The potential of Lidar in assessing elements of cultural heritage hidden under forests

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ABSTRACT: Knowledge of the historic landscape is far stronger in agricultural areas than in woodlands because conventional aerial photography that has been the mainstay of airborne archaeological reconnaissance is unable to detect finer features hidden under forest canopies. As Lidar (Light Detection and Ranging) remote sensing enjoys the advantages of excellent vertical and horizontal resolution range and has the capacity to record the topography even under vegetation, it now offers new prospects for heritage assessment purposes.

This technique has been tested in various projects for obtaining high resolution assessments of earthworks that survived in woodlands, such as ridge and furrow or burial mounds near Rastatt in South West Germany. These examples show to what extent data obtained from airborne laser scanning missions carried out by the state survey agency of Baden-Württemberg for the purposes of upgrading the state’s altimetric database can also be of use for heritage assessment and preservation purposes. Examples presented here and showing also the detection range for fine scale structures provided by this method may be helpful for optimising any other airborne laser scanning approach (requested point density, use of method in mountainous areas, etc.).

1 INTRODUCTION

LIDAR, an acronym for Light Detection and Ranging, is rapidly emerging as an important tool for modern topographical surveys. While using this technique is becoming commonplace as a solution for generating digital terrain models in applied fields like hydrology, natural hazard assessment, resource monitoring, civil engineering and industry, its application for heritage purposes still lags behind.
The attempt to assess the distribution pattern of ridge and furrow as remains from medieval fields conserved under forests near Rastatt (Baden) provided a particular opportunity to test this methodology for heritage purposes. Because ground surveys i.e. geomatic levelling initially considered to collect fine scale 3D resolution data of these corrugated earthworks soon proved to be too labour-intensive to be conducted on larger areas, airborne laser scanning missions commissioned by the land survey agency of Baden-Württemberg to upgrade contour maps offered such an interesting possibility to assess usefulness for heritage purposes. Along with the assessment of ridge and furrow, also other examples of heritage structures revealed by this assessment in other parts of Baden-Württemberg were selected.

The purpose here is to provide heritage surveyors with the potential of this methodology in forested areas and to discuss limitations that should be considered when opting for this technique.

2 METHODS

2.1 Principles of the Laser Scanning technique

For readers unfamiliar with this technique, detailed descriptions may be found in Ackermann, (1999). In short, airborne laser scanning is based on distance measurements and precise orientation of the measurements between a sensor and a reflecting surface. It is used in conjunction with airborne GPS and an inertial measurement unit, allowing then getting highly accurate elevation data. The system operates on the principle of reflecting a pulsed laser off an oscillating mirror and measuring the time of flight to determine the distance travelled by the laser pulse. An integrated geopositioning system determines the sensor’s precise position (x, y) and altitude (z). This information, combined with the angle of the mirror, is used to calculate 3-D positions of terrain points. Lidar systems yield elevation data with an accuracy that ranges from 0.5 m to less than a decimetre, depending on the altitude of the aircraft and the frequency of the readings.

A special issue is the restitution of the data in forested areas (Hyppä et al. 2001; Pfeiffer et al. 1999), since Lidar does not discriminate collecting features such as trees, buildings, as well as the ground. The entire data set is known as a “point cloud.” If the laser pulse is sufficiently powerful and the canopy has gaps, some energy will penetrate completely to be reflected back from the ground.

Automatic algorithms can remove surface objects such as vegetation, buildings and other structures. Once removed, the processed LIDAR data set is known as a “bald earth” DHM (Digital Height Model), which is used for orthorectification and contour creation. Limitations include the fact that some vegetation and large buildings are not removed if the filtering is not aggressive enough. Other problems arise when the terrain surface is under-sampled. In addition, because LIDAR has finite point spacing, it may not capture sharp terrain breaks precisely. Furthermore, certain types of land cover, such as thick grass in a field, can cause a systematic bias.

Analysing data in 3-D then helps users visualise spatial relationships for sound decision-making, and facilitates effective and clear communication of planning ideas.
2.2 The Laser Scanning project of Baden Württemberg

The Land and Survey bureau of the Baden-Württemberg state (Landesvermessungsamt) has adopted the airborne laser scanning technique for the purpose of upgrading existing contour maps of the entire state (Hoss, 1997; Gültlinger et al. 2001). It was aimed at providing comprehensive altimetry data at a resolution of around one meter mesh width in space and less than 50 cm in height. A special demand for such high accuracy was mainly from flood protection agencies, but additional interest emerged also from a wide range of other potential users. The company Topscan was commissioned with the flight campaigns and delivery of data sets. The project started in 2000 and was due to be completed by the end of 2005. Technical details of the flight missions are listed in the table below.

Data processing scheme: The dataset provided by Topscan was first pre-processed by the services of the Land surveying agency. This step included the automatic filtering of ground and height points, as well as georeferencing the data into Gauss Krüger coordinate system. A further step consisted in interactive postprocessing of this first filtering result to fully remove all objects from the bare ground. Once this was done, a Digital Elevation Model (also Digital Terrain Model) of the ground surface could be obtained.

2.3 The study sites

All sites selected for the purpose of this study were included in the Topscan flight mission encompassing the whole land of Baden-Württemberg.

2.3.1 The Rastatt ridge and furrow field system

This site includes an exceptionally well preserved pattern of a medieval ridge and furrow field system whose terrestrial surveys (Hauger et al. 2001) earlier revealed the great extent and good state of preservation of the microtopography. The area is located on a sandy and dry flat terrace from the River Rhine near Rastatt, some 30 km south of Karlsruhe. It includes various stands with older mixed forests (beeches, pine trees and Norway spruces), as well as areas with denser young stands. The corrugated fields dating back to the Middle Age display height differences of 30 to 50 cm, often hardly visible from the ground due to obscuring underwood vegetation.

2.3.2 Other archaeological sites in Baden Württemberg

For the purpose of assessing the degree of delectability of other features of interest for future heritage surveys, additional sites were selected by the archaeological services. These included;

Table 1. Topscan laser scanner performance parameters.

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Scan frequency</th>
<th>Scan angle</th>
<th>Wave length</th>
<th>Strip width</th>
<th>Pulse repetition</th>
<th>Point spacing</th>
<th>Flight velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 m</td>
<td>25 Hz</td>
<td>+/- 20°</td>
<td>1.55 m</td>
<td>400 m</td>
<td>25.000 Hz</td>
<td>1.5 m</td>
<td>80 m/s</td>
</tr>
</tbody>
</table>

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The remains of the hillfort of Hohennagold that dates back to the 11th century and which occupies a prominent, elongated ridge mainly covered by forests (mixed stands),

The star redoubt of Ötisheim near Pforzheim that may be referred as belonging to the “Eppinger defence Line”.

The deserted mining complex of Wiesloch dating back to the earlier Middle-Age and known for tin and lead excavations. The remnant landscape includes a cluster of various mining related features such as ping crates (depths of one to four meters, diameter of 6 to 8 meters) and waste-piles.

3 RESULTS

3.1 The detection and assessment of ridge and furrow field system

The data made available for this pilot study were in ASCII format. By interpolating the data in Erdas Imagine a DSM (Digital Surface Model) was created from the height points (Figure 1a), while the corresponding DTM (Digital Terrain Model) was obtained from the ground points (Figure 1b).

While the scenery in first pulse (Figure 1a) does not reveal the ridge and furrow microrelief, the DTM (Figure 1b) clearly shows the typical corrugated surface topography. This is especially evident when visualising in 3-D images with different viewing directions (Figure 2, below). These figures clearly portray the pattern of the earlier medieval landscapes with the strips and furlongs. Additional structures that may be detected at a first glance include tumuli or earth mounds seen in the upper right part of Figure 1b. In contrast, ridge and furrow structures may no longer be detected in the open landscape with arable land where they have been levelled off. In some of these modern fields, aerial photographs by Braasch (unpublished) have revealed the ancient pattern as crop marks appearing in the refilled furrows.

3.1.1 Assessing the ridge and furrow

Besides the visual detection of the patterns, another purpose was to assess the sizes (surface area, length, width) and heights of the ridge and furrow. These parameters were determined using the 3D analyst extension of ArcView 3.2. It involved manual delineation of single furlongs (Figure 3).

The 3D analyst extension can measure the surface area and volume of surfaces. The surface area is measured taking height into consideration. This parameter is different from the 2D planimetric extent of every model. The 2D planimetric surface is a virtually square area when a surface is viewed from above. The surface area on the other hand is the real surface and gives sufficient information about surface roughness and undulation. The greater the difference between the two parameters is, the rougher the surface will be.

The length is determined by measuring the distance across a ridge and the mean width of a furlong calculated by dividing its planimetric area with its corresponding length.

The determination of height proceeded with the establishment of spatial profiles across the ridges. The spatial profiles are later demonstrated in the form of graphs from which height values are easily read (Figure 4). Distance is plotted on the horizontal axis and elevation (height) on the vertical axis.
Quite insightful for landscape research is a closer analysis of the patterns revealed by the sceneries. The visualisation of these structures under forest as provided by this technique recalls also in some respect the aerial oblique photographs of ridge and furrow still visible in unforested countryside under grassland (Beresford & Saint Joseph, 1979). Compared to the terrestrial mapping (Hauger et al. 2001) this image unveils many details.

Figure 1. The pilot study area (1 km × 1 km) displayed as [a] digital surface model (DSM); [b] digital height model (DHM).

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and structures that were overlooked during these ground surveys. In addition, the position of other structures included in this landscape as revealed by the laser data is quite instructive. As an example, the Sandbach river is shown to cut the ancient pattern of ridge and furrow, indicating that it is of anthropogenic origin. The same applies of course to the very straight ditch (Hardtgraben) crossing the area: In the present case, as

Figure 2. 3-D Visualization (Virtual GIS).

Figure 3. delineated furlongs for size assessments.
written archives suggest that it was built during the 15th century, evidence is provided that ridge and furrow were generated at an earlier date.

3.2 Additional archaeological structures

The Laser scanning data of the site were then processed by the land survey agency to generate fine scale Digital Terrain Models. Displayed here are the last pulse sceneries obtained for the selected sites and revealing the landscape devoid of any forest cover.

The hillfort of Hohennagold (Figure 5) The defences of the hillfort including some surviving ramparts defending the fort as well as a defensive circuit appear well in this 3-D representation. In addition, as may be seen here, this survey has successfully traced the course of some missing defences and other features like terrace borders and some earth mounds that could be tumuli.

The star redoubt fortification of Ötisheim near Pforzheim (Figure 6). As a star shaped geometric feature, this redoubt rising around 2.5 m above the surroundings becomes clearly apparent in 3-D representation.

The deserted mining area of Wiesloch. This scenery provides a good overview of the distribution pattern and the different sizes of the ping crates (Figure 7), with also remnants of other activities that still need clarification.

Figure 5. The hillfort of Hohennagold.
4 DISCUSSION AND CONCLUSIONS

The approach adopted here shows that laser measurements do clearly reveal topographic structures like those displayed by these corrugated fields or other structures whose minimal size exceeds one meter, despite being hidden under a forest canopy creating true-to-life renderings of the countryside.

In this regard it is interesting to note that in the case of the ridge and furrow site, differences in canopy density resulting from the “lothar” storm in 1999 (Figure 1a), apparently did not affect the quality of the Digital Terrain Model obtained (Figure 1b).

Compared to terrestrial mapping as done in an earlier stage of this project (Hauger et al. 2000), laser scanning has proved its efficiency in rapidly generating dense accurate digital models of the topography and vertical structures of targeted surfaces.

Figure 6. The star redoubt fortification of Ötisheim near Pforzheim.

Figure 7. Deserted mining complex of Wiesloch.
However, the accuracy of the measurements still remains to be tested by ground measurements. It depends on several factors, including also the degree to which the post processing is successful. Moreover, while delineation of ridges (polygons) was done by manual digitisation on the screen, algorithms could possibly be developed in a further stage to automatically discern the single furlongs and take there measurements. De Boer (2005) has successfully developed such algorithms to automatically excerpt earth mounds from Lidar data in the Netherlands. Such testing on the degree of delectability of the earthworks as well as the accuracy assessments derived from laser data analyses will be the focus of Lidar missions of various archaeological sites in Alsace (F) Spring 2007.

As a whole, the resolution of these data and the relative ease of capture compares favourably with existing data sources, allowing large areas of landscape to be captured as three-dimensional surface data facilitating a scientific, analytical approach to the landscape. Similar results in assessing archeological sites in woodlands were obtained by Devereux et al (2004) in England, Bofinger et al. (2006) in Germany as well as by Doneus and Briese (2006) near Vienna (Austria). In this latter study, it could also be demonstrated how the use of full-waveform lasercanning proved successful in detecting still additional features and smaller sized elements.

In terms of costs, minimum entry prices for smaller projects in Germany range from less than 7000 Euro to upwards 20000 Euro depending upon the data provider. But of course, for projects, of only the order of tens of acres, the per acre cost becomes significantly higher due to the fixed sunk costs of mobilising the Lidar sensor. In the case of Baden Württemberg that now disposes on a nearly comprehensive coverage of the land (35000 km²), data may become available through the surveying agency (LVA) at following conditions (not including taxes):15 Euro/km² for untreated data and 60 Euro/km² for end-products usable for Digital Terrain Models generation.

Such conditions provide therefore a very attractive cost-effective alternative for future surveys of remnants of past landscapes. For archaeologists in general, it may open historic structures and archaeological sites to more visually detailed, accurate and efficient examination and can therefore be regarded as a very useful complement to aerial photographs, especially when forest canopies prevent visual identification of hidden patterns (see also Devereux et al. 2005). In planning such approaches, besides opting for a full waveform laser scanning (Doneus & Briese, 2006), using the intensity of Lidar data as shown by Challis et al. (2006) can also prove insightful especially in cases where archeological remains may become highlighted by wetness differences.

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