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Automatic detection of mound structures in airborne laser scanning data

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ABSTRACT

This paper describes a processing chain for the semi-automatic mapping of grave mounds from airborne laser scanning (ALS) data. In a digital terrain model (DTM) of the ALS ground points, the automatic method slides a template mound over all positions, and assigns confidence scores to anything resembling a mound. The integer scores range from 1 to 6. By using mound templates with gradually increasing radii from 1.0 to 16 m, the method is able to detect all mounds in this range, provided they are visible and well-formed in the DTM. Despite a high number of false positives, the method is a useful tool in semi-automatic, detailed mapping of known grave fields, especially when the number of ground points per square metre is sufficiently large. The method is also able to identify the location of a previously unknown grave field. We discuss possible improvements of the method. The highest potential for better detection performance is in ALS acquisition in the early spring or the late autumn, when leaves are not present.

1. Introduction

Several Norwegian municipalities are experiencing growing pressure on forested land for the development of, e.g., new residential areas, industry, tourism, or highways. The traditional mapping of cultural heritage, mainly based on chance discovery and inaccurate positioning, has proven inadequate for land use planning. Therefore, the Norwegian Directorate for Cultural Heritage, in cooperation with some counties and municipalities, is investing in the development of new methods, using new technology, for a more systematic mapping of cultural heritage.

One of the most frequent types of archaeological structure in Norway is grave mounds (Fig. 1), many of which are located in forested areas. By using airborne laser scanning (ALS) data, also called airborne lidar data, and by separating the ground returns from the returns from trees and buildings, forest vegetation can be removed from the data, and a detailed digital terrain model (DTM) of the ground surface can be constructed (Devereux et al., 2005). This makes it possible to detect grave mounds in a semi-automatic fashion, provided they manifest themselves as mound structures in the DTM of the ALS ground returns.

ALS data have been used by many authors for archaeological mapping (e.g., see Opitz and Cowley, 2013; Doneus et al., 2008; Bewley et al., 2005). For manual interpretation of the ALS data, a number of visualization methods exist. Hillshade and slope images may be generated by standard image processing and GIS software from a DTM. Hillshade images provide an intuitive visualization, but archaeological structures parallel to the illumination direction may be missed, so several illumination directions (Devereux et al., 2008) must be used if linear structures are to be mapped. Hesse (2010) subtracted a smoothed version of the ground surface DTM from the original to obtain a local relief model, thus enhancing local detail and suppressing the large-scale terrain. Kokalj et al. (2011) computed the sky-view factor to emphasize local detail. Doneus (2013) used openness for the same purpose, while Doneus et al. (2013) used a local relief model to map traces of the Viking Age harbour at Borre, Norway.

Although originally presented as visualization techniques, methods such as local relief model, sky-view factor or openness may be used in a pre-processing step for (semi-) automatic classification. Pregesbauer (2013) used openness for the semi-automatic mapping of grave mounds in the Birka-Hovgården UNESCO World Heritage monument in Sweden.

Pregesbauer (2013) compared pixel-based and object-based classification. In the latter, pixels are merged into segments (also called objects), which is followed by classification of the segments (or objects). Trier and Pilø (2012) used template matching instead of segmentation to identify candidate objects which were then classified. The difference between segmentation and template matching is that segmentation is a subdivision of the image into non-overlapping objects, whereas template matching may create overlapping objects. Typically, their union covers only a fraction of the entire image area.

Hesse (2010) noticed that some archaeological structures, such as burial mounds, can be confused with natural phenomena such as small natural hills, wood piles, and patches of low vegetation. Doneus et al. (2008) used full waveform lidar to better discriminate between low vegetation and structures of archaeological interest.

We have recently developed a method for the semi-automatic detection of hunting systems and iron extraction sites from ALS data (Trier and Pilø, 2012). This method is now in use as part of the standard

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Fig. 1. Examples of grave mounds, Larvik municipality, Vestfold County, Norway. Top: a grave mound in Bøkeskogen, with a thin layer of snow. Bottom: a grave mound in Brunlafeltet, with a looting pit in the middle.

procedure for archaeological mapping in Oppland County, Norway. The purpose of this study is to develop a similar method for the automatic detection of mounds in ALS data, to assist archaeologists in a more accurate and complete mapping of grave mounds. Preliminary results have been presented at conferences (Trier and Zortea, 2012; Trier et al., 2012, 2013).

2. Data

Larvik municipality in Vestfold County is known to contain a large number of grave mounds in forested areas. For 228 km^2 in the south of Larvik municipality, ALS data was acquired on 3–7 June 2010 by Blom Sweden with a TopEye laser scanner on a helicopter at 450 m altitude and 22 pulses/m^2. The raw data contain full waveform information, but were subsequently processed and converted by Blom Sweden to LAS 1.2 format, with up to 4 discrete returns for each emitted pulse. ALS data for the remaining 390 km^2 of Larvik municipality was collected at 1 pulse/m^2 on 24 May 2010 by Blom Geomatics with an Optech ALTM Gemini laser scanner on an airplane at 1275 m altitude.

Please note the distinction between pulses/m^2 and points/m^2. As each pulse may produce up to four discrete returns, typically from different parts of a tree canopy, the number of points/m^2 may be higher than the number of pulses/m^2. However, in the presence of tree vegetation, many pulses may never reach the ground, so the number of ground points/m^2 is typically much lower than the number of pulses/m^2.

Originally, data acquisition in late April 2010 was planned. However, the flight was delayed by over a month due to other engagements and

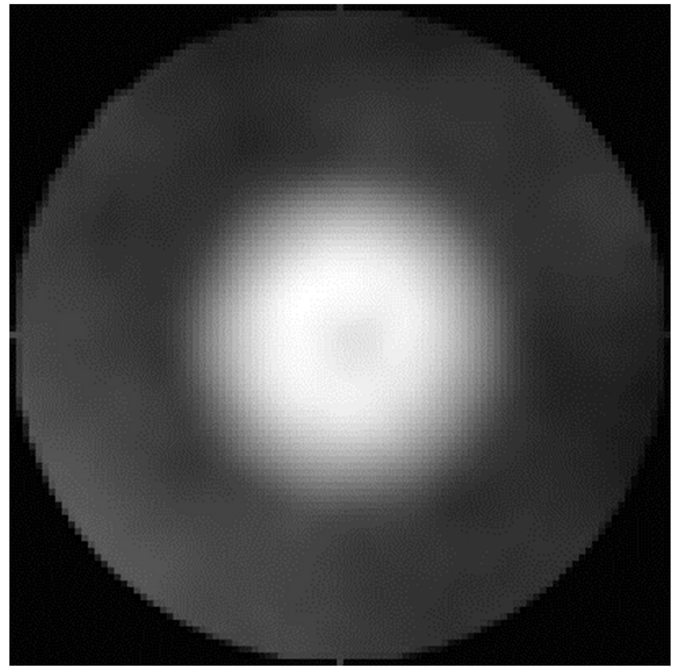

Fig. 2. Average grave mound, estimated from training data, including surrounding terrain within 2× radius from the centre. Average maximum mound height = 1.38 m; average mound radius = 6.27 m.

Table 1
Training data.

Name	Pulse density	Extent in UTM zone 32 N				Size (m × m)	Area (m^2)	# known mounds
		West	East	South	North			
Berg	22/m^2	552,800	552,930	6,539,150	6,539,250	130 × 100	13,000	4
Bommestad-1	22/m^2	561,420	561,500	6,550,030	6,550,110	80 × 80	6400	1
Bommestad-2	22/m^2	561,600	561,790	6,549,820	6,549,960	190 × 140	26,600	9
Bøkeskogen	22/m^2	558,600	558,950	6,546,800	6,547,140	350 × 340	119,000	72
Hvatumskjeet	22/m^2	554,850	554,960	6,542,230	6,542,570	110 × 340	37,400	12
Kjerneberget-1	22/m^2	561,600	561,730	6,548,850	6,549,000	130 × 150	19,500	2
Kjerneberget-2	22/m^2	562,120	562,250	6,548,760	6,548,870	130 × 110	14,300	19
Tanum	22/m^2	556,470	556,700	6,543,960	6,544,150	230 × 190	43,700	12
Valby-1	22/m^2	563,000	563,300	6,545,670	6,545,970	300 × 300	90,000	4
Valby-2	22/m^2	562,560	562,770	6,545,930	6,546,170	210 × 240	50,400	5
Valby-3	22/m^2	563,100	563,250	6,546,430	6,546,600	150 × 170	25,500	3
Valby-4	22/m^2	563,450	563,580	6,546,290	6,546,510	130 × 220	28,600	5
Valby-5	22/m^2	563,640	563,720	6,546,440	6,546,520	80 × 80	6400	1
Valby-6	22/m^2	563,740	563,830	6,546,220	6,546,340	90 × 120	10,800	4
Sum							491,600	153