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Full-waveform data for building roof step edge localization

Małgorzata Słota

AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Geoinformation Photogrammetry and Remote Sensing of Environment, Krakow, Poland

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ABSTRACT

Airborne laser scanning data perfectly represent flat or gently sloped areas; to date, however, accurate breakline detection is the main drawback of this technique. This issue becomes particularly important in the case of modeling buildings, where accuracy higher than the footprint size is often required. This article covers several issues related to full-waveform data registered on building step edges. First, the full-waveform data simulator was developed and presented in this paper. Second, this article provides a full description of the changes in echo amplitude, echo width and returned power caused by the presence of edges within the laser footprint. Additionally, two important properties of step edge echoes, peak shift and echo asymmetry, were noted and described. It was shown that these properties lead to incorrect echo positioning along the laser center line and can significantly reduce the edge points' accuracy. For these reasons and because all points are aligned with the center of the beam, regardless of the actual target position within the beam footprint, we can state that step edge points require geometric corrections. This article presents a novel algorithm for the refinement of step edge points. The main distinguishing advantage of the developed algorithm is the fact that none of the additional data, such as emitted signal parameters, beam divergence, approximate edge geometry or scanning settings, are required. The proposed algorithm works only on georeferenced profiles of reflected laser energy. Another major advantage is the simplicity of the calculation, allowing for very efficient data processing. Additionally, the developed method of point correction allows for the accurate determination of points lying on edges and edge point densification. For this reason, fully automatic localization of building roof step edges based on LiDAR full-waveform data with higher accuracy than the size of the lidar footprint is feasible.

1. Introduction

Currently, airborne laser scanning (ALS), also referred to as LiDAR (light detection and ranging), is one of the most efficient methods of 3D data acquisition over large areas. Therefore, this technology is widely used for forest inventories and urban modeling. Airborne laser scanning allows the acquisition of point clouds with high detail and accuracy. These discrete data sets perfectly represent flat or gently sloped areas; to date, however, accurate breaklines determination is the main drawback of this technique. This issue becomes particularly important in the case of modeling urban areas, where on the one hand, high accuracy is vital, but on the other hand, the presence of man-made objects, which are the cause of irregularities and spikes in the data, does not allow for a simple, accurate object reconstruction. The direct use of an unprocessed point cloud in those areas leads to major model errors in regions of discontinuity and therefore proves to be insufficient for accurate modeling of urban objects, especially buildings (Fig. 1a). For that reason, it is vital to build urban models that not only are based on point clouds but also include breaklines in the model generation process.

Due to the rapid development of measurement systems, as well as gradual digitization processes across various disciplines, a growing demand for accurate, realistic building models is expected. Therefore, automatic breakline detection based on lidar data is a very relevant issue. The difficulty arises when the spatial resolution of laser scanners is lower than resolution of required models. In such cases, the resolution of the building model could be enhanced by including edges obtained by finding intersection lines between adjacent planes that were fitted into the point cloud (Fig. 1b). This approach cannot be used in areas of roof overhangs or for step edges localization.

It should be noted that for step edges, a single laser pulse only partially reflects from the plane of the roof due to the beam

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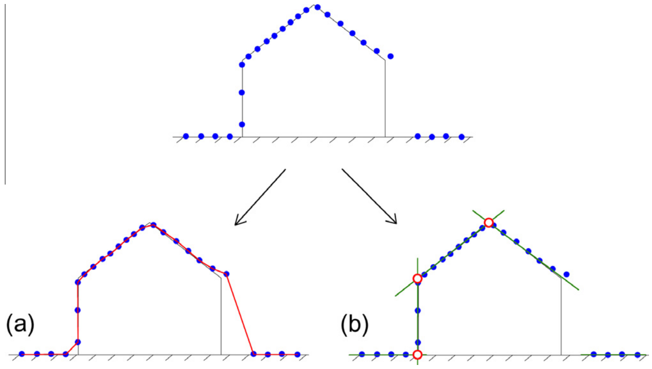

Fig. 1. Different approaches to building modeling: (a) model generated directly from an unprocessed point cloud; and (b) building edges extracted by intersecting planes.

divergence. These partial reflections occur not only for pulses whose beam centers are within the roof boundary but also for laser beams with centers just outside the boundary. When a point cloud is created, however, all returns are aligned down the center of the beam (Neilsen, 2011), regardless of the actual position of the edge within the beam footprint. Thus, the localization of step edges with accuracy better than the size of the lidar footprint is required (Jutzi et al., 2005). While using discrete echo scanning data, this requirement is difficult to fulfill; however, estimating how much energy was reflected from the roof can be significantly improved by analyzing returned laser energy profiles, called full-waveform (FW) data (Michelin et al., 2012).

1.1. Objectives of this work

This article focuses on the possibility of using full-waveform lidar data to improve the detection of building step edges. Section 1.2 describes the state of knowledge concerning edge detection algorithms based on lidar data. The method section provides information concerning the data used in the study, the properties of step edge waveforms and details of the algorithm of step edge point refinement. For the purpose of this study, a full-waveform data simulator was developed. The use of simulated data allows for the rapid and comparative analysis of reflected signals, as all of the settings of simulated data acquisition are easily changeable. A full description of the simulation principles with mathematical formulas can be found in Section 2.1. Based on the generated data, a study focused on changes in the step edge waveform parameters was performed. These changes depend on the distance from the laser line of sight to the edge, reflection geometry and pulse parameters. The results of the analysis along with plots illustrating the above relationships are presented in Section 2.2. The conducted study allows to put forward the thesis that lidar step edge points require geometric corrections. Therefore, Section 2.3 presents the novel edge points refinement algorithm. Because the main objective of the algorithm is the possibility of directly using data stored in standard formats (e.g., ASPRS LAS from version 1.3), the proposed method works only on georeferenced profiles of reflected laser energy. Any additional knowledge of emitted signal parameters, such as beam divergence or flight settings information, is not required. The presented method works based on data from a single trajectory with the assumption that laser beam directions for neighboring edge points are similar to each other and the analyzed step edge points belong to one straight edge section. In the case of overlapping data strips, the point refinement algorithm should be applied to each lidar strip separately. It should be noted that the proposed method does not cover the issues of building detection in a point cloud, roof planes segmentation and points topology – it is assumed that these steps have been carried out properly. The developed method of points correction allows for the fully automatic and accurate determination of points lying on the building step edges. Therefore, those points can be used for localizing step edges with accuracy better than the size of the lidar footprint, which is described in Section 3. Despite the fact that the original purpose of this research was to detect building roof step edges from full-waveform data, the obtained results and developed method of point correction could also be applied in other fields, which is noted in Section 4.

1.2. Related work

Research on the automatic breakline detection based on lidar data has been conducted since the early 1990s (Suk and Bhandarka, 1992). Initially, analysis was carried out on the regular data structures called rasters, or images computed by the interpolation of the attributes of an irregular point cloud to a regular grid. Depending on the type of interpolated attribute, different images can be determined. The most common are height, range and intensity images. The reason for using regular data sets instead of original points is the significant simplification of calculations, related to neighboring relations within a data set. The rasterization process, however, always results in a loss of information. Furthermore, in most cases, as a result of raster edge detection, a 2D breakline is extracted and an additional, separate process is required for height calculations (Brzank et al., 2005). Thus, when a high-accuracy breakline is required, despite the increase in computation time, vertical discontinuities should be extracted directly from the original point cloud. Currently, it is a common practice to roughly estimate edges from interpolated regular data and more precisely estimate the edge position based on original points. The edge detection methods based on lidar data can be divided into three groups, related to the type of data structure used in the calculation process:

(a) methods based on regular data structures (raster/image),
(b) methods based on the original point cloud,
(c) hybrid methods combining both the regular and original data sets.

All of these edge detection methods can be enhanced by using additional data, such as aerial images (Cheng et al., 2008; Li and Wu, 2008), 2D maps (Haala and Brenner, 1999; Teo et al., 2006; Vosselman and Dijkman, 2001), multispectral images (Demir and Baltsavias, 2012) or address points (Jarzabek-Rychard, 2012). Furthermore, full-waveform data can potentially increase the edge detection accuracy. However, edge detection methods based on airborne full-waveform data have been only carried out in Jutzi et al. (2005) and Michelin et al. (2012).

In general, most studies are focused on automatically finding breakline points or breakline pixels in the point cloud or images, after which the regularization step, using well-known generalization techniques or regression methods, is usually applied. Very few studies are focused on edge localization within the lidar footprint. Using discrete echo systems, such edge position detection could be achieved by an intensity attributes analysis, as only this value indicates the level of the energy decrease of edge reflections. Studies in this field have been conducted by Vosselman. In Vosselman (2002), an edges representation in reflectance images and their influence on edge location is presented, as well as the formula for the approximate distance between a point and the edge; however, the proposed method requires knowledge of approximate edge orientation and the approximate distance to the edge parameter.