ISPRS Journal of Photogrammetry and Remote Sensing 117 (2016) 141–148

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

A new adaptive method to filter terrestrial laser scanner point clouds using morphological filters and spectral information to conserve surface micro-topography

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ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form 2 April 2016
Accepted 2 April 2016
Available online 22 April 2016

Keywords:
Terrestrial laser scanning (TLS)
Digital Terrain Model (DTM)
Filter
Vegetation
Micro-topography

ABSTRACT

Terrestrial laser scanning (TLS), widely known as light detection and ranging (LiDAR) technology, is increasingly used to provide highly detailed digital terrain models (DTM) with millimetric precision and accuracy. In order to generate a DTM, TLS data has to be filtered from undesired spurious objects, such as vegetation, artificial structures, etc., Early filtering techniques, successfully applied to airborne laser scanning (ALS), fail when applied to TLS data, as they heavily smooth the terrain surface and do not retain their real morphology. In this article, we present a new methodology for filtering TLS data based on the geometric and radiometric properties of the scanned surfaces. This methodology was built on previous morphological filters that select the minimum point height within a sliding window as the real surface. However, contrary to those methods, which use a fixed window size, the new methodology operates under different spatial scales represented by different window sizes, and can be adapted to different types and sizes of plants. This methodology has been applied to two study areas of differing vegetation type and density. The accuracy of the final DTMs was improved by ~30% under dense canopy plants and over ~40% on the open spaces between plants, where other methodologies drastically underestimated the real surface heights. This resulted in more accurate representation of the soil surface and microtopography than up-to-date techniques, eventually having strong implications in hydrological and geomorphological studies.

1. Introduction

New generations of remote sensing instruments, such as terrestrial laser scanning (TLS), provide the possibility of quickly acquiring high resolution large-area 3D point clouds. Since the development of the first TLS in 1999, their accuracy has increased considerably. This has opened new possibilities in such different fields of geomorphology as surface morphology analysis (Smith et al., 2006; Cavalli et al., 2008; Guarnieri et al., 2009), hydrological studies (Mason et al., 2007; Casas et al., 2012; Rodríguez-Caballero et al., 2012), erosion and deposition quantification (Betts and DeRose, 1999; James et al., 2007), detection, modelling and monitoring landslide features (Biasion et al., 2005; Heritage and Hetherington, 2007; Oppikofer et al., 2008; Dunning et al., 2009) or microtopographic studies (Aguilar et al., 2009; Haubrock et al., 2009; Rodríguez-Caballero et al., 2012, 2015). Most of these studies are focused on soil surface morphology, which is of crucial importance to post processing stages for extracting bare soil surface data from the original point cloud and generating the corresponding Digital Terrain Models (DTMs). The filtering process and generation of accurate, precise high-resolution DTMs is a time consuming process that needs to be automated.

Several automatic and semi-automatic methods have been developed for filtering vegetation and eliminating it from LiDAR data. These methods can be classified in three main groups: morphological filters, progressive densification filters, and hierarchical

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http://dx.doi.org/10.1016/j.isprsjprs.2016.04.004
0924-2716/

robust interpolation filters (Axelsson, 1999). Morphological filters are based on the selection of the minimum value within a sliding window as surface points (Haralick and Shapiro, 1992). Progressive filters are based on an initial triangular network created from local minimum points to which additional points are added depending on their positions and the geometry of the new triangles generated when they are added (Axelsson, 1999). Hierarchical filters use linear prediction and hierarchical robust interpolation to define a surface model based on the point cloud (Kraus and Pfeifer, 1998). All of them were conceived for application to airborne laser scanning (ALS) datasets (Sithole and Vosselman, 2004; Wang et al., 2009; Meng et al., 2010). However, the geometry of data acquisition, the spatial area, density and point cloud properties in ALS datasets are completely different from those acquired by TLS (Pirotti et al., 2013a), increasing filtering process complexity.

New scanners that record multiple return echoes (e.g., Riegl VZ-line scanners) have introduced new elements for automatic filtering tools and models (Pirotti et al., 2013a,b). However, they do not work properly in areas covered by a dense pattern of low vegetation, like most grasslands, where the solution of two echoes in the same line of sight (i.e., multiple-target discrimination limit) should not be less than 80 cm (Pfennigbauer and Ullrich, 2009), and manual editing is still necessary (Pirotti et al., 2013b). Guarnieri et al. (2009) developed a novel, but simple method for TLS point cloud filtering and DTM generation using elevation information and reflectance of laser return intensity. This method is based on morphological filtering approach (Streutker and Glenn, 2006; Wang et al., 2009), also considers differences in the spectral response of vegetation and bare surfaces identified as a promising source of information for data filtering (Lichti, 2005). The Guarnieri approach was developed to filter TLS data in a tidal marsh ecosystem, which is characterised by low elevation features and continuous vegetation cover over a gentle slope. Under these conditions, morphological filters have been demonstrated to provide better results than linear prediction or hierarchical robust interpolation (Chang et al., 2008). However, the application of this methodology in areas with sparse vegetation cover and large non-vegetated areas, such as most of the arid and semiarid ecosystems, generates smoothed and unrealistic surfaces unrepresentative of the real microtopographic conditions.

Appropriate characterisation of a microtopographic soil surface in non-vegetated areas or with sparse vegetation cover is essential to properly understand and parameterize ecosystem processes occurring at the soil-atmosphere boundary (Martin et al., 2008). Surface morphology and microtopography control runoff generation (Allmaras et al., 1966; Kirkby, 2002; Rodríguez-Caballero et al., 2012) and evaporation (Chamizo et al., 2013), thus conditioning soil water availability and water erosion of non-vegetated areas (Gaur and Mathur, 2003; Rodríguez-Caballero et al., 2012), which may be one of the most important surface components in hyper-arid, arid and semi-arid regions around the world (Safriel et al., 2005). Moreover, these areas are usually covered by stones, or physical and biological soil crust, which also modify surface microtopography and its effect on the main processes controlling ecosystem functionality (Poesen and Lavee, 1994; Chamizo et al., 2012; Rodríguez-Caballero et al., 2013). It is therefore obvious that inclusion of these areas in filtering methods and DTM generation would improve modelling of hydrological, geomorphological and erosional processes in arid and semiarid environments. The aim of this paper is to present a new methodology for generating DTMs able to accurately represent soil surface morphology, especially in non-vegetated areas, using high-resolution TLS data. This methodology is a simple, integrated approach for automatic terrain extraction which strictly preserves the original morphology of non-vegetated areas.

Our work was based on an earlier approach to TLS filtering by Guarnieri et al. (2009) which combined spectral information with the selection of the minimum point height in a sliding window. However, our methodology identifies vegetated areas based on the spectral information, and then increases the sliding window size in steps, depending on vegetation properties. The ability to

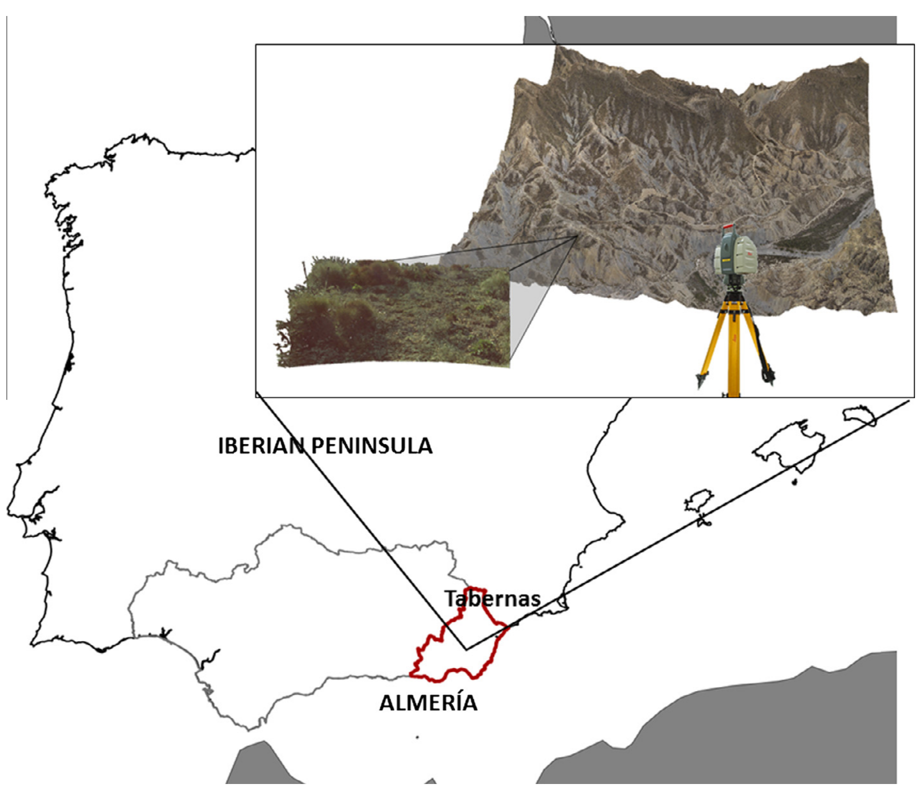

Fig. 1. El Cautivo experimental area location at the Southeast of Spain.