Extraction of façades with window information from oblique view airborne laser scanning point clouds

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Abstract. Point clouds from multi-looking oblique view airborne laser scanning can provide information about building façades, not only for a single building but also for a larger urban area. This has the disadvantage of a reduced point density. To gain window information for building models from that data an approach has to be developed which can cope with a point cloud with low resolution (around 10 points/m^2). In the procedure proposed here the point cloud is segmented to receive vertical planes. Then points behind these planes (here called: indoor points) are used to detect window positions. These positions are used as input information for the reconstruction of rectangular windows from holes in the façade plane points. A regulation of the window outlines of the same rows and columns is performed. The quality of the results is dependent on the regularity of the window arrangement.

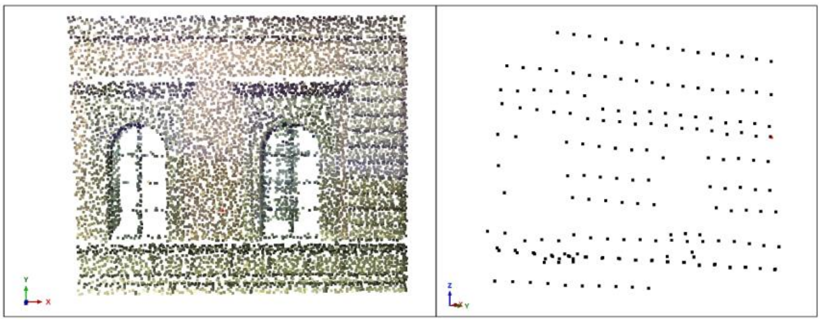
1. Introduction

Airborne laser scanners are not only able to look in the “classical” direction vertical to the ground (nadir) but also in an oblique direction. This can be used to obtain information in an urban environment concerning the façades of buildings, since multi-looking oblique view airborne laser scanning (ALS) data can provide point clouds with nearly complete 3D coverage of the sensed scene. Nadir looking ALS, instead, provides only few points on the façades, what limits their representation on planar structures (Haala and Kada 2010). In this paper an approach is introduced which is developed to gain window information automatically from oblique view ALS, aiming at building reconstruction with modelled roofs and façades or at the enrichment of existing city models with façade details.

Apart from a more realistic visualization the position of windows at buildings are of interest for example for thermal inspection. In this case the windows areas are no information areas, since the glass reflects the temperature of the surrounding, and need to be excluded. Known window positions can also be used to derive semantic information like the number of floors of a building.

An overview on automatic reconstruction techniques for building models from images as well as from laser scanning point clouds is given by Haala and Kada 2010, including many approaches for the automatic reconstruction of polyhedral models with roof structures (e.g. Rottensteiner et al. 2005). A recent approach for the reconstruction of roofs with arbitrary shape, based on level sets, is introduced by Kim and Shan 2011. A lot of approaches are based on the detection of planar patches, so the detection of planar structures in laser scanning point cloud is investigated by a lot of authors. For example Tarsha-Kurdi et al. 2007 compare Hough-Transform and an adapted RANSAC approach, which are both common methods. An overview on the topic of the recognition of structure from laser point clouds is given by Vosselman et al. 2004.

We try to reconstruct windows from an oblique view ALS point cloud, which point density is rather sparse as can be seen in Figure 1, where it is compared to a data set from terrestrial laser scanning (TLS). Approaches for the reconstruction of buildings from such dense point clouds are presented by Pu and Vosselman 2009 or Boulaassal et al. 2009. In both cases windows are detected by searching for long triangles in a TIN. Wang et al. 2011 introduce an approach to detect windows from mobile LiDAR. Window edge points are identified by the absence of neighbouring points in vertical or horizontal direction. Window reconstruction with image data is performed e.g. by Reznik and Mayer 2008 using ground view images or Meixner and Leberl 2010 using aerial photography. In the context of Building Information Models reconstruction techniques for laser point clouds are discussed by Tang et al. 2010.



a) b)

Figure 1: Comparison of a dense point cloud (~200 points/m^2) from terrestrial laser scanning (a) with a sparse point cloud (~5-10 points/m^2) from oblique view airborne laser scanning (b).

2. Approach

Holes (regions with no points at a façade) can occur also randomly and not only at window areas in an oblique view ALS point cloud. So, a strategy is chosen for the detection of windows, which is based on the assumption that in most cases there are some points which are lying behind the surface of a façade. This is because the laser pulse penetrates glass and is reflected inside the building. Here these reflections are called indoor points, an example for them is shown in Figure 2. For the reconstruction step the indoor points are removed. The holes in the façade can now be used in connection with the derived window positions.

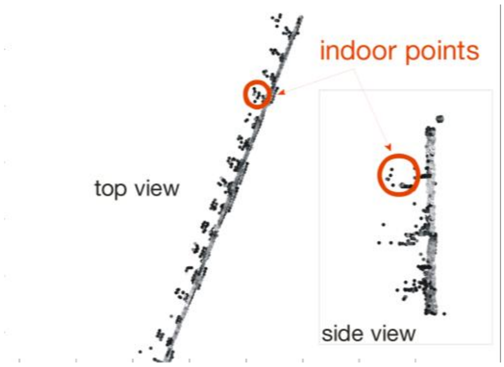


Figure 2: Example for indoor points of a single façade plane.

The following section describes the procedure in detail: First façade planes are detected using region growing in two successive steps (Section 2.1). After that windows are detected by processing the points, which are lying behind the detected façade planes (Section 2.2). Finally the windows are reconstructed based on the detected window positions. The final outline is determined by a summation of Rayleigh-Probability-Density-Functions (PDFs) (Section 2.3).

2.1 Façade Plane Detection

The detection of façade planes consists of a coarse and a fine processing step. In the coarse step vertical planes shall be detected, the fine step shall divide these planes into homogenous façade parts. First, normal vectors for all points are calculated by fitting a local plane to the points within a search radius *r*. For that the suitable functions of the Point Cloud Library (Rusu and Cousins 2011) are used. Points having normals which are not showing in a horizontal direction are excluded from further processing for the moment by applying the threshold φ_{thres}. The remaining points are segmented. Points of the set of *n* nearest neighbours of a single point are allocated to its segment if the angle between the normal vectors, projected into the horizontal plane, is smaller than the angle $\delta_{glo,thres}$, and the distance is smaller than $d_{glo,thres}$. A plane is fitted to the points of each segment in a least-square-sense. These planes are forced to be orthogonal by projecting the normal vector into the x-y-plane.

Now, every of the detected planes is processed by itself. They are divided into façade parts and points are extracted which are lying behind them. For that step all points from the complete point cloud lying within $\pm x_{bound}$ before or behind the detected planes are used. First the point cloud is segmented again but now the segmentation is based on a parameter which uses the horizontal distance d_{loc} between the points in façade normal direction. For every point a bounding box perpendicular to the normal direction with the size x_{loc} is used to get its neighbours ($x_{loc} < x_{bound}$). Points are fused to one segment if the distance d_{loc} is smaller than the threshold $d_{loc,thres}$. The problem is, if there is no clear jump between two planes, that there may remain connected façade parts (e.g. façade plane and the adjacent roof part). Because of this the best planes in one segment are selected by RANSAC. The parameter d_{ransac} is used for the decision if a point is an inlier. It has to be larger than $d_{loc,thres}$. Each plane found by RANSAC is used for window detection. The inliers are called façade points from now.

All mentioned parameters are visualized in Figure 3 and have to be adjusted based on the point density of the point cloud.

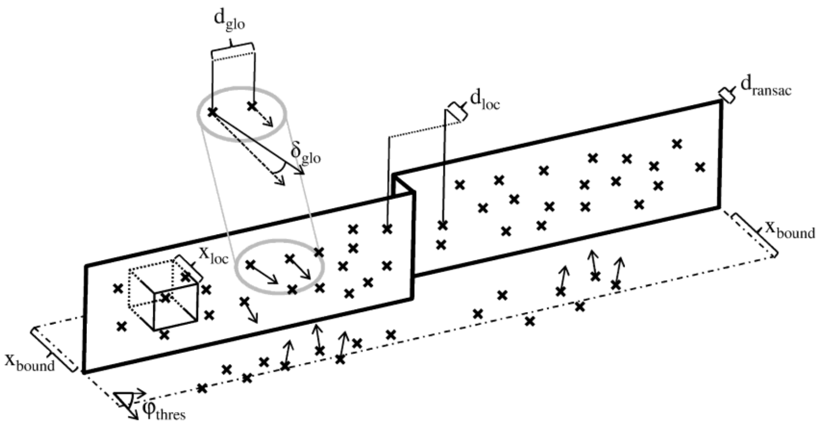


Figure 3: Parameters used for façade plane detection

2.2 Window Detection

For this step every façade is transformed into a façade coordinate system. For that the points are rotated so that the x-axis of the coordinate system is parallel to the normal of the façade plane. Now all points which are behind the façade point with the smallest x-coordinate are marked as indoor points. They are projected into the façade plane regarding the incidence angle of the laser φ_{inc}.

The indoor points are now used to determine the window position. From the indoor points a raster image is created. Every resolution cell is set to one if an indoor point exists and to zero otherwise. The image is oversampled and smoothed. The smoothing is performed by a cross-correlation with a horizontal and a vertical line mask to detect the window positions in the respective direction. Finally the values of each pixel in the image are summed up in vertical and horizontal direction, respectively. An example for this is shown in Figure 4. The local maxima in the resulting functions are the window positions. Assuming a regular arrangement a window is located at every possible combination of vertical and horizontal positions. The received window positions are used as seed points for the following reconstruction process.

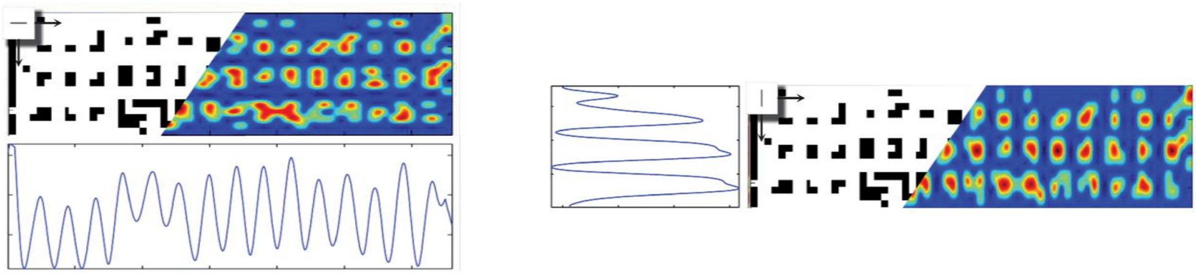


Figure 4: Oversampled and smoothed raster image and resulting functions after summation of pixel values in vertical and horizontal direction.

The window detection is explained in more detail in Tuttas and Stilla (2011) with the difference that no frequency is estimated for the appearance of the windows here.

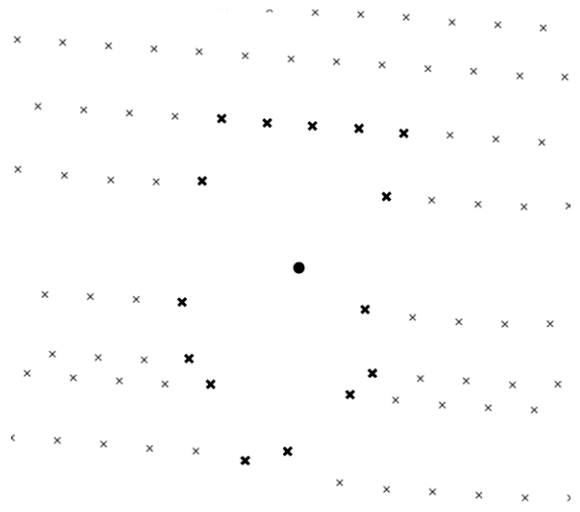
2.3 Window Reconstruction

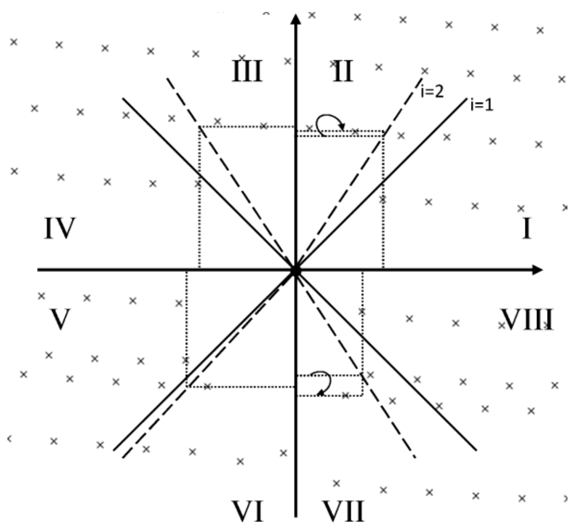
The resulting window positions are used to generate rectangular window outlines. First initial outlines are created from the window positions derived in the last step and the façade points. For every detected window position the largest rectangular area without points shall be found. Because of the sparse point cloud the window edges are not represented clearly in the point cloud (cf. Figure 5a). With respect to this circumstance, the following quadrant based algorithm is used to create the window outline. The principle of this algorithm is shown in Figure 5b. The space around the seed point is divided into eight sectors (I-VIII), whereby always two sectors are the upper and the lower part of one of the quadrants. The point closest to the seed point in y-direction, in the sectors II, III, VI and VII, sets the limits of the window in y-direction. The same holds for the other four sectors and the x-direction. In this way a corner point is created in every quadrant. Since windows are not square in general, the procedure is repeated iteratively. The corner point of the last step defines the direction of the new line which divides the quadrant. Then the corner points are determined in the same way, as long as their positions do not change anymore. From the resulting corner points the largest possible rectangle without a point inside is chosen as window outline (cf. Figure 5a).

Because of the low point density even a human observer can hardly determine the right window outline. So, the outlines of the previous steps are only hypothesis. The uncertainty of the edges shall be expressed with a Rayleigh-PDF (Equation 1):

$$y = \frac{x}{b^2} e^{\left(\frac{-x^2}{2b^2}\right)} \tag{1}$$

The cumulated density function at the position of the peak of this function has the value 0.4. Because of this it can be expressed, that it is more likely that the true outline lies closer to the seed point than the hypothesis. This is assumed since it is very probable that there are no laser points directly at the position of the window border. The PDF is calculated for every upper, lower, right and left edge of each window. The peak of the Rayleigh-Function is set to the position of the estimated edge. The factor *b* weights the function with the difference of the edge coordinates in adjacent sectors (I ↔VIII, II ↔ III, …). The larger the difference of the coordinates the larger is *b*. A larger *b* leads to a widened function, i.e. the original edge position is less secure.





a) b)

Figure 5: Window in a sparse point cloud with its surrounding points, the seed point from window detection (black circle) and the resulting rectangle (a). Graphical interpretation of the quadrant based approach for the reconstruction (b).

To derive the final window edges the squared Rayleigh-PDFs are summed up. This is done individually for the left, right, upper and lower edges. The local maxima in these functions are finally used as the best window edges. The maximum which is closest to the original position of an edge, defines its final position.

3. Experiments

3.1 Data

In Figure 6 our test dataset is shown, which consists of point clouds from four overflights over TU München with a helicopter. The acquisitions were made with an oblique view of around φ_{inc} = 45 degrees. The total amount of points is approximately 2.5 million. The co-registration was based on corresponding planes in the four single point clouds (Hebel and Stilla 2009).

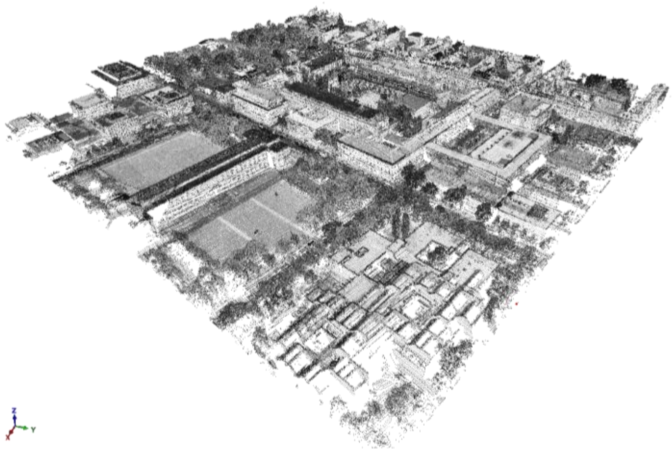


Figure 6: TUM test dataset with approx. 2.5 million points.

3.2 Results

In Figure 11 the overall result of our approach for the test dataset can be seen. The chosen parameters were x_{bound} = 5 m, x_{loc} = 2 m, $d_{loc,thres}$ = 5 cm and d_{ransac} = 20 cm . In Figure 7 to 9 the results for a single façade are depicted.

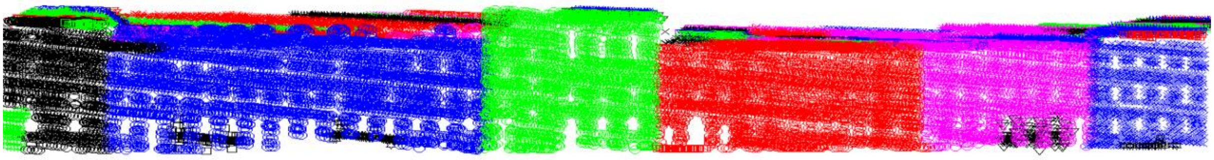


Figure 7: Example for a segmentation result using the horizontal distance in façade normal direction as parameter.

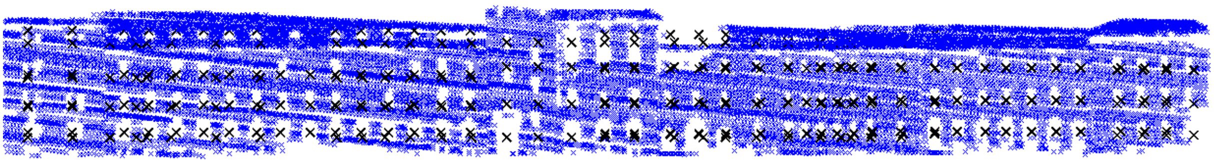


Figure 8: Detected windows for the façade shown in Figure 7.

Figure 9: Reconstructed windows from the detections shown in Figure 8.

In Figure 7 the façade parts after the segmentation with the parameter d_{loc} is shown. Figure 8 shows the detected window positions, which were used for the reconstruction process. The final result is shown in Figure 9. For this façade and for the façade shown in Figure 10 the amount of windows which were reconstructed at the position of a real window was calculated. The results can be seen in Table 1. This evaluation does not reflect the correctness of the geometry of the reconstruction. Because it is difficult to obtain or create ground truth data this has not been done yet, but it is clearly visible that there are some deficits. From the visual inspection it can be seen that the approach works better if more samples of one window type exist in one row or column of the façade.

Figure 10: Example for the reconstruction result of a single façade.

Table 1: Evaluation of the results shown in Figure 9 and 10 (the measure is "windows reconstructed at correct positions").

Façade	Windows reconstructed	Correct	Missed	False alarms
Figure 9	138	109	27	26
Figure 10	45	45	15	0

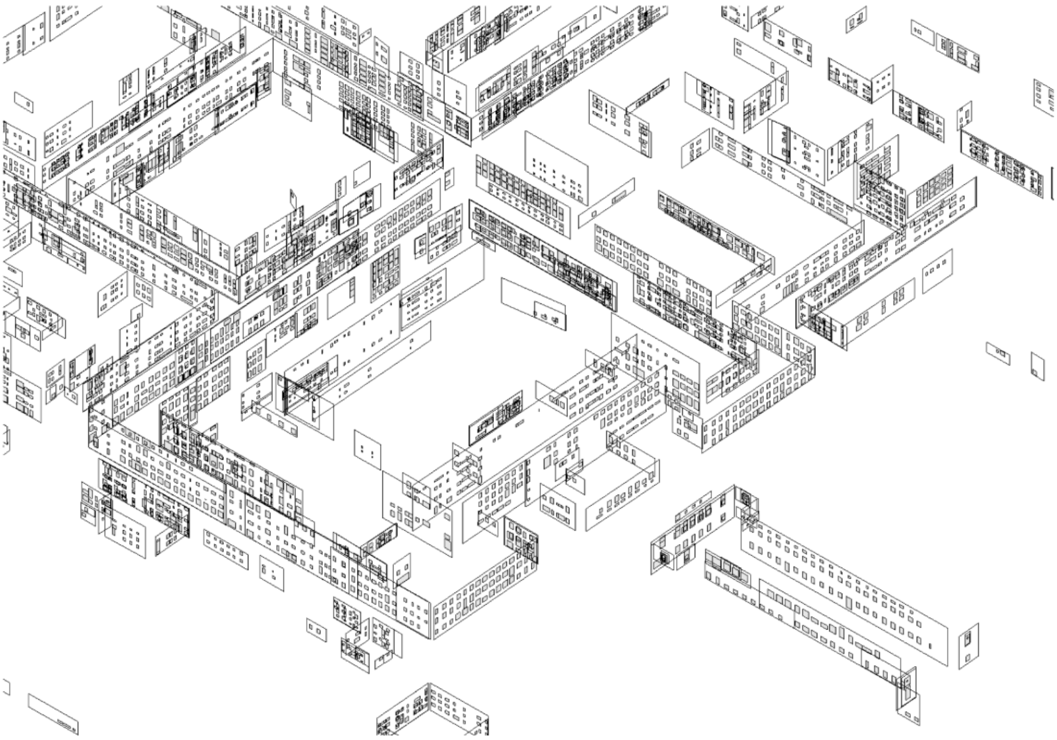


Figure 11: Overall result for the test data set shown in Figure 6.

4. Discussion and Conclusion

This paper shows an approach for the reconstruction of rectangular windows in a sparse point cloud. Other window shapes cannot be modelled, but it is also difficult or even impossible for human operators to clearly identify the true shape in this resolution class. Because of this and since most of the windows are normally rectangular, this assumption seems to be useful. It has been shown that the approach works for façades with a regular arrangement of windows. In other cases, as can be seen in Figure 11, it is possible that only a small part of the windows can be found and reconstructed. Problems occur e.g. because of façades with small windows (with missing indoor points) or glass façades, having no façade points. The evaluation for the whole test area can only be done manually and visually because of the missing ground truth data. The generation of such data is an important task, if a detailed evaluation shall be performed. Another drawback is that all façade intrusions and not only real windows are detected as windows. To overcome this problem, the usage of the intensity values or full waveform data could be a possible way in the future.

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