GENERATING BUILDING OUTLINES FROM TERRESTRIAL LASER SCANNING

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ABSTRACT:

Terrestrial laser scanned point cloud is a valuable data source for automatic building reconstruction. Detailed building facade structures from wall, roof, extrusion etc., can be recovered from the explicit three dimensional coordinates in the laser points. This paper presents our approach which generates building outlines semi-automatically from recognized building features. First, concave polygon outline are fitted from each feature segment directly; then outlines of occluded parts are generated from knowledge based assumptions; then the outline edges, where different features intersect, are corrected with plane intersecting; and finally different outlines are combined to make a solid polyhedron building model. The method is tested with a terrestrial laser point cloud of an urban area. Promising result models are acquired from this method.

1. INTRODUCTION

Nowadays, reconstructing 3D building models has become a quite popular research topic in both Digital Photogrammetry and Computer Vision. This is because of the increasing demand for 3D building models from several society fields such as urban planning, environment, transportation, and virtual tourism.

Due to the huge number of urban objects in a city and variety of shapes, manual reconstruction of a city is a rather time-consuming and expensive procedure (Brenner 2005). First, manual creation of building models is slow and can hardly be accelerated. A common manual reconstructing procedure starts with generating 2D building outlines from 2D GIS data, then elevating 2D outlines with certain height to a 3D rough model, then adding 3D structures by observing images and modeling with commercial 3D modeling packages such as 3DStudio Max, and finally the 3D model is textured by manually selecting certain parts from images. The speed of these steps is very dependent on building complexity and operator proficiency. Second, manual updating of city models can be very slow, not only because manual change detection for huge amount of data is slow, and also manual modeling of the changed zones is slow. Third, there is still lack of automated systems for referencing between different data sources (laser point cloud, imagery, 2D map). Integration of multiple data sources, for example between laser point cloud and 2D map, is required to maintain the topology correctness between models acquainted from different data set.

A lot of research has been done to automate the process of 3D building reconstruction. From the main data source used for the reconstruction, the proposed algorithms can be divided into imagery based approaches (Haala 1996, Baillar and Zisserman 1999, Surveg and Vosselman 2004, etc.) and laser altimetry approaches (Brenner 2000, Rottensteiner and Briese 2003, etc.). Digital imagery has been used to obtain three-dimensional information of the earth's surface for decades, but the bottleneck of image understanding is still a difficult problem to solve till now (Brenner 2005). But if the digital imagery is combined with other data sources such as digital map and laser scanned point clouds, the automation of reconstruction process

can be greatly increased. Laser altimetry records surface information with accurate and high dense 3D points, thus gives great potential for reliable 3D surface modeling. As a new technology born during 1990s, laser altimetry has been more and more used to acquire city model automatically.

Building reconstruction algorithms also differ significantly from different data acquisition aspects. Airborne systems, both imagery and laser scanning, are able to acquire urban scene rapidly, while most information is only available for roof, due to the oblique acquisition aspect. Therefore the building models generated from airborne approaches usually contain little structure on facades. However, nowadays aerial photography company (Pictometry) can take multiple oblique photos from cameras pointing different angles. Aerial imagery compiled from these oblique photos contains also façade information. Terrestrial systems, or close-range systems, provide much higher resolution and accuracy on building facades and low sloped roofs, but can hardly reach high or sloped roofs. Airborne systems are more used for bird view city models, and terrestrial systems are required when realistic virtual worlds with detailed façade structures are to be built. Figure 1 gives a comparison of the building models reconstructed from airborne laser points (left) and from terrestrial laser points (right).
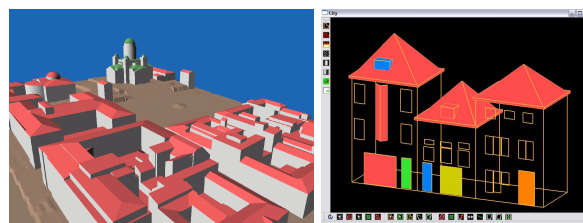

Figure 1. City models reconstructed from airborne laser points (left, available at http:// http://www.commission3.isprs.org/wg3) and terrestrial laser points (right, available from (Pu 2007))

This paper presents a new approach which generates building façade outlines automatically from terrestrial laser scanned point clouds. A bottom-up building reconstruction process based on terrestrial laser scanning is given in (Pu 2007), which

consists of the steps of feature extraction, modeling, refining and texturing. During the modeling step, outline polygons of recognized building features (wall, door, roof, dormer, window, extrusion) are generated by geometry fitting of each feature segment. Then the solid polyhedron model of a building is created by combining the fitted outline polygons. Outline generation is no doubt a vital step during the whole reconstruction process. In reality there are various building shapes, some of which can be very complex. Therefore the accuracy, level of detail of the final model, as well as the whole reconstruction speed, is pretty dependent on the efficiency of the outline generation algorithm.

In section 2 we first introduce the previous work of this research. The building outline generation algorithm is described in section 3. Section 4 evaluates the method with a test case. Some concluding remarks are drawn in the final section.

2. PREVIOUS WORK

An automatic approach to extract building façade features from TLS point cloud is presented in (Pu and Vosselman 2006). A brief introduction is give here for its strong relevance with building outline generation. The method first defines several important building features based on human knowledge about building facades. Assumptions, such as "walls are the large vertical regions on building facade", "roofs are the non-vertical regions on top of walls", "extrusions are larges regions on walls, and intersect walls", are defined and translated to features constraints. Then the TLS point cloud for a building facade is segmented with a surface growing algorithm (Vosselman et.al 2004), so that points belonging to the same planes are grouped together. Finally, each segment is compared with different building feature constraints to determine which feature this segment represents. Figure 2 shows the feature extraction results.

The above feature extraction method works fine for most facades features, except for windows. This is because the feature extraction algorithm mainly counts on a good segmentation. Window frames are usually small parts of wall, and sometimes windows are not covered with curtains. Hence terrestrial laser scanners can only retrieves few laser points for windows. Insufficient information leads to bad segmentation for windows, and in turn leads to bad window recognition. (Pu and Vosselman 2007) presents a window extraction method by detecting the holes on walls. The result is also illustrated in Figure 2.
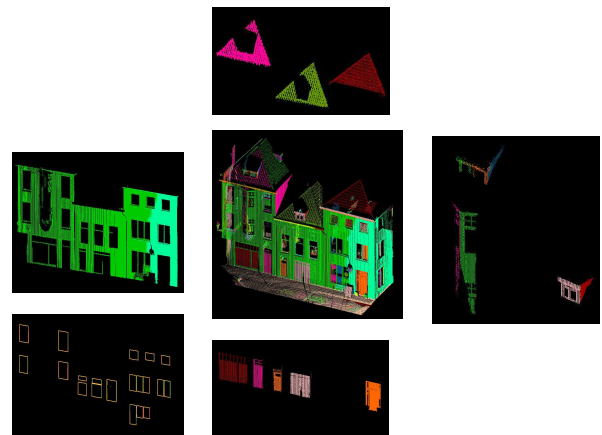

Figure 2. Automatic feature extraction from terrestrial laser scanning

3. OUTLINE GENERATION

In our approach, building outline generation can be seen as a process of polygon fitting plus knowledge-based occlusion assumption. Polygon fitting can be achieved either by least square method or Hough transformation. Occlusion assumption is required because direct polygon fitting might be inaccurate due to limit of data acquisition and segmentation errors.

Although outlines for different feature segments are separately generated, there are two necessary priority rules:
1. Roof and extrusion should be processed later than wall.
2. Dormer should be processed later than roof.

This is because generated outlines of roof, extrusion and dormers would be more accurate, if their supporting body's geometry has been determined.

3.1. Wall outline

We have adopted the least square method for wall outline generation. First, upper contour points (Figure 3 left top) are derived by selecting the highest points along a left- right scan line. Then we try to fit lines by growing the upper contour points from the most left point to right. When the current target point is too far away from current growing line, or this point would cause significant angle change in the current growing line, the algorithm sets this target point as a local ending, and calculates a line segment by least square fitting all the previous points. This procedure continues till all the points in the upper contour have been processed. There are a few parameters involved, such as minimum number of points in a line segment, maximum distance between point and line, maximum angle change caused by adding current point, etc. The fitted upper contour line before filling the gaps is shown in Figure 3 left bottom.

There are usually many structures in the bottom part of a wall façade, such as doors, large windows, and decorations. These structures sometimes make the wall's bottom outline quite complex. Assuming that the left and right side walls are vertical, their projection on the façade view would be two vertical line segments, or in other words, the wall's left and right outline would be two vertical line segments. From the wall's upper

contour points, we pick the most left (L) and most right (R) points. The left outline is then determined by point L and its projection point to ground level plane; and so is the right outline. Figure 3 right gives the final result.
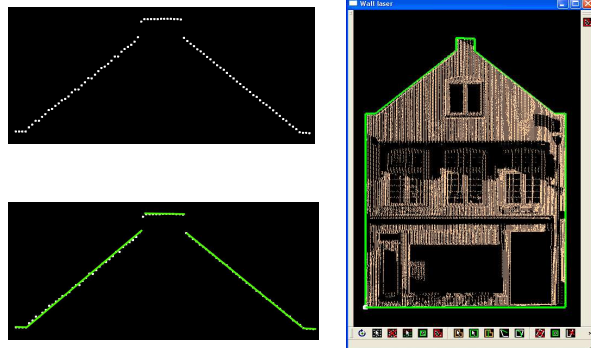

Figure 3. Generating wall outline

3.2. Extrusion outline

For an extrusion which has its main face parallel to a supporting wall, most laser points are available for the main face, while there are not many laser points for the side face patches. The façade outline for this extrusion type is generated with a concave polygon fitting algorithm, which is given as follows:
Generate the TIN for the façade points.
Delete long TIN edges, most of which are within the concave parts.
Derive the contour points. We start with the point with largest X coordinate, which is guaranteed one of the contour points. Then we find all the points which are connected with the starting point among the TIN. The second contour point is the just the first point among the connected points, which is in counter-clockwise order starting from three o'clock. This iteration continues, till the contour is closed.
Hough transformation is applied to the contour points. A line segment is determined if there is enough number of points required by the Hough transformation parameters, otherwise these points are treated as a gap, and a gap line segment is generated which is perpendicular to the dominant direction determined by the Hough transformation.
The concave polygon is combined by connecting all the line segments.

Usually some faces are occluded behind the main extrusion face. To generated outline for these hidden faces, we first project the vertices of outline to the supporting wall plane. Outlines for the occluded faces are bounded from the vertices of façade outlines and their projection points (see Figure 4 left).

For an extrusion which has two or more main faces, we couldn't just simply generate the outlines for different face and combine them. This is because errors in data acquisition and outline fitting will result in inconsistency for the edges between different extrusion surfaces, and the edges where extrusion surfaces and its supporting wall intersect. For this extrusion type, our approach is to first generate outlines separately for different extrusion faces using the concave polygon algorithm described above, and then find the parts of the outlines which are parallel and very close to the edges between extrusion faces. Then we intersect the extrusion faces, which results in an intersection line segment, and replace all the outline parts with intersection lines, so that the edges are consistent. Finally we do

the same intersection and replacement for the edges where extrusion intersects its supporting wall. Figure 4 right shows the result of outlining an extrusion with two main faces.

Figure 4. Generating extrusion outline
(Left: an extrusion with one façade face; right: an extrusion with two façade faces)

3.3. Roof outline

The generation of roof outline is similar as the approach for the extrusion outline. We also start with outline polygon fitting of a roof segment, and then replace the bottom boundary with the intersection line between roof plane and wall plane. One minor difference between generating of roof outline and extrusion outline is that we try to fit a rougher outline polygon of the roof segment, or in other words, we need fewer details on roof outline boundary. This is because we know that roofs have relatively simple shapes, and segmentation errors can easily cause discontinuity of the roof boundary. Figure 5 gives an example of the roof outline.
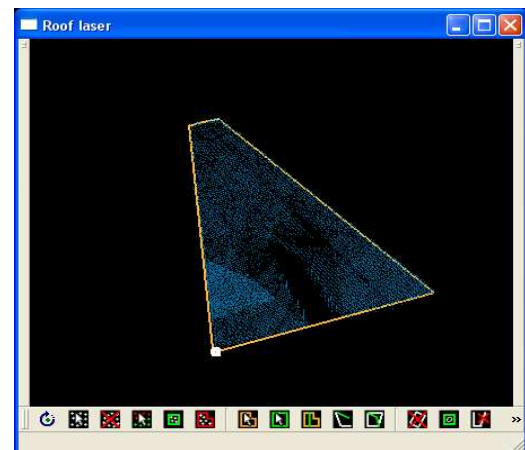

Figure 5. Generating roof outline

3.4. Window and door outline

Detection of windows as holes on walls is explained in (Pu and Vosselman 2007). From the knowledge that most window and doors have rectangle shape, we generate the window and door outline by simply fitting the laser point set to its minimum boundary rectangles. From the detected window boundary points, or the detected door feature segment, we first determine the most left and most right points, and then find the maximum and minimum z value. The minimum boundary rectangle is then

determined by combining the x, y values of the most left/right points, and the maximum/minimum z values. Intrusion side faces, which are the up, down, left, and right parts between the windows/doors and their supporting wall, are also generated by projecting outline vertices to the wall plane. An example of fitted window outline, as well as the intrusion faces, is shown in Figure 6.
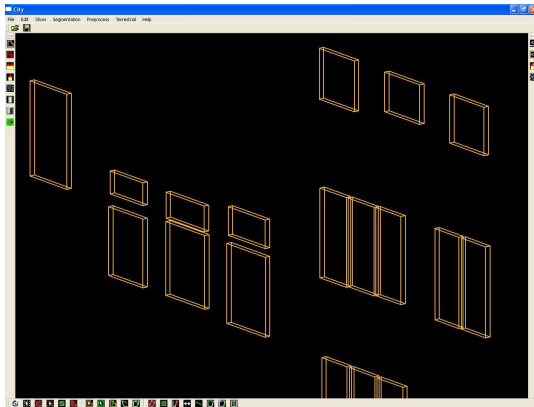

Figure 6. Generating window outline

3.5. Dormer outline

Similarly, the dormer's concave outline polygon is fitted first. Considering the dormer is a small part on the roof, there is usually not many laser points available. This will sometimes cause unreliable edges, if only outline polygon fitting is applied. We can revise the unreliability edges by making the almost vertical polygon edges vertical, and the almost horizontal edges horizontal. This is based on the observation of dormer shapes that the outline edges are usually vertical or horizontal. The next step is to find the roof segment of which this dormer is built. Finally we project the outline vertices of dormer façade to its supporting roof plane, to generate the rest of the dormer outline. The intersection edges replace the original outline polygon edges, same as we did for generating the extrusion outline and roof outline.

The dormer windows are also detected and their outlines are also generated. The detection of dormer window is by the same algorithm to detect wall windows (Pu and Vosselman 2007), if we treat the dormer façade as a "wall". The outlines for dormer windows are generated with the same strategy as normal windows: simply fitting rectangles. Figure 6 shows an example of dormer outline and dormer window outline.
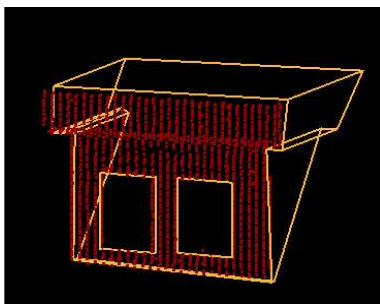

Figure 7. Generating dormer outline

4. METHOD EVALUATION

An outline generation algorithm should be able to handle the following problems:
- Correctness.
- Efficiency
- Level of detail

We have tested our methods with a terrestrial laser scanning dataset taken in a Dutch town: Vlaardingen. The test dataset contains 14 buildings with different shapes. The result is shown in Figure 8.
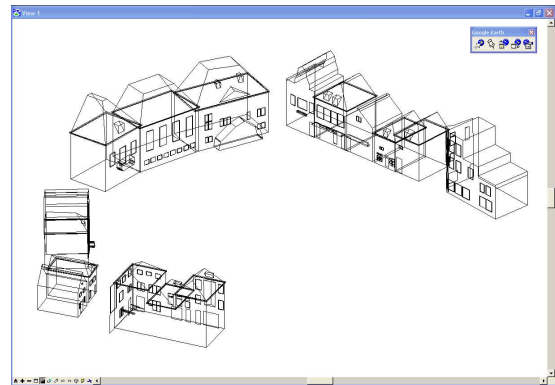

Figure 8. Automatic reconstructed Vlaardingen city model

The generated building outlines are compared with the original laser point cloud by visualizing in the same window. The point density of the point cloud is 400-600 points per square meter. So the average distance between points is 5 cm. For direct geometry fitted outlines, the distances between these outlines and the point clouds boundaries are between 0 to10 cm. However, the generated outlines are not reliable for the occluded parts, such as back side of walls and roofs. This is because outlines for occluded parts are generated according to assumptions, which could be rather different from reality. Furthermore, a lot of windows are not detected, due to the complexity of window shapes.

Generating the whole scene took approximately 80 minutes, including data preprocessing, segmentation, feature extraction and outline generation.

The generated building outlines achieve very high level of detail. Outlines for both large features, such as wall and roof, and small features, such as balcony, dormer window, advertisement board and awning, are all automatically generated. Rougher level of detail can be easily implemented by changing the detail factor, which is a parameter of the outline generation algorithm.

5. CONCLUDING REMARKS

In this paper we introduced an accurate and robust approach to automatically generate building outlines from terrestrial laser scanning. Outlines for different building features are generated separately, and the strategy differs as well based on knowledge about different features. The following conclusions are drawn from this research:

- The process of building outline generation can be automated from terrestrial laser point clouds, as shown throughout the paper.
- Building outlines generated from terrestrial laser points can achieve high level of detail. Both large structures (wall, extrusion, and roof) and tiny structures (window, door, and dormer) are detected and modeled.
- Outlines for occluded parts are not reliable, because no laser point is available, and the assumptions can be quite different from reality.
- There is still quite a lot of improvement required in this research. The next step of this research will be focused on:
- Validate and improve the current model with panoramic imagery.
- Extend the current method to handle more complex building shapes.
- Texture the building model with automatic selections from panoramic imagery.

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