

EXTRACTING WINDOWS FROM TERRESTRIAL LASER SCANNING

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ABSTRACT:

With the high density point clouds obtained with terrestrial laser scanning, detailed building facade structures, such as windows, can be recovered. There are usually only a few laser points available for windows, because window frames are small parts on walls, and window glass reflects no laser beam. Insufficient raw laser information makes it very difficult to recover reliable geometry of a window without human interaction. In this paper, we describe an approach to automatically extract windows from terrestrial point clouds. First, a segmentation process will group laser points in planar segments. Walls, doors and extrusions will be detected by applying feature constraints. Then, two detection strategies for windows are presented, depending on whether a window is covered with curtains or not. Windows which are not covered with curtains reflect no laser beam during the scanning process, and therefore cause holes on the wall segments. Laser points are available for windows which are covered with curtains, but they usually are not on the same plane as its wall and will therefore be grouped into other segments than wall segments. This again results in holes on wall segments. Holes on the wall are recognized by searching long edges from the TIN, generated for wall segments. After filtering out the holes caused by doors and extrusions, the remaining holes are believed to be caused by windows, and hence fitted to rectangles. The result from our approach is evaluated and discussed with examples of reconstructed building facades.

1. INTRODUCTION

Recently, the topic of building reconstruction has become a popular research of interest. This is because various applications, such as virtual tourism, urban planning, and cultural documentations, require realistic building models. Many algorithms and systems have been proposed towards the topic of building reconstruction after several years' research. According to the position of data acquisition, the reconstruction algorithms can be categorized to airborne based (Brenner 2005, Maas 2001, Suveg and Vosselman 2004) and terrestrial based (Haala et.al. 2006, Remondino and El-Hakim 2006).

Taking the airborne images or airborne laser points as primary data source, airborne reconstruction approaches are able to reconstruct building roofs well. However, it is very difficult to recover facade structures from airborne approaches, because the oblique acquisition aspect makes it very difficult to retrieve sufficient raw data for facades. Only a few pixels or laser points are available for facade is the usual case. In contrast, terrestrial approaches are able to provide abundant facade information. In particular, terrestrial laser scanning gives explicit 3D information, which enables the rapid and accurate capture of the geometry of a complex building facade; terrestrial laser scanning also provides high density point clouds, which gives enough raw data from which accurate and detailed 3D models can be obtained.

Many researchers are active in the field of extracting geometry features from laser point cloud. Edge based approaches (Gross and Thoennessen 2006, Sotooth 2006, Wani and Arabnia 2003) aim at detecting boundary points from point cloud, and then fit to lines. The surfaces based approaches use local surface

properties as a similarity measure, and merge together the points which are spatially close and have similar surface properties. These surfaces can be either planar surface (Dold and Brenner 2004, Schuster 2004), or curved surfaces such as cylinder, sphere and cone (Rabbani et.al. 2006).

With the extracted geometry features, we can extract higher level of features with semantic meanings. In (Pu and Vosselman 2006) the authors described an automatic method to extract building features from terrestrial laser scanning. The method first defines several important building features (walls, roofs, doors, extrusion) with building constraints. Then the terrestrial laser point cloud for a building facade is segmented, 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. It is possible to extend this approach, so that more detailed structures, such as windows, can be extracted. The recognized wall segments usually contain many holes, which mostly result from windows. A feature based method is employed to recognize door and extrusion segments. This can be used to discard holes caused by doors and extrusions. Combination of feature extraction and holes detection leads to a robust algorithm for extracting windows.

In section 2 we first give a brief introduction on building feature extraction. Section 3 describes how windows are extracted from holes on wall segments, and evaluates this approach. Some concluding remarks are given in section 4.

2. FEATURE EXTRACTION

2.1 Building feature extraction

An automatic method to extract building features has been demonstrated in a previous paper. Here we give a brief introduction because of its strong relevance to the window

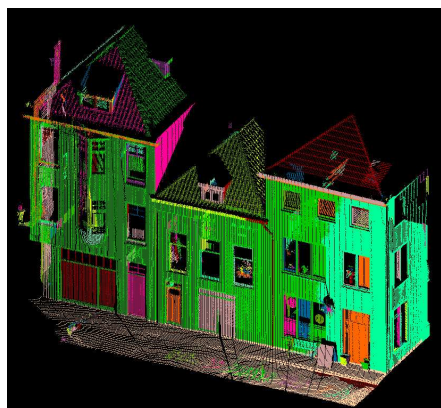
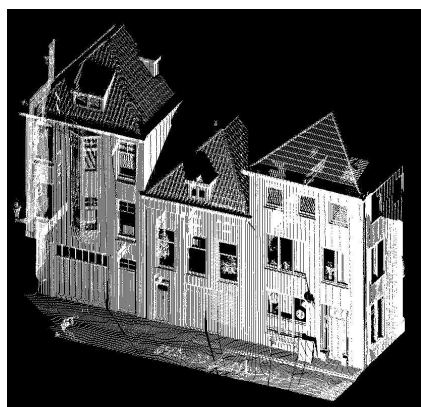


Figure 1. Left: terrestrial laser scanned building facade; right: segmentation result

	Size	Position	Direction	Topology
Wall	Segment(s) with larger area		Vertical	May intersect ground
Roof	Segment(s) with large area	Above wall	Not vertical	Intersects a wall
Door	Area within certain range	On the wall	Vertical	Intersects the ground
Extrusion		A little outside the wall/roof		

Table 1. Constraints for building features

seed surfaces which consist of a group of nearby points that fit well to a plane. Then seed surfaces are grown to their nearby points. Only the points within certain distance to the seed surface and with a perpendicular distance to the seed plane below some threshold can be added to the seed surface. Figure 1 shows a terrestrial laser scanned building facade, and its segmentation result.

- Feature constraints.** Some important building features (wall, roof, door, extrusion) are defined with feature constraints, related to size, position, direction and topology. All feature constraints are derived from human knowledge about building structures. For example, we know that a wall is a large vertical patch, and that a wall intersects the ground. The feature constraints for wall feature can be defined as: a large area (size) on a vertical plane (direction) with an intersection with the ground plane (topology). Table 1 gives the constraints for different features. Most of the tolerance values are independent of different data set because of the semantics. For example, the tolerance for how vertical can a wall be, is at least 80 degree with XOY plane. An extrusion must be at least 25 centimeters outside the wall plane. These tolerance values are set appropriate for most buildings.
- Feature extraction.** Convex hulls for all segments are computed first to approximate segments, because it is much easier to derive geometry properties (area, directions, etc.) from polygons than point sets. Next, the convex hull for each segment is checked with the feature

extraction approach. There are three main steps:

- Segmentation.** The planar surface growing algorithm by (Vosselman et.al. 2004) is adopted because it is suitable for segmenting planar surfaces. The planar surface growing algorithm first selects

constraints defined in Table 1, to determine which of the four features (wall, roof, door, and extrusion) the segment is. Figure 2 gives the recognition results. Sometimes a feature might be over-segmented, when the global threshold value is too strict. Therefore all attached feature segments are found and merged to combine a bigger feature segment. For example, the two wall segments in Figure 2 attach to each other, so they will be combined to a bigger wall segment.

2.2 Feature based window extraction

Theoretically, windows can also be extracted as a feature, with the similar method of extracting wall, door, roof, and extrusion. From knowledge about windows, a window feature can be defined as: area not too large (size), on the wall (position), on a vertical plane (direction). Figure 2 also gives the recognized window feature segments.

The result in Figure 2 is not satisfactory. Not all windows are recognized, and even recognized feature segments give incomplete and inaccurate geometry. The main reason for the failure is that the feature extraction algorithm mainly counts on a relatively good segmentation. Window frames are usually small parts of wall, so terrestrial laser scanning retrieves only a few laser points for windows. When a window is not covered with a curtain, the terrestrial laser beam will just penetrate the glass, and no laser points will be reflected in the window center. Insufficient information leads to bad segmentation for windows, and in turn leads to bad window recognition.

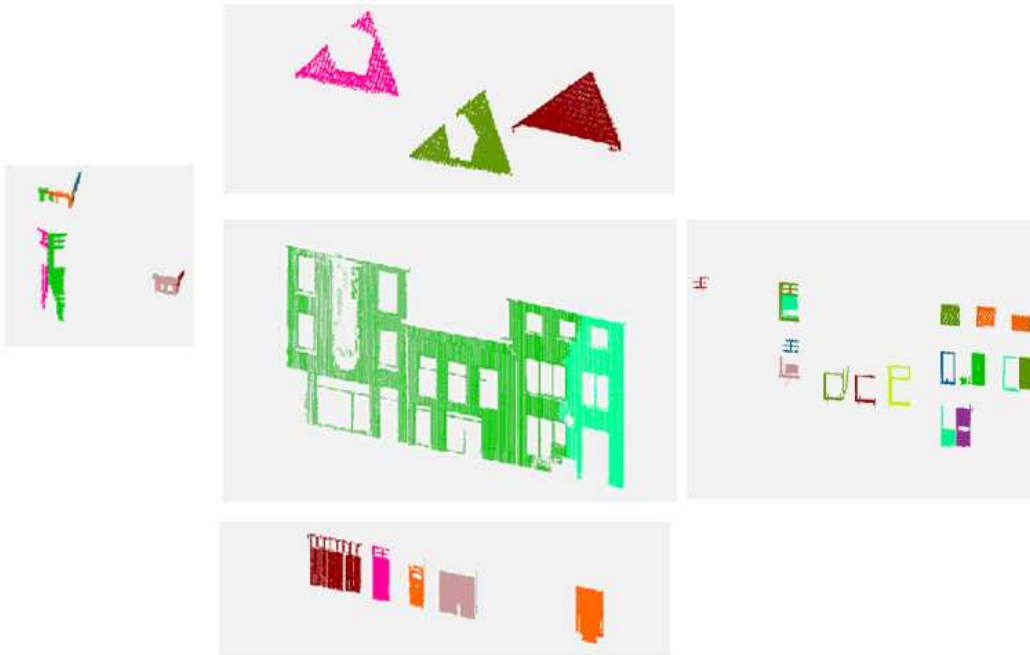


Figure 2. Feature recognition results (extrusion, roof, wall, door, window)

3. WINDOW EXTRACTION

3.1 Hole-based extraction method

The feature based approach is able to recognize large building features such as walls and roofs, but doesn't work well for windows, because of the lack of laser points on windows or window frames. Figure 2 illustrates the recognized wall feature segment, with some holes on it. It is obvious that these holes are caused by windows, doors and extrusions on the wall. An alternative method, which extracts windows from wall holes, is developed. The main steps are:

- **Triangulation.** A TIN for each wall segment is generated first, as shown in Figure 3.
- **Extracting boundary points.** Long TIN edges appear only at the outer boundary (wall outline) or inner boundary (holes) of a wall. Boundary points are just the end points for the TIN edges with long length. Figure 4a gives the extracted boundary points.
- **Clustering.** Points belonging to the same hole are grouped together. The clustering algorithm is given as follows:
 - 1) Choose a boundary point A which has no label value yet. Label A with an integer value: i.
 - 2) Finds all the long TIN edges which connect to this A. For all of these long edges, determine the other end points: B.
 - 3) Give B the same label value: i, if B is not labeled yet.
 - 4) Make B the new A, iterate step 2) to step 4), until no more unlabelled points can be found.
 - 5) Choose another unlabelled boundary point A, give it a label value: i+1, repeat step 2) to step 5), until all boundary points are labeled.

The different colors in Figure 4a, 4b, 4c, 4d are because different point clusters are colored with their labels.

- **Extracting holes.** Among a TIN mesh, the interior triangles always have three neighbor triangles, while the

triangles on the outer boundary have only one or two neighbor triangles. Therefore we first get all the triangles that have a boundary point as a vertex, and check these triangles about the number of their neighbor triangles. If three, then the checked triangle is an interior triangle, and the boundary point is an interior boundary (hole) point. Otherwise the boundary point is an outer boundary (wall outline) point. Figure 4b and 4c illustrates the two kinds of boundary points.

- **Removing holes caused by extrusion and door.** The holes in Figure 4d are compared with the extrusion and door segments in Figure 2. If a hole doesn't have overlap with any extrusion or door segment, it is considered a window hole. Figure 4d gives the result after this step.
- **Filtering.** Remove some noise holes which have irregular shapes, such as extremely long and narrow, or very small (longest edge shorter than 40 centimeter).
- **Fitting rectangles.** Assuming windows to be rectangular, the window holes are finally fitted to rectangles as shown in Figure 4e. This is done by choosing the most left point (L), most right point (R), top point (T) and bottom point (B) from each point cluster. The x, y coordinates of the left-bottom corner of the rectangle equal the x, y coordinates of point L, and the z coordinate equals the z coordinate of B. In this way the coordinates for the other three corners can also be determined. We are aware this method is only accurate for the following assumption:
 - The wall is vertical.
 - The left and right border of the window is vertical.
 - The window is rectangle.

The first two assumptions are true for most windows. If a window is not rectangle, then a minimum bounding rectangle will be fitted.



Figure 3. TIN of a building facade, with zooming in a hole corner

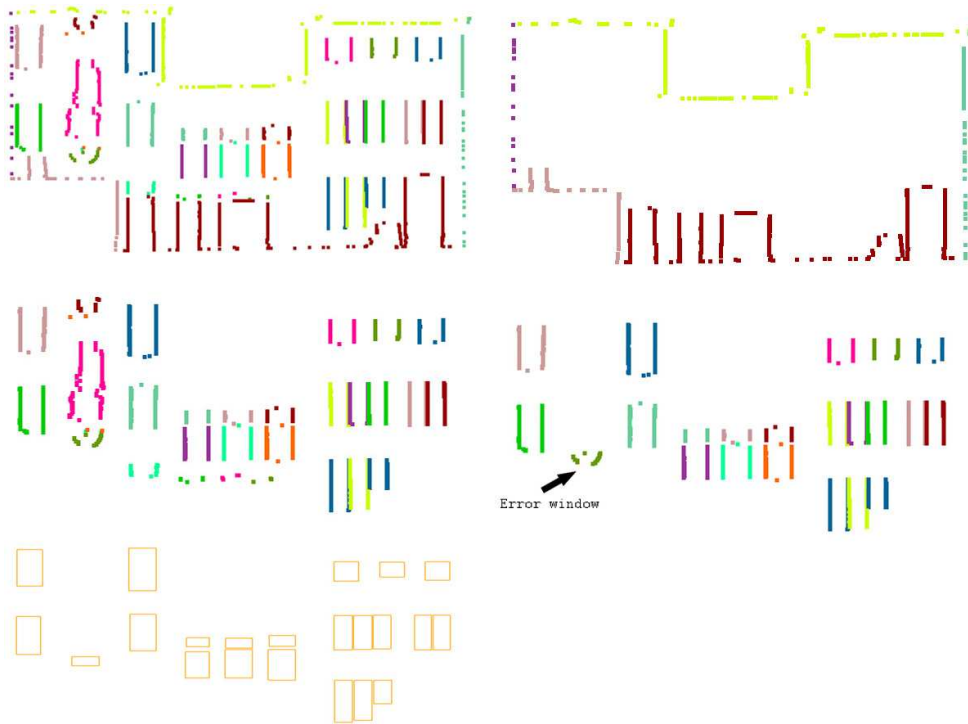


Figure 4. Extracting windows from wall holes (from left to right, top to down): (a) boundary points (b) outer boundary points (c) hole points (d) hole points after filtering (e) reconstructed windows by fitting points to rectangles

3.2 Method evaluation

The hole-based extraction method provides a robust approach to extract windows from terrestrial laser scanning. Our experiments on 12 building facades show that more than 90% of the windows can be accurately recognized. Figure 5 illustrates some experiment result. As the rule “windows are holes on walls” is valid for almost every building, we can expect the method achieving high accuracy also for other data sets. The algorithm only takes a few seconds, because no heavy computation is involved.

Sometimes a few windows are extracted which don't exist in reality, such as the indicated error window in Figure 4d. These error windows usually appear at places of a building extrusion. This is because the feature recognition algorithm still doesn't

work perfectly for extrusion. When an extrusion has a complex shape, e.g. the extrusion in Figure 2 has a curved patch on the bottom, not all segments of this extrusion can be recognized. The extrusion segments, which are not correctly recognized, still result in holes on wall segments. These extrusion holes are not removed when all the holes are compared with extrusion segments, so they remain and are treated as window holes. This kind of error windows seldom appears for doors, because doors have simple shapes and recognition of doors is very reliable.

Another unsolved issue is that the real holes on the wall are recognized as windows. For example, the building in Figure 5 left has 3 holes on the wall bottom. These holes satisfy all the definitions for windows in our approach: they are holes on the wall segments; they don't overlap with any door or extrusion

segments. Further research is required to distinguish the real holes and holes caused by windows, door and extrusions. The extracted windows can be smaller than reality, when there are obstacles on these windows. In Figure 6, the most right window on the ground floor is partly covered with some decorations. This is why the fitted rectangle is actually only the top half of this window. In Figure 7 the bigger window on the 1st floor is firstly extracted as three holes as a result of the frame decorations. The left and right holes are filtered out because



Figure 5. An example showing holes in the wall recognized as windows.



Figure 6. An example showing an extracted window is smaller than reality, as a result of obstacles on this window



Figure 7. Another example showing extracted window is smaller than reality

they have very narrow shape. Only the middle hole is fitted to rectangle. In the same façade, the second most right window on the ground floor is also smaller than reality, because some plants obstacle a big part of this window.

Furthermore, only windows on walls can be extracted so far. Extracting windows from dormers and extrusions are still need to be investigated.

4. CONCLUDING REMARKS

In this paper we have presented an automatic method to extract windows from terrestrial laser scanning. First, terrestrial laser points for a building facade are segmented and then wall segments are recognized by comparing each segment with feature constraints. A TIN of the wall segments is generated and both exterior boundary points and the hole boundary points are extracted from the end points of long edges in the TIN. After filtering out exterior boundary points, the hole points are further classified into window points, extrusion points and door points. This is done by comparing each hole with the recognized extrusion and door segments.

The hole-based window extraction method proved to be a very promising approach. In the future we will focus on how to add semantic knowledge to improve the extraction accuracy. Especially, knowledge about windows will be helpful to remove wrong windows which is caused by miss recognized extrusions, holes on walls, and other unpredictable cases. Next, considering terrestrial imagery provides confident edge information, we will explore the possibility to reconstruct more detailed building structure by fusing terrestrial laser points and terrestrial imagery.

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