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Archaeological prospection of forested areas using full-waveform airborne laser scanning

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Abstract

Airborne laser scanning (ALS) is a potential tool for recognising and measuring topographic earthwork features in wooded areas. To explore its potential for archaeological reconnaissance in a densely forested area, a test scan covering an Iron Age hillfort in the eastern part of Austria was carried out during the first phase of a research project.

ALS sensors can penetrate vegetation canopies allowing the underlying terrain elevation to be accurately modelled. The latest generation of airborne laser scanners was used in the project. This sensor digitally records the entire waveform of the received laser echoes. We argue that the digital terrain model (DTM) generated from entire waveform ALS data could be classified with greater confidence providing a more accurate DTM than with previous ALS devices. The processing algorithms used to create the interpretative DTM are discussed in detail.

Using the described procedures it was possible to remove most of the forest canopy and understorey (brushwood and low level vegetation) covering the archaeological features. The ALS DTM was compared with a detailed topographic mapping of the visible archaeological traces collected by a terrestrial survey. Significantly, very low earthwork features, which were not recognized by the trained surveyors in the field, were identified in the ALS-derived DTM. Therefore, in this study area ALS has been demonstrated as an important tool for systematic archaeological prospection in vegetated areas. There are, however, some restrictions, which are discussed in the paper.

Keywords: LiDAR; Airborne laser scanning; Full-waveform; DTM; Archaeological prospection; Forest; Earthwork

1. Introduction

Despite the success of archaeological prospection in agriculturally dominated regions, the identification of sites within wooded areas remains problematic. At present there is no prospection method for the systematic discovery of buried sites in forests. Fortunately, micro and macro topographic earthwork features tend to be well preserved in forested areas, due to the stabilizing effect of vegetation on erosion processes and the lack of surficial disturbance through mechanical action (such as ploughing).

Large (macro topographic) earthworks can be recognised from the air (using optical aerial photography techniques) typically as shadow marks or snow marks (Wilson, 2000, p. 38), even through the tree canopy. They are also visible from the ground and can be mapped using traditional surveying techniques: however, a woodland environment can make survey difficult and features may be obscured by brushwood and scrub. Conversely, low (micro topographic) earthworks, especially when covered with dense vegetation, are practically invisible from the air and can be difficult to locate on the ground even by an experienced surveyor.

To be able to facilitate identification of low earthwork features, one would need a dense coverage of surface terrain points that are accurately located in the x, y and z dimension. These points are used to generate a Digital Terrain Model

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(DTM) that can be used for archaeological interpretation. Only a few years ago, the measurement of such a huge quantity of points would have been impossible for larger areas, but with the recent development of Airborne Laser scanning (ALS) there is now the means to produce dense, precise, and accurate terrain models (Ackermann, 1999; Kraus, 2004, pp. 449–470; Wehr and Lohr, 1999) even under forest canopy (Kraus and Pfeifer, 1998; Pfeifer et al., 1999). In this paper an approach employing ALS techniques is presented.

There are an increasing number of ALS-applications in archaeology, but investigations in forests are rare (Devereux et al., 2005; Harmon et al., 2006; Sittler, 2004; Sittler and Schellberg, 2006; Risbøl et al., 2006). All published examples used terrain models derived from data collected by conventional ALS. We argue that conventional ALS may not be able to resolve the difference between near ground vegetation and the underlying terrain which can reduce the quality of any resultant DTM (Pfeifer et al., 2004). This inhibits any subsequent archaeological identification of low earthwork features.

This paper will present the latest generation of full-waveform recording ALS systems. It is hypothesised that these sensors have a number of advantages, especially in vegetated areas, which can lead to a better identification of low earthwork features. After introducing the basic techniques of ALS processing, the paper will deal with the under-represented aspect of deriving an archaeologically relevant digital terrain model (DTM) from unfiltered ALS data. The value of full-waveform ALS data is illustrated with a case study of an Iron Age hillfort in the eastern part of Austria.

2. Conventional and Full-waveform ALS

2.1. Principle of ALS

ALS, also referred to as LiDAR (Light Detection and Ranging), is an active remote sensing technique (Wehr and Lohr, 1999). The laser scanner is usually mounted below an aeroplane or helicopter, where it emits short infrared pulses into different directions across the flight path towards the earth's surface (typically 30,000–100,000 pulses per second). Each pulse will result in one or more echoes reflected from various objects along its path (vegetation, buildings, cars, ground surface etc.). The location of each reflecting object is calculated using the angle of the emitted laser beam, the distances to the reflecting object (measured by the time delay between emission and each received echo), and the position of the scanner (typically determined using differential global positioning system (dGPS) and an inertial measurement unit (IMU)).

Currently, there are two different types of ALS sensor system available: discrete echo scanners (conventional scanners) and full-waveform scanners (Fig. 1). Discrete echo scanners detect a representative trigger signal for multiple echoes in real time using analogue detectors. While most detectors deliver only the first and last echo, some can distinguish up to four distinct echoes from multiple targets from a single laser pulse. These sensors can be considered to be "lossy" as the majority of the received signal is discarded by the analogue detectors.

Full-waveform scanners digitise the entire analogue echo waveform for each emitted laser beam (typically with an interval of 1 ns, cf. Fig. 1, right part of the ranging unit) and convert the signal in a digital data stream, which has to be post-processed (Wagner et al., 2004, p. 105). During post-processing the full waveform can be modelled as a series of Gaussian distribution functions (GDF) (Hug et al., 2004; Wagner et al., 2006), each representing an individual object – laser interaction. Different algorithms can be applied to segment the data stream in different ways suited to the users need. This means that the user is not restricted to a group of discrete echoes controlled by a detector but can generate his own algorithms that respond to the physical and biological environments within which the laser interacts. Full-waveform scanners discard significantly less data than conventional scanners during the data collection process.

2.2. Limitations of conventional ALS

By selecting only the first echo of the scanned data (first echo data), a digital surface model (DSM) can be derived. Using only the last echo point cloud (last echo data) will theoretically result in a digital terrain model (DTM) representing the surface beneath the vegetation cover. However, where one would be confident that the majority of first pulse echoes will correspond with the surface model, one is less confident that the last pulse will correspond with the terrain model (i.e. the laser pulse may not actually penetrate through to the ground). Therefore, the last echo data has to be classified (typically the term filtered is used) into terrain and off-terrain points to improve DTM accuracy. Advanced filter methods have been devised to remove off-terrain points and have been compared by Sithole and Vosselman (2003). Since the archaeological interpretation of an ALS scan is mainly based on the derived DTM, it is critical that off-terrain points are removed from any data set.

With conventional scanners, as important information has been discarded during data collection, all the filtering algorithms rely on an analysis of the relative spatial variance to determine terrain and off-terrain points. Additionally, the range resolution to discriminate two consecutive echoes of the analogue detectors is typically 1.5 m (Kraus, 2004, p. 451). This is good enough to clearly distinguish trees from the terrain surface, but will not allow discrimination of low level vegetation from the ground (see also Fig. 1, where under "discrete echo determination" the detected echo (solid line) is a mixture of the terrain and scrub reflection (dotted lines)). So, in areas with low vegetation the resulting DTM will often not be a satisfactory representation of the terrain surface. This makes the interpretation of micro-topographical archaeological features difficult.

2.3. Conventional ALS and archaeological applications

All previous archaeological ALS applications have been conducted using conventional systems. In most cases, ALS