Journal of Archaeological Science 38 (2011) 2061–2070

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Flights into the past: full-waveform airborne laser scanning data for archaeological investigation

R. Lasaponara [a], R. Coluzzi [a,*], N. Masini [b,1]

[a] Istituto di Metodologie per l'Analisi Ambientale, IMAA-CNR, C.da S.Loja – 85050 Tito Sc. (PZ), Italy
[b] Istituto per i Beni Archeologici e Monumentali, IBAM-CNR, Sezione di Potenza, 85050 Tito Sc. (PZ), Italy

ARTICLE INFO

Article history:
Received 1 February 2010
Received in revised form
22 September 2010
Accepted 3 October 2010

Keywords:
Landscape archaeology
Airborne laser scanning
Full-Waveform
Data processing
Basilicata
Medieval archaeology

ABSTRACT

Airborne Light Detection and Ranging (LiDAR) is a quite recent (mid-1990s) remote sensing technique used to measure terrain elevation. Recent studies have examined the possibility of using LiDAR in archaeological investigations to map and characterize earthworks, to capture features that may be indistinguishable on the ground and to aid the planning of archaeological excavation campaigns.

Despite the great potential of LiDAR in archaeology, also linked to its unique capability to penetrate vegetation canopies and identify archaeological earthworks and remains even under dense vegetation cover, the use of airborne laser scanning data encounters serious challenges. Data filtering and processing as well as pattern extraction, classification of terrain information from raw LiDAR data is still a challenging ongoing research.

In this paper, we present the data processing chain along with the threshold-based algorithm we devised for the classification of ground and non-ground points and for the detection of archaeological features. The classification of laser data was performed using a strategy based on a set of "filtrations of the filtrate". Appropriate criteria for the classification and filtering were set to gradually refine the intermediate results in order to obtain the vegetation heights and to discriminate between canopy, understory and micro-topographic relief of archaeological interest. We selected sample areas within two abandoned medieval settlements in Southern Italy characterized by the presence of low and heterogeneous herbaceous cover and complex topographical and morphological features, which make the identification of archaeological features really complex.

Results from our investigations pointed out that the applied data processing enables the detection of micro-topographic relief in sparsely as well as in densely vegetated areas. The most important facts to cope with different environmental situations are mainly linked with (i) the resolution of the acquired data set and (ii) the data acquisition and processing chain specifically devised for archaeological purposes.

1. Introduction

The advent of LiDAR (Light Detection And Ranging) technologies generally known as airborne laser scanning (ALS) has completely revolutionized the area of topographic surveying. The applications of ALS have been increasing rapidly over recent years and the improvement of the sensor technique has made possible not only to monitor the surface of the earth but also to carry out a variety of new promising applications.

Recent studies have examined the possibility of using LiDAR for archaeological investigations and landscape studies by depicting and analyzing ancient earthworks in forested and non-forested areas (Motkin, 2001; Holden et al., 2002; Barnes, 2003; Bewley, 2003; Shell and Roughley, 2004; Sittler, 2004; Devereux et al., 2005; Challis, 2006; Doneus and Briese, 2006; Sittler and Schellberg, 2006; Risbol et al., 2006; Harmon et al., 2006; Corns and Shaw, 2008; Crutchley, 2008).

The latest generation of ALS is the Full –Waveform (FW) scanner that offers improved capabilities especially in areas with complex morphology and/or dense vegetation cover. Nevertheless, up to now investigations based on the latest generation of ALS are still quite rare. The majority of published studies are based on data collected by conventional ALS. Some investigations were carried

* Corresponding author. Tel.: +39 0971 427 214; fax: +39 0971 427 271.
E-mail addresses: lasaponara@imaa.cnr.it (R. Lasaponara), coluzzi@imaa.cnr.it (R. Coluzzi), n.masini@ibam.cnr.it (N. Masini).
[1] Tel.: +39 0971 427 321; fax: +39 0971 427 333.

0305-4403/$ – see front matter
doi:10.1016/j.jas.2010.10.003

out to assess the potential of both conventional and Full-Waveform LiDAR in known archaeological sites, such as an Iron Age hill fort, fossilized ridge and furrow and round barrows hidden under dense vegetation (Devereux et al., 2005; Sittler, 2004; Doneus and Briese, 2006). The results from these studies were generally highly satisfactory, but the full processing chain as well the algorithms used for extracting information from LiDAR raw data were generally not fully described. Despite the great potential, as well as the availability of numerous softwares and codes, the use of ALS data encounters serious challenges, mainly linked to the data processing and analysis, which must be carried out with caution in archaeological studies (Doneus et al., 2008). In this context, basic requirements are the reduction of signal distortion and mis-identification rate. To serve the purpose of archaeology and archaeological landscape studies, the reduction of omission and/or commission errors is mandatory to avoid that subtle archaeological features (such asditches, banks, round barrows, walls etc.) should be filtered out. The reliability of final Digital Terrain Model (DTM) products is linked to the success of removing non-ground points from LIDAR datasets and it is critical in determining the effectiveness of LiDAR for archaeology. The use of Full-Waveform ALS systems may improve the possibilities of correctly classifying terrain and off terrain objects.

In this paper, we present the data processing chain and the threshold-based algorithm devised for the classification of ground and non-ground points and for the discrimination of canopy, understory and micro-topographic relief of archaeological interest. The algorithm was applied to some test areas, located in two medieval sites in Southern Italy and characterized by diverse morphological features and cover types, in order to assess its effectiveness and reliability.

Results from our investigations pointed out that the data processing we set up is a valuable tool to detect and map micro-topographic relief in sparsely as well as in densely vegetated areas.

2. LiDAR in archaeology: sensors and data processing issues

2.1. Conventional and Full-waveform ALS

ALS is an active remote sensing technique that provides direct range measurements between laser scanner and earth's topography. Such distance measurements are mapped into 3D point clouds.

There are two different types of ALS: (i) conventional scanners based on discrete echo and (ii) FW scanners. The first detect a representative trigger signal for each laser beam, whereas the latter permit one to digitize the complete waveform of each back-scattered pulse; thus allowing us to improve the classification of terrain and off terrain objects, such as low vegetation, houses, and other natural or man-made structures lying on the terrain surface (Doneus et al., 2008), adequate filtering techniques.

The reduction of mis-classification and signal distortion is mandatory for the identification of archaeological micro-relief and for their interpretation. Moreover, the FW ALS sensor can effectively penetrate vegetation canopies. It enables us to obtain an accurate DTM(altimetrical accuracy <0.1 m) and therefore to detect archaeological structures and earthworks even under dense vegetation cover.

2.2. Data filtering

The classification of terrain and off terrain objects is crucial for the identification of archaeological features and subsequent interpretation (i.e. earthworks, surface structures, walls, etc.). Therefore, it is mandatory to apply adequate filtering methods which allow us to obtain accurate DTM even in presence of low vegetation and complex geomorphology, as in the test areas investigated in the current study (see section 4).

According Sithole and Vosselman (2004) on the basis of the structure of bare-earth points in a local neighborhood, filtering methods can been categorized into four groups: slope-based, block-minimum, surface-based and clustering/segmentation.

Slope-based algorithms measure the difference in slope (or height) between two points, and assume that the highest point belongs to an object if the slope is higher than a given threshold value.

By using Block-minimum algorithms, bare-Earth points reside on a horizontal plane (assumed as discriminant function) with a corresponding buffer zone.

Surface-based filtering methods assume as discriminant function a parametric surface with a corresponding buffer which defines a region in 3D space where ground points are expected to reside.

Finally, clustering/segmentation filtering approach assumes that any points belong to an object if their cluster is above its neighborhood.

Among the above-said filtering groups, the surface-based category appears to provide better results in separating points on a (ground) surface from other points (Sithole and Vosselman, 2004).

Examples of surface-based algorithms are: Axelsson (2000), Briese and Pfeifer (2001), Elmqvist (2001), (Sohn and Dowman, 2002), Wack and Wimmer (2002).

Axelsson's algorithm is based on a progressive Triangulation Irregular Network (TIN) densification. Starting from a coarse TIN surface (obtained from reference points which are neighborhood minima), new points are added in an iterative way if they meet criteria based on distances to TIN facets and angles to the vertices of the triangle.

Briese and Pfeifer (2001) is a hierarchic based method. Starting from an approximate surface it performs interpolations in each hierarchy level by assuming weight values based on vertical distance of the points to the same approximate surface, thus allowing to carry out the classification.

Elmqvist algorithm is based on the concept of membrane floating upwards from beneath the point cloud, which defines the form of the bare-Earth (Elmqvist, 2001).

Sohn algorithm uses a two-step (downward and upward) progressive densification of a TIN. The first (downward) operates a triangulation of four points closest to the corners of the rectangular bounds of the point cloud. The lowest point within each triangle is added to the triangulation. This process is repeated until no triangle has a point beneath it. The second step (upward) is performed in order to extract other bare-Earth points not catched by the downward.

In the Wack and Wimmer (2002) algorithm a raster DEM is generated from a raw point cloud in a hierarchical approach.

The circumstances under which the filtering methods could meet difficulties and limits (also considered by Sithole and Vosselman (2004) as testbed for a qualitative and quantitative assessment) generally are the following: i) outliers; ii) spatial and morphological object complexity; iii) attached objects; iv) low vegetation; v) and geomorphological discontinuities.

i) Outliers could be low (caused by multi-path errors and errors in the laser range-finder) and high (birds, low-flying aircraft, or errors in the laser range-finder).
ii) The spatial and morphological object complexity is a circumstance which typically characterizes an urban environment. In particular the filter algorithms are likely to fail in presence of very large objects, very small objects (elongated objects, low point count, such as vehicles), very low objects (walls, cars), complex shape.
iii) The attached objects are objects spanning the gaps between bare-Earth surfaces such as building on slopes, bridges, natural/artificial ramps.