Robust Building Roof Segmentation in Airborne 3D Point Cloud Data

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Abstract

Numerous applications related to urban landscape demand automatic recognition of buildings and planar structures from airborne laser scanning (ALS) data. Approximation of geometric features is an essential step in point clouds segmentation and surface reconstruction. Often, the saliency features are estimated using principal component analysis (PCA), which is sensitive to noise and tend to smooth the sharp features. Hence, the segmentation results into unreliable reconstructed surfaces. This article presents a new approach to segment the point clouds in order to reconstruct roofs and detect buildings. It combines PCA and Low-Rank Subspace with prior Knowledge (LRSCPK) methods for normal estimation. The points around the anisotropic surfaces are identified using local neighbourhood covariance analysis followed by the normal estimation using PCA. Then, the normals for the points around sharp features are re-estimated using a consistent isotropic sub neighbourhood using LRSCPK. Demonstration on three real-world ALS samples shows the ability of combined approach to generate more accurate and robust normals. The developed segmentation approach is also tested using two benchmark datasets: ISPRS and Australian. Per-object and per-area completeness and correctness results indicate the robustness of the approach and the quality of the reconstructed surfaces and extracted buildings.

1 Proposed Methodology

The workflow of the proposed approach consists of three major steps as shown in Figure 1. Firstly, ALS data is divided into ground and non-ground point clouds and the candidate building regions are identified. Secondly, the building roof primitives are extracted from each candidate region using the proposed segmentation method. Finally, the planes on the trees are eliminated by the refinement process followed by the planar and building outline approximation. Detailed explanation is provided in the following sections.

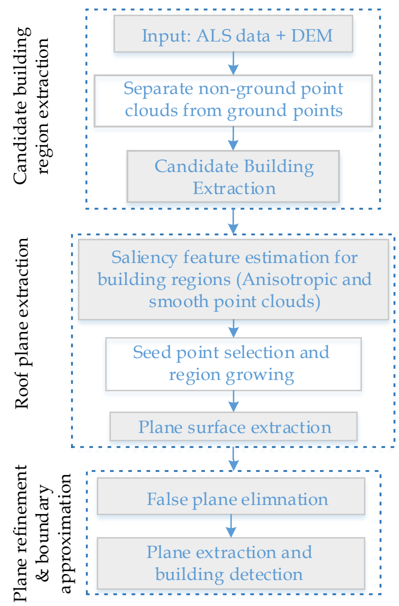

Figure 1: Workflow of the proposed approach

1.1 Candidate building region identification

First step for building roof segmentation is to separate the area of interest from other points. We, therefore, use a 1 m height threshold using a ground height from DTM for extraction of these points. This process eliminates low height features including bare-earth, road side furniture, cars, and bushes, while leaving objects above the threshold including buildings and trees.

For the non-ground point clouds, a neighborhood connection is established using delaunay triangulation. The key idea behind the candidate region identification is to remove the triangles connecting the edges between different objects. Accordingly, the edges of any triangle having a length larger than twice of the point cloud spacing are classified anomalous and thus removed. Then, following the new boundary approximation algorithm (not presented here), the candidate building regions are identified and their corresponding boundaries are estimated.

1.2 Roof feature extraction

The segmentation process begins with the selection of a seed point. A point that does not belong to sharp features and has the most flatness value is identified as a seed believing that the region growing will be more successful for areas where the spatial variation is the least. After getting a seed point, we take its k local neighborhood points N_p. To maintain the topology of the roof primitives, the points which have the angular difference between the normal vector of seed and N_P within a predefined threshold θ_t, a fictitious plane is fitted using the least squares method. If the plane fitting error and the difference between point clouds height and fitted plane's height are smaller than their fitting error ε_t and flat plane tolerance ξ_t, these points are added into the region, which is grown until new neighbouring points meet the above criteria, otherwise a new seed point is chosen.

1.3 Plane refinement and building boundary approximation

As a result of the segmentation, some of the extracted planes may belong to trees and other non-building structures. We call these the false positive planes, which can be removed using a rule-based procedure following the criteria. The planar features, such as its area, standard deviation, local neighbourhood, and the presence of straight line segments around its boundary, are used to decide whether a plane is a false positive.

It is observed that a plane fitted on a tree is usually small in size and has a higher standard deviation value than a plane on a building. Therefore, a plane is discarded as a false positive regardless of the other parameters either if its area is $\leq 1\text{m}^2$ or the standard deviation of point clouds in a given plane is higher than the user define threshold. Moreover, the presence of long straight lines along the boundary of a plane, is also utilised to remove the false planes on trees and other non-building structures. In addition, the remaining planes if exist in the local neighbourhood of a false positive plane are also removed as false alarms. Figure 2(a) shows the final extracted roof planes after the refinement process. Each candidate building region is further processed iteratively to identify the individual buildings. Therefore, LiDAR points of the neighbouring roof planes are combined and a boundary estimation algorithm (described earlier) is used to estimate the boundary of the buildings present in a given candidate region. Figure 2(b) shows the building boundary for the sample scene.

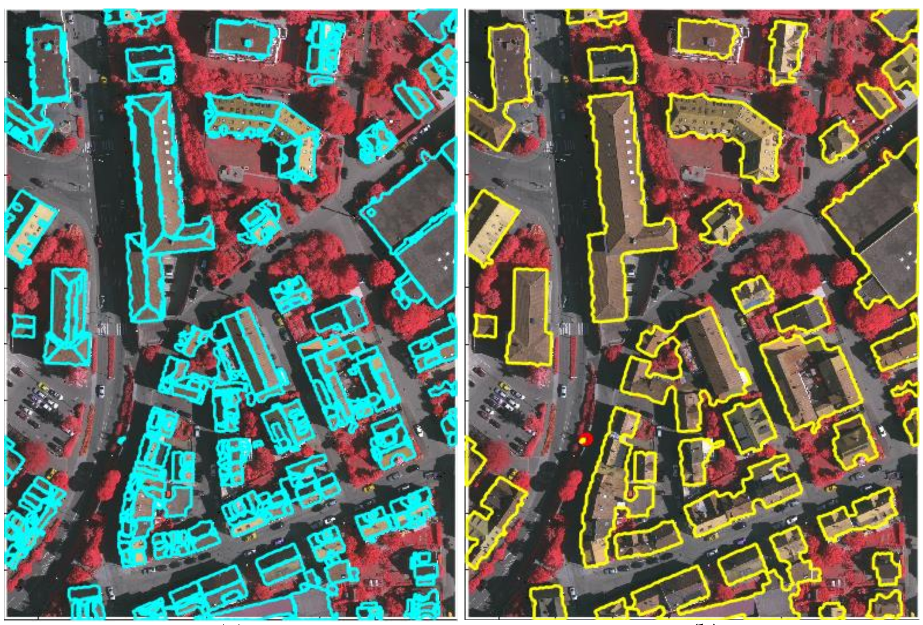
(a) (b)

Figure 2: (a) Extracted plane boundaries, and (b) Extracted building boundaries. Both are laid on the for the ISPRS (Area 1) image just for demonstration