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Iterative processing of laser scanning data by full waveform analysis

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Abstract

The latest developments in laser scanners allow capturing and digitizing of the full waveform of the backscattered pulse. The waveform can be analyzed for measurement features such as range, reflectance values and spreading of the pulse. These features are used to distinguish between locally planar surface elements and partly penetrable objects caused by partial occlusions. This pre-segmentation and the derived range values are used to automatically generate surface primitives in the form of planes. This allows refining each range value taking the surface geometry in a close neighborhood into account. To refine the modeling of the surface, partly occluded surface areas are extended by prediction of the expected range values. This prediction is further improved by considering the surface slope for the estimated received waveform. Then the point cloud associated with the surface is enhanced by additional range values that were missed in the first processing step due to weak signal response. This procedure is repeated several times until all useful range values are considered to estimate the surface.

Keywords: Laser scanning; Waveform analysis; Feature extraction

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1. Introduction

The generation of accurate 3D models from laser scanning data for a description of man-made objects is of great interest in photogrammetric research. Detailed description of objects such as buildings requires sampling the surface as a point cloud as dense and complete as possible. However, depending on the scene and the point of view of the laser scanning system, foreground objects like trees in the line of sight of the laser beam interrupt the uniform sampling of the surfaces. These gaps in the sampling of the surface are called partly occluded regions. Maas (2000) included a discussion about partly occluded regions in his work on TIN (Triangulated Irregular Network) structures and least-squares matching. A different strategy to handle gaps in the point cloud is the application of morphological operations (Gorte and Pfeifer, 2004). Morphological operations can also be used in the case that no reflections of the region can be measured due to total occlusion by an impervious object. However, vegetation often shows a semi-penetrable property.

State of the art laser scanning systems allow recording the first and last pulse or a given number of pulses. While first pulse registration is the optimum choice to measure the hull of partially penetrable objects, e.g. canopy of trees, last pulse registration should be chosen to measure impenetrable surfaces, e.g. ground surface below vegetation for airborne applications or a building behind vegetation for terrestrial applications.

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Recent developments in commercial airborne laser scanning systems have led to systems such as OPTECH ALTM 3100, TOPEYE MK II, and TOPOSYS HARRIER 56 (based on RIEGL LMS-Q560) that allow capturing the waveform:. These systems are specified to operate with a transmitted pulse width of 4–10 ns at full-width-at-half-maximum (FWHM) and allow digitization and acquisition of the waveform with approximately 0.5–1 GSample/s. Detailed overviews for laser scanning systems are given in (Huising and Gomes Pereira, 1998; Wehr and Lohr, 1999; Baltsavias, 1999).

In contrast to airborne systems, the prototype of the terrestrial laser scanning system ECHIDNA (Lovell et al., 2003) allows to capture the waveform of the backscattered pulse. Terrestrial applications often show a distribution of objects that range from several meters in the foreground to hundreds of meters in the background. Multiple reflections of objects within the beam corridor can be extracted from the full waveform data (Reitberger et al., 2006; Ullrich and Reichert, 2005).

Assuming that waveforms are sampled with sufficiently high frequency, techniques of digital signal processing can be applied. Comparing the transmitted and the received waveform by the cross-correlation function can improve the range estimation. The argument of the maximum of the cross-correlation function estimates the range value with higher reliability and accuracy than the amplitude of the received waveform alone. Details of the improvement can be found in Hofton and Blair (2002), Jutzi and Stilla (2005), and Thiel et al. (2005).

Different surfaces have to be analyzed for different applications. For example for urban objects, it is relevant to deal with objects at different elevations (Brenner et al., 2001). In rural environments it is relevant to deal with randomly distributed natural objects (Reitberger et al., 2006). The impact of the scene on the received waveform has been discussed using standard examples (Jutzi et al., 2002; Wagner et al., 2004; Jutzi and Stilla, 2006).

The focus of this work is reconstruction of man-made objects that can be approximated by planar surfaces. A robust algorithm for finding planes can be implemented using the RANSAC algorithm (Fischler and Bolles, 1981; Hartley and Zisserman, 2000). Many authors have used RANSAC in 2D for extraction of low parameterized transformation models (Workshop 25 Years of RANSAC, 2006). However RANSAC can also be used to fit planes (Brenner et al., 2001) or cylinders (Beder and Förstner, 2006) to 3D point clouds. While Brenner et al. (2001) exploit well defined neighborhood relations to bound the search region for plane primitives, Beder and Förstner (2006) make no assumptions about the search regions. In both approaches a coarse estimation of the variance of point distances to the fitted model is required. The membership of points to the fitted model is determined by a constant threshold. Local distortions of the point distribution caused by details of the object that are not represented by the model at the given level of detail (LOD) lead to exclusion of the points related to these details. This disadvantage can be overcome by an improved RANSAC based on automatic threshold detection. Speaking precisely, it is possible to capture all points of the object even when the current model does not fit the corresponding point cloud exactly at the current LOD.

In this paper, we propose a method for iterative knowledge-based processing of terrestrial laser scanning data by full waveform analysis. The approach that we present improves the point density and accuracy of the range values. Furthermore, it allows closing gaps in partly occluded surface regions by knowledge-based search.

In Section 2, the surface response of a planar surface with slope is derived. Using this surface response, the corresponding range value is estimated and the correlation function is analyzed. The derived property values are used in a pre-segmentation to separate locally planar surface elements from partly penetrable objects. The result of this process is used to extract surface primitives by RANSAC with automatic threshold selection. In an iterative processing step the slope of the surface is used to improve the accuracy of the range value by increasing the cross-correlation between the received waveform and the expected surface response. This procedure requires the assumption that the surface is locally planar. In Section 3, outdoor experiments with an experimental laser scanning system capturing an urban scene are described. The results of the iterative processing are presented in Section 4. In Section 5 the improvement of the point clouds and the pre-segmentation are discussed. Section 6 completes the contribution with a summary of the advantages of our approach and directions of further research.

2. Methods

The following section describes the whole processing chain. An overview of the processing chain is depicted in Fig. 1. First we introduce the concept of estimating the surface response in Section 2.1. The general interaction between a surface and a laser pulse is analyzed. The output of the analysis is the reduction of the 3D surface characteristic to a 1D range dependent signal. In the following this signal will be called the surface response. A theoretical derivation of the surface response as a function of the slope of a planar surface is given in Section 2.2. In Section 2.3, we introduce a