusing on buildings[J]. Computer Vision and Image Understanding, 1999. 74(2):138-149.

3.　Gamba P ,Houshmand B, Digital Surface Models and Building Extraction: A Comparison of IFSAR and LIDAR Data[J]. IEEE Transactions on Geoscience and Remote Sensing, 2000. 38(4):1959-1968.

4.　Maas H-G. Two algorithms for extracting building models from raw laser altimetry data(A). in ISPRS Journal of Photogrammetry & Remote Sensing(C). 1999. 54(2/3): 153~163.

5.　Brunn A ,Weidner U. Extracting Buildings From Digital Surface Models(A). in Internatioanl Archives of Photogrammetry and Remote Sensing(C). 1997. 32.

6.　Rottensteiner F, Trinder J, Clode S. Data Acquisition for 3D City Models from LIDAR :Extracting Buildings and Roads(A). in Proceedings of the 25th IEEE International Geoscience And Remote Sensing Symposium (C). Seoul (South Korea). 2005: 521-524.

7.　LIU Jingnan,ZHANG Xiaohong, Classification of Laser Scanning Altimetry Data Using Laser Intensity[J]. Geomatics and Information Science of Wuhan University, 2005. 30(3):189-193.

8.　Rottensteiner F, et al. Building Dectection Using LIDAR Data and Multispectral Images(A). in Digital Image Computing: Techniques and Applications (C). Macquarie University, Sydney, Australia. 2003(2): 673-682.

9.　Rottensteiner F ,Jansa J. Automatic Extraction of Buildings From LIDAR Data and Aerial Images(A). in Internatioanl Archives of Photogrammetry and Remote Sensing(C). Ottawa 2002. 34(4): 569-574.

10.　Sohn G ,Dowman I, Data fusion of high-resolution satellite imagery and LiDAR data for automatic building extraction[J]. International Journal of Photogrammetry and Remote Sensing, 2007. 62(1):43-63.

11.　Kilian, Haala, Englich. Capture and evaluation of airborne laser scanner data(A). in International

Archives of Photogrammetry and Remote Sensing(C). Vienna. 1996. 31(B3): 383-388.

12. Lohmann P, Koch A, Schaeffer M. Approaches to the Filtering of Laser Scanner Data(A). in International Archives of Photogrammetry and Remote Sensing(C). Amsterdam. 2000. 33: 540-547.

13. Liang X X, Zhang J X, Li H T. An Adaptive Morphological Filter for LIDAR Data Filtering in Urban Area[J].Joural of Remote Sensing 2007. 11(2):276-281.

14. Masaharu ,Ohtsubo. A Filtering Method of Airborne Laser Scanner Data for Complex Terrain(A). in International Archives of Photogrammetry and Remote Sensing(C). Herold. 2002. 34(3B): 165-169.

15. Akel, Zilbeistein, Doytsher. Automatic DTM Extraction from Dense Raw LIDAR Data in Urban Areas (A). in Proceeding of FIG working week (C). Paris,France. 2003.