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Automatic extraction of building roofs using LIDAR data and multispectral imagery

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ABSTRACT

Automatic 3D extraction of building roofs from remotely sensed data is important for many applications including city modelling. This paper proposes a new method for automatic 3D roof extraction through an effective integration of LIDAR (Light Detection And Ranging) data and multispectral orthoimagery. Using the ground height from a DEM (Digital Elevation Model), the raw LIDAR points are separated into two groups. The first group contains the ground points that are exploited to constitute a 'ground mask'. The second group contains the non-ground points which are segmented using an innovative image line guided segmentation technique to extract the roof planes. The image lines are extracted from the grey-scale version of the orthoimage and then classified into several classes such as 'ground', 'tree', 'roof edge' and 'roof ridge' using the ground mask and colour and texture information from the orthoimagery. During segmentation of the non-ground LIDAR points, the lines from the latter two classes are used as baselines to locate the nearby LIDAR points of the neighbouring planes. For each plane a robust seed region is thereby defined using the nearby non-ground LIDAR points of a baseline and this region is iteratively grown to extract the complete roof plane. Finally, a newly proposed rule-based procedure is applied to remove planes constructed on trees. Experimental results show that the proposed method can successfully remove vegetation and so offers high extraction rates.

1. Introduction

Up to date 3D building models are important for many GIS (Geographic Information System) applications such as urban planning, disaster management and automatic city planning (Gröger and Plümer, 2012). Therefore, 3D building reconstruction has been an area of active research within the photogrammetric, remote sensing and computer vision communities for the last two decades. Building reconstruction implies the extraction of 3D building information, which includes corners, edges and planes of the building facades and roofs from remotely sensed data such as aerial imagery and LIDAR (Light Detection And Ranging) data. The facades and roofs are then reconstructed using the available information. Although the problem is well understood and in many cases accurate modelling results are delivered, the major drawback is that the current level of automation is comparatively low (Cheng et al., 2011).

Three-dimensional building roof reconstruction from aerial imagery alone seriously lacks in automation partially due to shadows, occlusions and poor contrast. The introduction of LIDAR has offered a favourable option for improving the level of automation in 3D reconstruction when compared to image-based reconstruction alone. However, the quality of the reconstructed building roofs from LIDAR data is restricted by the ground resolution of the LIDAR which is still generally lower than that of the aerial imagery. That is why the integration of aerial imagery and LIDAR data has been considered complementary in automatic 3D reconstruction of building roofs. The issue of how to optimally integrate data from the two sources with dissimilar characteristics is still to be resolved and relatively few approaches have thus far been published.

Different approaches for building roof reconstruction have been reported in the literature. In the *model driven* approach, also known as the *parametric* approach, a predefined catalogue of roof forms (e.g., flat, saddle, etc.) is prescribed and the model that best fits the data is chosen. An advantage of this approach is that the final roof shape is always topologically correct. The disadvantage, however, is that complex roof shapes cannot be reconstructed if they are not in the input catalogue. In addition, the level of detail in the reconstructed building is compromised as the input models

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usually consist of rectangular footprints. In the *data driven* approach, also known as the *generic* approach (Lafarge et al., 2010) or polyhedral approach (Satari et al., 2012), the roof is reconstructed from planar patches derived from segmentation algorithms. The challenge here is to identify neighbouring planar segments and their relationship, for example, coplanar patches, intersection lines or step edges between neighbouring planes. The main advantage of this approach is that polyhedral buildings of arbitrary shape may be reconstructed (Rottensteiner, 2003). The main drawback of data driven methods is their susceptibility to the incompleteness and inaccuracy of the input data; for example, low contrast and shadow in images and low point density in LIDAR data. Therefore, some roof features such as small dormer windows and chimneys cannot be represented if the resolution of the input data is low. Moreover, if a roof is assumed to be a combination of a set of 2D planar faces, a building with a curved roof structure cannot be reconstructed. Nonetheless, in the presence of high density LIDAR and image data, curved surfaces can be well approximated (Dorninger and Pfeifer, 2008). The *structural* approach, also known as the *global strategy* (Lafarge et al., 2010) or Hybrid approach (Satari et al., 2012), exhibits both model and data driven characteristics. For example, Satari et al. (2012) applied the data driven approach to reconstruct cardinal planes and the model-driven approach to reconstruct dormers.

The reported research in this paper concentrates on 3D extraction of roof planes. A new data driven approach is proposed for automatic 3D roof extraction through an effective integration of LIDAR data and multispectral imagery. The LIDAR data is divided into two groups: ground and non-ground points. The ground points are used to generate a 'ground mask'. The non-ground points are iteratively segmented to extract the roof planes. The structural image lines are classified into several classes ('ground', 'tree', 'roof edge' and 'roof ridge') using the ground mask, colour orthoimagery and image texture information. In an iterative procedure, the non-ground LIDAR points near to a long roof edge or ridge line (known as the baseline) are used to obtain a roof plane. Finally, a newly proposed rule-based procedure is applied to remove planes constructed on trees. Promising experimental results for 3D extraction of building roofs have been obtained for two test data sets.

Note that the initial version of this method was introduced in Awrangjeb et al. (2012a), where the preliminary idea was briefly presented without any objective evaluation of the extracted roof planes. This paper not only presents full details of the approach and the objective evaluation results, but also proposes a new rule-based procedure in order to remove trees.

The rest of the paper is organised as follows: Section 2 presents a review of the prominent data driven methods for 3D building roof extraction. Section 3 details the proposed extraction algorithm. Section 4 presents the results for two test data sets, discusses the sensitivity of two algorithmic parameters and compares the results of the proposed technique with those of existing data driven techniques. Concluding remarks are then provided in Section 5.

2. Literature review

The 3D reconstruction of building roofs comprises two important steps (Rottensteiner et al., 2004). The *detection* step is a classification task and delivers regions of interest in the form of 2D lines or positions of the building boundary. The *reconstruction* step constructs the 3D models within the regions of interest using the available information from the sensor data. The detection step significantly reduces the search space for the reconstruction step. In this section, a review of some of the prominent *data driven* methods for 3D roof reconstruction is presented.

Methods using ground plans (Vosselman and Dijkman, 2001) simplify the problem by partitioning the given plan and finding the most appropriate planar segment for each partition. However, in the absence of a ground plan or if it is not up to date, such methods revert to semi-automatic (Dorninger and Pfeifer, 2008). Rottensteiner (2003) automatically generated 3D building models from point clouds alone. However, due to the use of LIDAR data alone, the level of detail of the reconstructed models and their positional accuracy were poor. An improvement involving the fusion of high resolution aerial imagery with a LIDAR DSM (Digital Surface Model) was latter proposed (Rottensteiner et al., 2004).

Khoshelham et al. (2005) applied a split-and-merge technique on a DSM guided image segmentation technique for automatic extraction of roof planes. In evaluation, the accuracy of reconstructed planes was shown for four simple gable roofs only. Chen et al. (2006) reconstructed buildings with straight (flat and gable roofs only) and curvilinear (flat roof only) boundaries from LIDAR and image data. Though the evaluation results were promising, the method could not detect buildings smaller than 30 m^2 in area and for the detected buildings both planimetric and height errors were high.

Park et al. (2006) reconstructed large complex buildings using LIDAR data and digital maps. Unlike other methods, this method was able to reconstruct buildings as small as 4 m^2. However, in the absence of a ground plan, or if the plan is not up to date, the method becomes semi-automatic. In addition, objective evaluation results were missing in the published paper. Dorninger and Pfeifer (2008) proposed a method using LIDAR point clouds. Since the success of the proposed automated procedure was low, the authors advised manual pre-processing and post-processing steps. In the pre-processing step, a coarse selection of building regions was accomplished by digitizing each building interactively. In the post-processing step, the erroneous building models were indicated and rectified by means of commercial CAD software. Moreover, some of the algorithmic parameters were set interactively. Sampath and Shan (2010) presented a solution framework for segmentation (detection) and reconstruction of polyhedral building roofs from high density LIDAR data. They provided good evaluation results for both segmentation and reconstruction. However, due to removal of LIDAR points near the plane boundaries, the method exhibited high reconstruction errors on small planes. Furthermore, the fuzzy k-means clustering algorithm was computationally expensive (Khoshelham et al., 2005).

Habib et al. (2010) reported on semi-automatic polyhedral building model generation through integration of LIDAR data and stereo imagery. Planar roof patches were first generated from the LIDAR data and then 3D image lines were matched along the LIDAR boundaries. Finally, a manual monoplotting procedure was used to both delete incorrect boundaries and add necessary boundary segments. Some true boundaries were missed and erroneous boundaries were detected due to relief displacement, shadows and low image contrast. Cheng et al. (2011) integrated multi-view aerial imagery with LIDAR data for 3D building model reconstruction. This was a semi-automatic method since in many cases 20–30% of roof lines needed to be manually edited. In addition, this method was computationally expensive and failed to reconstruct complex roof structures. Jochem et al. (2012) proposed a roof plane segmentation technique from raster LIDAR data using a seed point based region growing technique. Vegetation was removed using the slope-adaptive LIDAR echo ratio and the approach showed good object-based evaluation results on a large data set using a threshold-free evaluation system. However, because of the use of gridded height data, there was an associated loss of accuracy in the extracted planes.