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# Interpreting cultural remains in airborne laser scanning generated digital terrain models: effects of size and shape on detection success rates

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ABSTRACT

In this study, detection success rates were evaluated for cultural remains that were detected manually based on interpretation of digital terrain models (DTM) derived from airborne laser scanning data and with a resolution of 1, 5 and 10 points $m^{-2}$. The group of cultural remains included charcoal kilns, charcoal pits, hollow-roads, various pits, house foundations, tar kilns, grave mounds and pit-falls. The effects on the interpretation success of different types of cultural remains and their physical properties were studied: size, shape and elevation difference showing that the detection success rates varied considerably. The main tendency was that large cultural remains with clear geometrical shape (ovals and circles) and large elevation difference were much more successfully detected and classified compared to the smaller ones, especially those without a clear geometrical shape. The study also showed that it was the identification of the larger structures which profited most from an increased resolution of the DTM, and it was of no help to increase resolution in order to improve the identification of the irregularly shaped cultural remains.



## 1. Introduction

During the last decade, discrete pulse airborne laser scanning (ALS) has emerged as a useful technique for the archaeological community (Doneus and Briese, 2011) with regard to derivation of digital terrain models (DTMs) to be used for the detection of cultural remains and monuments. Technically, a DTM is obtained from ALS data by first classifying the echoes from each emitted pulse into ground echoes and off-ground echoes and subsequently terrain modelling from the ground echoes. Compared to other remote sensing techniques used for the detection of cultural remains, the main advantages of ALS are the possibilities to effectively identify and remove the vegetation response from the dataset and analyse the surface topography. Although removal of vegetation data from the dataset is an essential advantage, it is important to mention that dense vegetation can lead to reduced canopy penetration ability and consecutive lower point density on the ground resulting in a coarser DTM. In turn this will reduce the ability to identify cultural features. Still, the possibility of working with a 3D-model of the surface topography free from most vegetation is one of the main reasons for the widespread interest in ALS for archaeological purposes.

The point density of the ALS data will affect the quality of the DTM and thus also the detection success rates of cultural remains. Bollandsås et al. (2012) studied the relationship between detection success rates and point density (1, 5, and 10 points $m^{-2}$) for nine $500 \times 500$ m areas within their study area. On average 24% (ranging from 0 to 68%) of all cultural remains were detected with DTMs derived from ALS data with 1 point $m^{-2}$. Corresponding mean values for DTMs derived from ALS data with 5 and 10 points $m^{-2}$ were 56% (11–90%) and 62% (11–87%), respectively. However, Bollandsås et al. (2012) did not analyze if there were differences in the detection success rates between specific types or categories (small/large, different shapes etc.) of cultural remains. Such analyses are highly interesting because correct classification and labelling of cultural remains is necessary for proper management. These analyses are also important for future studies on tuning automated algorithms for detection of cultural remains. To develop such algorithms, however, is out of the scope of the current study.

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The objective of the study at hand was twofold. The first objective was to assess if there were differences in detection success rates between different types of cultural remains that are manually detected using DTMs derived from ALS data. The data also enabled assessments of differences in detection success rates between different ALS point densities. The second objective was to assess differences in detection success rates between different categories based on the physical properties of the cultural remains. The categories were shape (circular, oval, square or irregular), size (maximum extension vertically as well as horizontally), and elevation (elevation difference from the top to the bottom of each remain).

## 2. Background

In many countries and regions, forested areas are those areas with the most sparse archaeological survey coverage today. Examples of the poor quality of surveys in forested areas can be found in former studies (Risbøl, 2005; Gustafsson et al., 2009). The quality of the field based surveys in forested areas with regard to proportion of known cultural remains is also lower compared to other land cover types. This makes ALS a highly relevant data source in order to improve the extent and quality of such surveys (Devereux et al., 2005; Doneus and Briese, 2006; Risbøl et al., 2006; Bofinger and Hesse, 2011; Georges-Leroy, 2011; Rutar and Črešnar 2011). The incomplete databases of cultural heritage represent a challenge to cultural heritage management, and this affects the way in which landscapes are understood by archaeologists as scenes of human activity (Risbøl, 2013). The poor quality of survey data in forested areas has a severe impact on the ability to exert an informed management in accordance with good preservation practices; the large number of new remains identified through ALS will have an important impact on the understanding and management of these areas. Some studies have indicated a substantial increase in the number of identified remains in forested areas when DTMs derived from ALS data are taken into use (Doneus and Briese, 2011; Georges-Leroy, 2011; Hesse, 2013).

It is evident from these studies that remains identified through ALS survey will rapidly come to constitute the majority of documented archaeology in forested areas. Further, given the difficulty of on the ground survey across large forested areas, it is suggested that 100% verification of the remains identified through the ALS surveys is neither practical nor desirable. It is therefore essential that the extent is established to which one can be confident in the interpretations of the ALS survey data. A number of studies have sought to establish confidence levels through comprehensive field checks. In a study carried out by Gallagher and Josephs (2008), 78% of 32 detected anomalies turned out to be cultural remains when verified in field. Furthermore, previous studies have indicated that detection success rates of cultural remains from DTMs differ for different types of cultural remains. In a Norwegian study (Risbøl, 2010), 74% of 62 charcoal pits in a forested area were detected but none of the six iron production sites (slag heaps) when ALS generated relief models were interpreted using a geographical information system (GIS). However, the results were improved when the DTM was interpreted with the use of the Quick Terrain Modeller (QTM) software (http://www.appliedimagery.com/) designed to easily handle and enhance ALS derived terrain models. Using this software in an attempt to detect cultural remains in an adjacent part of the aforementioned forested area, 83% of 20 charcoal pits and 1 out of 2 iron production sites were detected (Risbøl, 2010). These studies highlight two important points. First, that the reliability of the detection and identification of remains varies based on the character of the remains. Second, that the manner in which the data is visualized has a significant impact on the reliability of the interpretations. The present study makes a more formal and comprehensive analysis of these points.

Even though some studies have pointed out that small and less distinct remains are hard to detect (Doneus and Briese, 2006; Risbøl et al., 2006; Hesse, 2010; Shaw and Corns, 2011), no studies have been conducted so far that specifically address the relationship between detection success rates and physical properties with the cultural remains in forests, for example size and shape, although it is touched upon in some publications (Sittler and Schellberg, 2006; Gallagher and Josephs, 2008; Risbøl, 2010; Bofinger and Hesse, 2011; Georges-Leroy, 2011). In addition, some cultural remains with certain properties can be difficult to detect even by means of DTM interpretation and some of those cultural remains actually detected can be erroneously classified. For example, in some cases grave mounds have been misinterpreted as natural terrain elevations (Bofinger and Hesse, 2011) and similar confusions have occurred with slag heaps (Risbøl et al., 2006). However, Risbøl (2010) found that once an anomaly had been detected and defined as reminiscent of human activity, the classification accuracy was high.

As indicated earlier, interpretation of DTMs derived from ALS data in order to detect cultural remains is still a relatively new method in archaeology. Even though technically advanced approaches have been developed in recent years in order to enhance the visualising of DTMs, by, for instance, creating hill-shaded representations from multiple view directions (Devereux et al., 2008), or by the use of Local Relief Models (Hesse, 2010) or sky-view factor (Kokalj et al., 2011), most archaeologists using ALS generated DTMs in their work use hill-shaded images as their primary visual cue to ALS data (Štular et al., 2012). A comparative study of a series of different visualisation techniques have been published by Challis et al. (2011) and Bennett et al. (2012). Thus, more studies that assess the quality of such interpretations are needed, especially studies that assess the relationship between detection success rates and the different types of cultural remains as well as different categories according to size and shape. Furthermore, it is also important to increase knowledge about which types of cultural remains or monuments are most often confused. Misinterpretation can cause a poor understanding of the cultural history of the landscape. Accurate information on the presence and absence of the different cultural remain categories is of high relevance for improving the understanding of how landscapes were utilized by humans in the past and how single cultural remains enter into a larger context. Further, correct classification of cultural remains is also important for understanding the time-depth of a landscape and how human impact on the landscape changes with time. Additionally, the fact that some remains might be protected by law while others are not, emphasizes the importance of right classifications. Therefore, in many instances exact information is needed in order to comply with the legal regulations concerning the management of cultural heritage.

Thus, in the present study we wanted to evaluate the detection success rate for a range of cultural remains situated in a forested area.

## 3. Material and methods

### 3.1. Study area

The study area is situated in Eidsvoll and Nannestad municipalities, 40–50 km north of Oslo in the south-eastern part of Norway (60°15′N, 11°10′E, approximately 200 m above sea level (Fig. 1)). Within this area land-cover is mostly forest (70%) dominated by conifer species. The area was chosen because it was expected to hold a variety of cultural remains within a relatively