Automatic Building Facade Detection in Mobile Laser Scanner point Clouds

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Abstract: Mobile Laser Scanner (MLS) has been increasingly used in the modeling of building façade geometry as a means of fast capturing of point data in built-up areas. The processing of such data to extract building façade features automatically is a crucial step in the modeling schemes. This paper presents a segmentation strategy that can be used to segment the façade features in massive point clouds, obtained in MLS. First, object points are isolated from ground points based on the local height histogram analysis. Consequently, initial classification based on the surface roughness is carried out within the dominant facade clusters, obtained by the analysis of linearity of points in 2D space, to classify building points roughly. Each element of the facades such as window, door & wall, are then extracted as planar faces by adopting an Advanced Segmentation step. The planarity of segments is defined by using the RANSAC (Random Sample Consensus) plane fitting. The approach has been tested with MLS data sets, acquired by different systems and the results demonstrate that the method is functional for generating reliable building façade models.

1 Introduction

The impression of a 3D polyhedral building model can be enriched by introducing relevant façade features to the model. Because of that, techniques for an automatic reconstruction of building façades are of high importance. LiDAR data is frequently used for the reconstruction as it has a high automation potential. In this end, modern vehicle-based MLS is promising as it can collect accurate 3D geometry data of urban objects. The usefulness of MLS data for the extraction of urban features has for instance been demonstrated by (RUTZINGER et al., 2009). In general, the workflow of building façade modeling can be divided into three major steps: extraction of building façade points, recognition of building façade features (i.e. door, window, etc.) and model reconstruction based on a 3D topology. The first step is crucial as the subsequent steps directly rely on the result of the first step.

Normally, the geometry of most building facades can be described by a set of planar faces. Although many sophisticated approaches exist to detect planar surfaces (for instance RANSAC, 3D Hough transformation etc.), these methods may be cumbersome, if the algorithm has to deal with a huge amount of data (RUTZINGER et al., 2009; BOULAASSAl et al., 2007). Therefore, in this paper, we propose an improved segment based building façades extraction approach, which can be used to process massive data sets acquired in heterogeneous environments. The proposed method separates the building facades, from other objects, by analyzing their planarity and linearity. Initially, the entire point cloud is divided into individual building clusters in order to reduce the processing time and to detect most reliable and accurate planes of building facades.

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Afterwards, a roughness based planar segmentation method is utilized to extract façade features. Accordingly, misguidance due to object heterogeneity is reduced.

The overall structure of the paper is organized into five main sections. The first section introduces the rationale of the research. Section two presents a brief overview of existing 3D point cloud processing approaches which can be used for the segmentation of building façade features from other objects. In section three, the proposed method is discussed in detail. Experimental results and conclusions are discussed in section 4 and 5 respectively.

2 Related Work

A voxel based approach to derive planar faces from TLS data is presented by (DOUILLARD et al., 2010). In this method, the amount of data to be processed is reduced by converting original point clouds into a voxel space. Although it is helpful for efficient processing, the data conversion causes a great loss of spatial information as it aggregates irregular point clouds into a region. Alternatively, a KD-tree data structure is often used to work with original point data (for example PU & VOSSELMAN, 2009). Another method is presented in (HAMMOUDI et al., 2009) by combining the Hough Transform, the k-mean clustering algorithm and the RANSAC method. First, 3D points are projected onto a 2D grid space and then points in cells with high point density are considered as façade points. Afterwards, k-means clustering in Hough space is used to determine the exact numbers of facades within a cluster; 2D lines are then computed for each detected cluster. Finally, best fitted lines are extracted using the RANSAC and dominant façade planes are then extracted by intersecting 2D façade lines. (PU & VOSSELMAN, 2009) adopt the region growing concept on top of the 3D Hough Transform to extract planar facade features in TLS data. In this method, seed segments are detected by a Hough Transform and are extended by adding adjacent points if their distance to the plane is below than some threshold. Once there are no more points to be added for a particular segment, the next seed surface is selected and grown. (RUTZINGER et al., 2009 & 2011) apply the same segmentation method for the extraction of vertical building walls from MLS data. Their results confirm that this plane estimation method can be performed well with both TLS and MLS data. However, the Hough Transform may be very sensitive to the segmentation parameters (TARSHA-KURDI et al., 2007). Instead, RANSAC is increasingly used to segment planar faces. The determination of planar surfaces based on the RANSAC method is studied by (BOULAASSAL et al., 2007), where an adoption of RANSAC algorithm is used to improve the quality of plane detection. They assume that the best plane is the one containing the maximum number of points with low standard deviation. Thus, the extended way allows them to detect the best plane within a short time. Later on, (BOULAASSAL et al., 2008) points, relevant to the derived planes are removed and improved the detection performance further.

Our contribution to the research field of façade point extraction is to utilize synergetic properties of both 2D and 3D environment of point clouds to the processing workflow, which assists for gaining an efficient and reliable outcome.

3 Proposed Method

The whole process is structured hierarchically to minimize the amount of points to be processed. It consists of a sequence of three processing stages. First, the input data is classified as ground and non-ground points. Second, points which belong to the facades are identified and grouped as dominant building clusters. Third, each point cluster is segmented into planar surfaces. Each phase is described in detail in the following sections.

3.1 Ground Point Classification

In general, ground points can be defined by points residing on smooth non-vertical lowest surfaces. The method adopted in this paper is similar to the methods described by (MAAS et al., 2008) and (BELTON, 2010). First, the point cloud is partitioned into several 3D vertical columns (or volumetric cells) having a lateral dimension of $dx \times dy$. The Z-axis of each column is then split into several bins with a height dz. For each point, the corresponding column S_i, in which the point falls, is calculated, and the histogram bin corresponding to its z-value within the calculated column is incremented. Then, the elevation histogram for each column is computed. The histogram bin belonging to the lowest significant peak of the height histogram is selected as the bin corresponding to the ground, and the height of the bin is considered as the ground height of the corresponding column.

Nevertheless, there are some columns which don't contain ground points, so that the selected ground height from the height histogram are invalid. In this case, the ground height of the column could be interpolated from the heights of the neighboring columns. The column and any adjacent column, whose ground height is below a certain height difference, are then merged. Although the majority of non-ground points can be eliminated this way, some lowest part of the objects such as lower parts of building facades and poles may erroneously be labeled as the ground. A planar surface through the ground points is therefore estimated for each column and adjusted by adding or removing points determined as inliers or outliers respectively. These selected points can be segmented into continuous and smooth ground regions by applying a region growing method (fig. 1). However, as it is out of the goal of this paper, this is not discussed here in detailed.

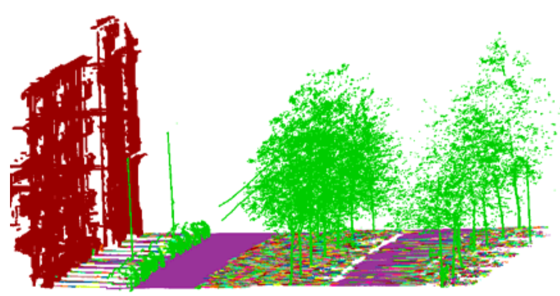

Fig. 1: Points classified as terrain, building and others; brown & green colors show the building facades & other objects points while magenta (smooth regions) and other colors represent the terrain

3.2 Clustering of Building Points

As the majority of building façades can be described by a set of planar surfaces, the point cloud should be segmented into planar faces to extract building façade features. Processing time may be considerable when extracting planar regions from massive large 3D point clouds. If the search

space can be reduced by delimiting the space into selected façade clusters (individual building point clusters) or by utilizing an efficient data reduction technique which doesn't loose important details such as 3D Alpha shape (RUTZINGER et al, 2011), processing difficulties may be solved. In our approach, we adopt the first case, as the point reduction would reduce the precision of subsequent façade modeling.
Our method is based on the assumption that a building can be described, in 2D space, by their lines representing projections of planes. Therefore, 2D projected data are taken at a defined height interval and possible lines, passing through the façade planes, are detected using a 2D Hough transformation given by (TARSHA-KURDI et al., 2007). Due to the co-planar arrangement of building facades, especially in built-up areas, a detected line is often referring to façade planes, belonging to more than one building. Thus, the most dominant line segment, from the detected line, is chosen by splitting the line into several line segments based on the gap between the consecutive points and a defined threshold. Simultaneously, points relevant to that line segment are removed from the Hough space in order to increase the detection performance. All other 3D points belonging to components of the selected building façade such as balconies, roofs etc., are added by applying a connected component analysis through the k-nearest neighbors. The line detection process stops when a detected line segment is smaller than a certain length. In this way, all the dominant building façade clusters are extracted as shown in the fig. 2.

3.3 Segmentation of Building Façades into Planar Surfaces

Once the building façade clusters are identified, the next process is to extract individual planar surfaces from each façade cluster. In general, facade features such as doors or windows can be assumed to be smooth, whereas natural features, located close to the building are scattered. Thus, surface roughness of the points should be analyzed prior to the planar segmentation, as the point clusters might contain many vegetation patches. Our façade feature segmentation process is carried out in two stages: Rough classification of building points by surface roughness analysis and advanced planar segmentation.

3.3.1 Rough Classification

First, k-nearest neighbors of each point is obtained, and the standard deviation of the orthogonal regression plane fitting residuals is computed to determine the surface roughness of each point. For a given point i, if the k-number of neighbors including the point itself is defined by (x_i, y_i, z_i) such that i = 0 to k, the equation of the orthogonal plane can be obtained using equation 1.

$$nx \cdot (x_i - x_0) + ny \cdot (y_i - y_0) + nz(z_i - z_0) = 0 \qquad (1)$$

where (x_0, y_0, z_0) is the centroid of the points, d is the distance from the origin and (nx, ny, nz) is the normal vector of fitted plane in x,y,z direction respectively.
The normal vector is obtained by least square minimization while the residuals (i.e. the distance from each point (res_i) to the derived plane) are calculated using equation 2.

$$res_i = abs(nx(x_i - x_0) + ny(y_i - y_0) + nz(z_i - z_0)) / \sqrt{(nx^2 + ny^2 + nz^2})\qquad (2)$$

Once the entire residuals are computed, the surface roughness for the current point can be determined using equation 3.

$$\sigma = \sqrt{1/(k-1)\sum_{i=0}^{k}(res_i - \mu)} \qquad (3)$$

where k is the number of neighbors for a given point, μ is the mean residual for the point cluster and 'res' & σ is the residual and the roughness value of each point respectively.

Now, surface roughness value of each point is analyzed and points, whose roughness value is below a defined threshold, are taken as potential building points. Although most of the building points can be detected by the roughness analysis, points at the building edges are mis-classified. Thus, planar segmentation method based on region growing, highlighted in next section, is applied to rectify the above issue and also to detect individual planar faces. Some results of the roughness analysis are shown in fig. 2 (right).

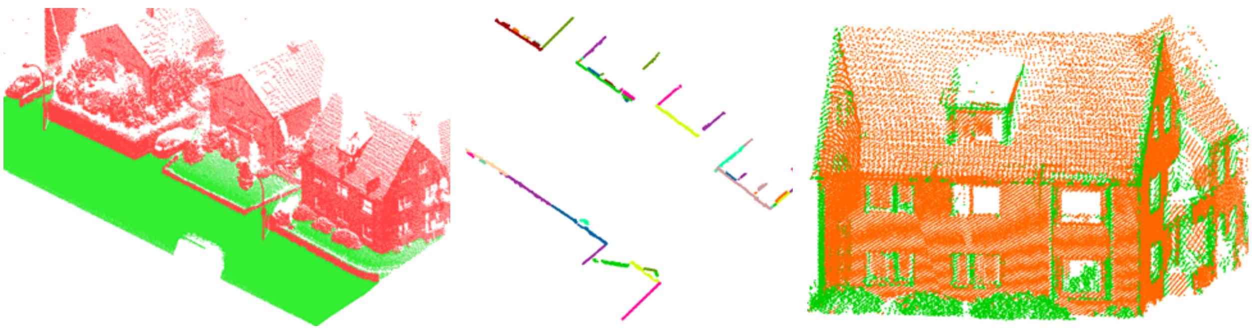

Fig. 2: Point cloud from a part of Bonn, Germany, Points classified as terrain & object points (left), Detected building footprints (middle) and roughness analysis (right): Orange represents building and green represents edges or other proximity objects.

3.3.2 Advanced Planar segmentation

Planar growing segmentation is started by selecting a random point, which has been identified as a building point as explained in section 3.3.1. This selected random point will be the initial seed for the seed segment. If the point has not been segmented previously, a new segment number is assigned and examined the status of the neighboring points. If at least one neighboring point has a non-building label, another random point is chosen whose entire neighborhood has building labels. This neighborhood, including the random point, is then analyzed further by fitting a plane based on the RANSAC approach. Although some variants of RANSAC such as adoptive RANSAC, sequential RANSAC may show increased performances (BOULAASSAL et al., 2008), we use the traditional RANSAC algorithm to detect the best plan with maximum number of inliers, since we have a low number of points to be examined. If the fitted plane contains inliers below a given threshold, then the selected seed points are ignored and another set of points will be selected based on the same criteria. Once a good plane is found, then the point cluster, which has been used to fit the plane, is taken as the seed segment for growing. For the growing, neighboring points of each point on the seed segment are examined and added to the seed segment if their distance to the fitted plane does not exceed some predefined threshold. This

growing is continued until no more neighboring points to be satisfied the growing criteria. At the end, the plane parameters are re-calculated using least square minimization. In this way, every point is assigned to a segment. Some results of our algorithm are shown in fig. 4.
Although the problem of intertwined planes (i.e., connection of co-planar plane) does not present in our results, the erroneous segmentation of points which are located closer to the plane intersection (i.e., plane intersection problem), remains in the results. The method, we use to rectify this problem, is described in the following section in detail.

3.3.3 Plane intersection problem

The problem occurs, if the local neighborhood of a seed segment point does not belong to a single plane. Thus, common points, located along the intersection line of two segments, for example at a building corner, will be segmented to the first detected plane but not to the nearest plane. Fig. 3 illustrates how the plane intersection problem is influenced to the segmentation process.

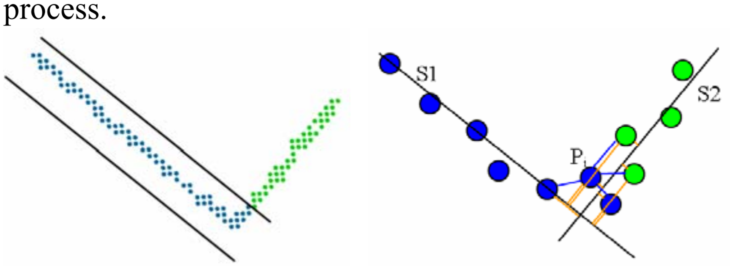

Fig. 3: The intersection problem (left). Correction of Intersection points that lay near the edge (right). The blue lines show the neighborhood of the intersection point Pi, while the orange lines represent the residuals of the points to the both segments S1 and S2

In this case, intersection points located closer to the segment boundary (i.e. edges) must be chosen and should be analyzed to ensure whether it has been assigned to the correct plane (segment) or not. This verification can be done using normal orientation or other attributes of intersect points such as intensity, spectral information and so on. However, in this study, it is done purely based on the surface residuals. First, surface residuals, with respect to the both planes, i.e. current and intersecting plane, are calculated for the intersection point and its neighboring points except non-segmented points. The standard deviation values of both sets of residuals are then computed, and the plane with the smallest value is selected as the correct plane for the intersection point to be assigned to. If the smallest value belongs to the current segment, the point is removed from the segment, that it has already been allocated, and the planes for both segments are recalculated using least square adjustment. In this way, each point is segmented into the correct plane.

4 Results and Discussion

The algorithm has been tested on two different MLS data sets acquired in Dresden and Bonn in Germany. The results of the first stage, i.e. the classification of ground and non-ground points, shown in fig.1, confirm that most objects types such as building, trees and poles can be successfully classified as non-ground points. Similarly, ground points can also be correctly extracted. However, further refinements are needed in order to identify points having tiny changes such as curbstones of roads, as we still cannot discriminate roads from the ground.

Although classified non-ground points are taken as the input for the building façade extraction, dominant building clusters are identified based on the 2D projected data. Thus, the efficiency of the subsequent processing steps is enhanced substantially as we are able to restrict the processing bounds into individual clusters. Accordingly, building façade planar detection is performed in 3D, within the potential regions (fig.2-right). Most of the planar faces such as building walls and building roofs are represented by a low surface roughness, less than 0.04, in our experiments; thus, the majority of the building points have been classified correctly except points near to the building edges, as shown in fig.1. In our approach, seed segments are derived from the orange colored points as explained in the section 3.3.2. Hence, surface roughness is assisted for the correct recognition of seed segment and consequently the detection of correct façade planes.
Some results of the advanced segmentation algorithm, referring to different data sets acquired by MLS and TLS techniques, are presented in fig.4. The figures show that different facade features such as windows, doors and walls can be clearly extracted by our approach. Moreover, edge points are accurately segmented into their corresponding correct surfaces.

Fig. 4: Segmentation results of different data sets, acquired from MLS (top left and bottom) and TLS (top middle & top right): The different features are denoted by different colours.

5 Conclusion and Future Work

An automatic façade point extraction method, appropriate for massive point clouds, is outlined. Potential building clusters are recognized effectively from the raw point clouds and planar faces are extracted based on RANSAC and region growing concepts. Based on the surface roughness of the points, an enhanced seed point recognition method is introduced. Thus, quality segments are obtained. The advantage of the proposed algorithm is that the workflow decreases the number of points to be processed by means of a step by step process, which further allows for a better handling of very large MLS point clouds efficiently. Our results confirm the feasibility and robustness of the approach for segmenting different types of point clouds. Recognized planar faces will be used for the automated modeling of façade features such as doors, windows, walls and so on, in future.

6 Acknowledgement

The authors would like to thank Top-Scan GmbH for providing the MLS data in Bonn, Germany. Thanks also to Mr. Dominik Vock for supporting to us by acquiring MLS data from Münchner Straße, Dresden, and to Dr. Danilo Schneider for providing the TLS data of the TUD rectorate building.

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