AIRBORNE LASER SCANNING OF CULTURAL FEATURES IN NORWEGIAN FORESTS: PRELIMINARY RESULTS FROM A PILOT PROJECT[1]

Ole Risbøl
NIKU – Norwegian Institute for Cultural Heritage Research[2]

Background to the project

Using air-borne laser scanning – lidar or LiDaR (Light Detection and Ranging) as it is usually called – for archaeological purposes is relatively new. However, some recent projects have tested this method in different types of terrain, scanning different kinds of monuments or remains (see for instance Bewley *et al.*; Devereux *et al.* 2005; Sittler 2004). Inspired by the promising results of these projects we wanted to try out the method in Norway under the specific conditions faced by Norwegian archaeology and cultural heritage management. Money was raised for a pilot project, mainly carried out in 2005 and reported on in 2006 (Risbøl *et al.* 2006)[3].

Cultural remains in Norwegian forests

The background to the project is to be seen in the light of the registration of cultural remains in Norway, along with the possibility of enhancing the situation by the use of new technical methods such as remote sensing.

According to the Norwegian Cultural Heritage Act all monuments and sites earlier than 1537 AD are automatically protected. Monuments and sites are defined as '*all traces of human activity in our physical environment*'. This is a rather strict provision, hardly surpassed in any other country. Nevertheless, there is a large amount of destruction of monuments and sites. Many cultural remains are illegally damaged each year, both deliberately

[1] The Klaipėda seminar took place in November 2005 and this paper first and foremost presents the results of our project at that time.

[2] The pilot project was carried out in collaboration with Arnt Kristian Gjertsen, NIJOS – Norwegian Institute of Land Inventory, and Kjetil Skare, Hedmark County Council. It was funded by the participating institutes along with support from the Norwegian Directorate for Cultural Heritage.

[3] It was subsequently agreed that the project would continue in 2006 with additional financial support from the Norwegian Directorate for Cultural Heritage. See also: http://www.niku.no/index.asp?strurl=//applications/system/publish/view/showobject.asp?infoobjectid=1001416

and accidentally. The main reason for this is the lack of archaeological surveys covering all parts of the landscape. In the period 1963-1991, the systematic registration of prehistoric and medieval monuments and sites was carried out on a national scale. Because of economic limitations, prioritizing was necessary and attention was concentrated on infield areas while forest and other outfield areas received little consideration. The result is that thousands of legally protected cultural remains are not mapped and therefore not taken into account, for instance those located in woodland. To put it another way: in a legal sense the tools for managing cultural monuments in forests are appropriate, but the inventories are not.

Excluding forest areas from the national survey has resulted in a distorted picture of the cultural landscape. This is serious because 38% of the Norwegian land area is forested, equal to 123,585 sq.km. The majority of this area has never been examined for cultural monuments. Over the past two decades some major archaeological projects have been carried out in outfield areas, revealing the very varied history of large, non-agrarian areas in forests and mountains. Surveys and excavations have contributed to a better understanding of the significance of forested areas as a space for a wide range of activities in prehistoric and historic times. This is thought-provoking with regard to the possibility of managing this part of our cultural heritage. The point is well illustrated in the results of a large archaeological field-survey study, the Gråfjell-project. In response to the establishment of a new military regional training and firing range in SE Norway, a forest and outfield area of approximately 230 km^2 was surveyed by archaeologists in four stages from 1999-2003 (Risbøl 2005). In total, 3000 features were recorded, of which two-thirds were protected by the Norwegian Cultural Heritage Act. Prior to the survey only 144 of these were known.

The use of lidar

The lidar project was carried out as a potential method of improving the registration situation. Our main goal was to test airborne lidar in Norwegian forest contexts. Three clear constituent goals

were formulated: 1) To what extent is it possible to locate cultural remains hidden by vegetation from the air? 2) Is the method useful in mapping cultural remains? 3) Is it possible to define the structures detected by lidar? In other words: is it possible to distinguish cultural features from natural ones, to map these with accuracy and to interpret exactly what kinds of cultural remains we are actually seeing on the lidar maps?

Air-borne laser scanning works in the following way: the lidar device is installed in an aircraft, from which a huge number of laser pulses are transmitted towards the earth surface below. When the pulses hit the surface, or some physical object above the surface, echoes are returned to the aircraft, where they are recorded and stored. Each pulse is simultaneously given an x-, y- and z-coordinate by a GPS system which is also installed in the aircraft. A pulse is a bundle of rays that widens with the distance from the aircraft. The 'footprint' when it reaches the surface below will be between 15 and 60cm across. By collecting data in this manner one is able to create a precise topographical map, or digital terrain model (DTM), of the surface. The precision is usually around 0.5-1.0m in the x- and y-coordinates and 15-30cm in the z-coordinate.

The laser scanning was carried out in June 2005 using a small aircraft, a PA 31 Piper Navajo, to collect the x, y and z-data from the test area. The aircraft was flown at an altitude of 1000m with a speed of 75m per second. 70,000 pulses were launched every second and 4 returns of each pulse were stored, of which the last were the ones penetrating the vegetation and reaching the surface of the ground. The ground points make it possible to create digital terrain models, which is the aim when objects on the ground are to be uncovered. Lidar data was collected along 14 traverses, each with a width of 611m and side overlaps of 55%. The overlaps optimise the possibility for laser rays to reach the ground – even in areas with quite dense vegetation – due to the variation of the direction of the rays. In this way an average of three or four points per square metre were collected and processed and maps in the form of relief models were created covering the test area. The relief models were analysed visually by the project group in order to

single out a range of different, more or less clear, anomalies which were then interpreted. After the analyses we spent three days in the field for the purpose of testing the results of the analyses.

The test area is situated in SE Norway in a landscape dominated by coniferous forest and substantial areas of bog. It covers 10 km^2. Parts of it had been systematically surveyed by ordinary fieldwork methods a few years before our project. The assortment of cultural remains in the test area is fairly limited and consists first and foremost of iron production sites (Figure 1), charcoal pits (Figure 2), a few pitfalls for elk and some tar kilns. Iron production sites and charcoal pits in this area usually date from the late Iron Age and early Middle Ages – approximately 900-1300 AD – while the tar kilns tend to be a few centuries younger. In this period the iron production was based on bog ore and charcoal made from timber from the extensive forest areas. The pitfalls are probably medieval but might be older.

Charcoal pits are the most common prehistoric cultural features in Norwegian forests. In these pits, which are situated in the area around the iron production sites, charcoal was produced for use in the iron production. The average charcoal pit in this area has a diameter of 5-6m and is between 0.5m and 1.0m deep, with an encircling bank. Pitfalls for elk resemble charcoal pits but are deeper; usually ≥1m.

Figure 1. Two examples of typical slag heaps.

Figure 2. Two examples of typical charcoal pits.

The visible parts of the iron production sites usually consist of one to four slag heaps on each site. Some of the heaps are round, some oblong, and where there are more than one they lie at a distance of 7-8m from one another. Usually the height is less than 1m. The round slag heaps have a diameter of approximately 5m. The oblong ones have a length of approximately 7-8m and a width of around 4-5m. In some cases smaller heaps containing charcoal or roasted bog material meant for use in the furnace are visible on the production site as well.

Tar production was carried out either in kilns or in oblong ditches situated on sloping terrain. In the test area only oblong ditches were found. They are approximately 10m long, with a bank along each side and with a total width of 2-3m. At the lower end of the ditch there is normally a pit for collecting tar. Tar was produced from resinous pinewood and was used, for instance, in preserving wooden buildings, boats, ropes and fishing nets.

Results

In addition to the relief models, orthophotos were taken over the test area. The orthophotos gave information about the state of the forest: for instance the density of the forest cover. In the test area some large bogs and clearings stand out as open areas, while other areas are rather densely covered with trees, predominantly conifers but also with some deciduous trees (Figure 3). To distinguish cultural monuments based on ordinary vertical photographs of

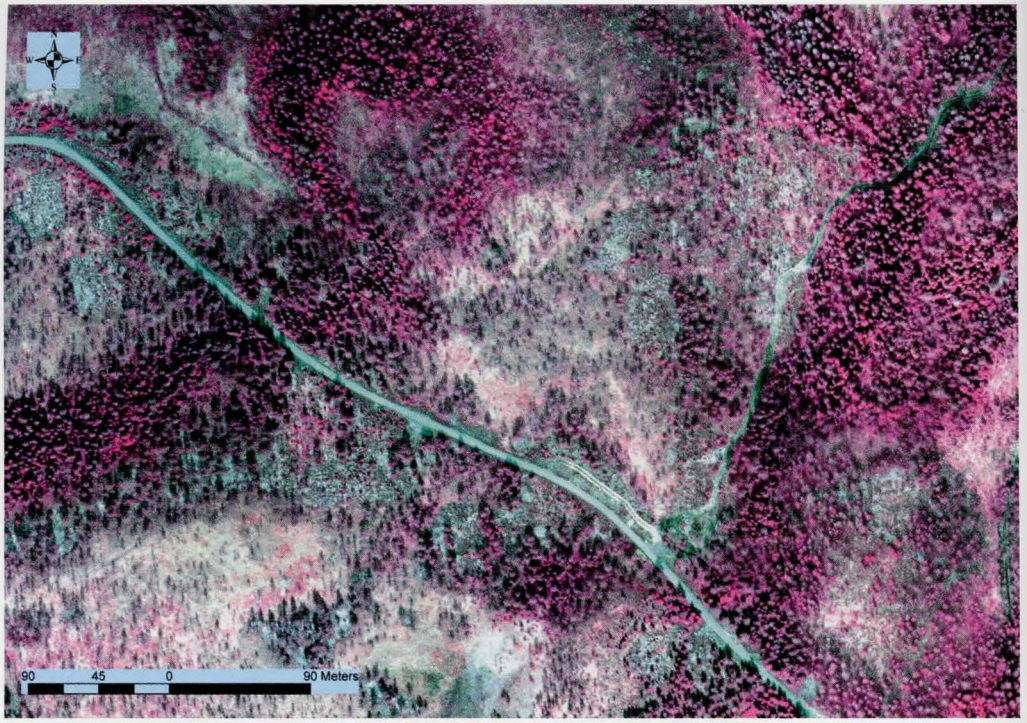


Figure 3. Orthophoto covering a section of the test area.

this kind is very difficult in the open areas, and quite impossible in areas with dense forest. Tree canopies, and vegetation in general, are well-known obstacles that cause problems in the use of aerial photography and satellite imagery when features on the ground surface are to be studied (Devereux *et al.* 2005).

Based on the lidar data a digital terrain model was created of the topography under the forest canopy (Figure 4). To make a relief-effect on the model in order to enhance the possibility of gaining information from these maps oblique lighting has to be added to the terrain model. In our case the DTM was illuminated from the northeast at an elevation of 20 degrees. This was done by using a hill shading operation in GIS. On the DTM some structures are then easily distinguishable as concave and convex features. The charcoal pits, in particular, are clearly and regularly visible while the slag heaps do not show up as clearly.

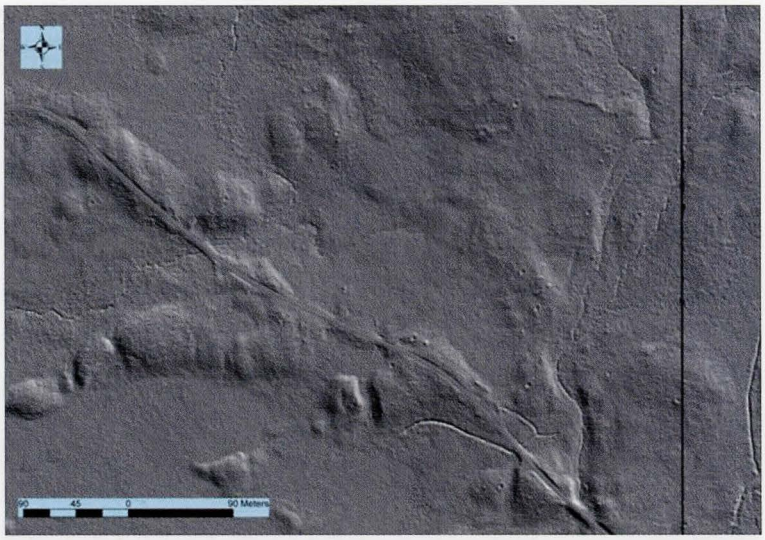
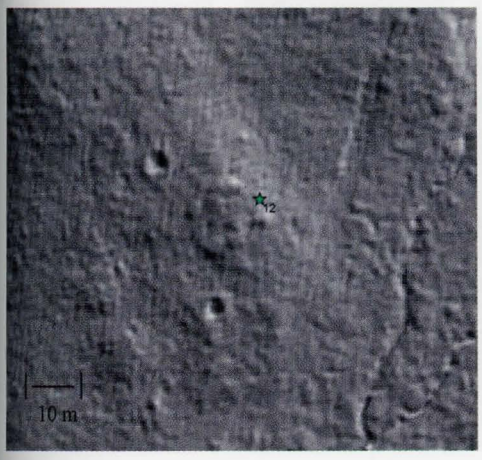


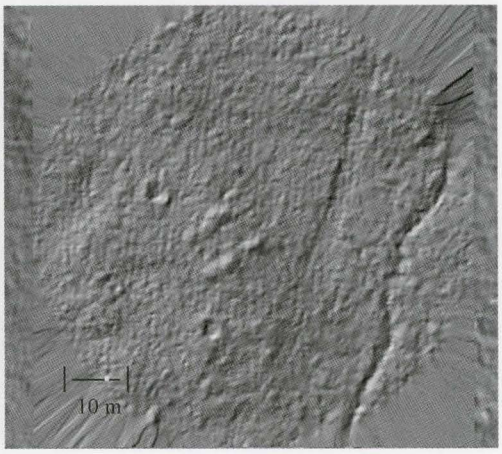
Figure 4. The same section as shown on the lidar map, with the vegetation eliminated.

Figure 5. Close-up of a smaller section of forest hiding an iron production site and two charcoal pits. Site No.12, with light coming from the northeast.

Figure 6. Site No.12 with light coming from the northwest, improving the visibility of the slag heaps.

An area with an iron production site (site No.12), with two adjacent charcoal pits, was singled out in the project and analysed more thoroughly (Figures 5 and 6). On the model we see the charcoal pits quite clearly while the slag heaps are less obvious. By chance the oblong slag heaps are oriented northeast-southwest, the same direction as the illumination, a circumstance that results in only a subtle shadow effect. To check whether moving the light would enhance the visibility of the slag heaps we made a test moving the light direction. In Figure 5 the DTM is illuminated from





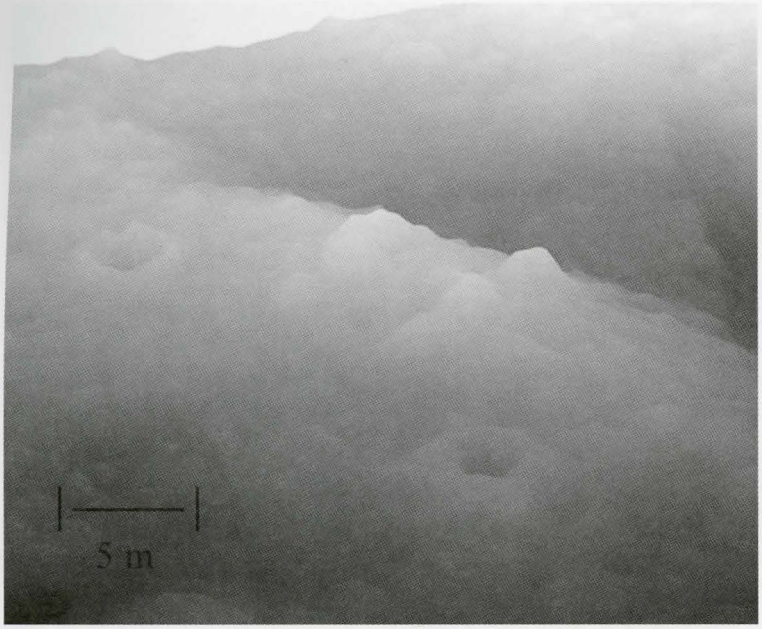


Figure 7. Perspective plot with the scale of the z-coordinate exaggerated.

the northeast but moving the light towards the northwest makes a considerable difference, as shown in Figure 6, the slag heaps now standing out more clearly.

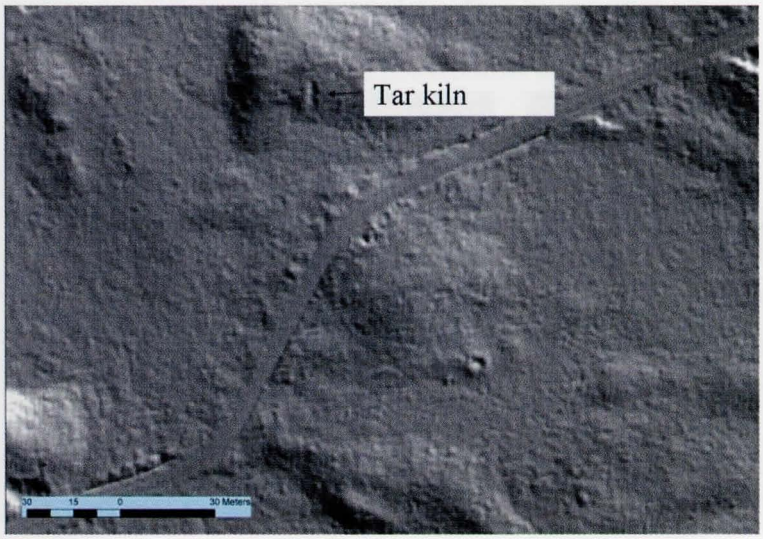


Figure 8. Relief model with a ditch for tar production.

In this way, manipulating the light direction increases the possibility of interpreting the anomalies. To change the direction of the illumination is not the only way in which to improve the readability of the relief models. Another means is to create perspective plots as shown in Figure 7. In this plot the height of the structures is exaggerated by manipulating the z-coordinate, thus making them more distinctive. The perspective of the observer is also moved from air view to ground view.

Figure 9. Ditch for charcoal production.

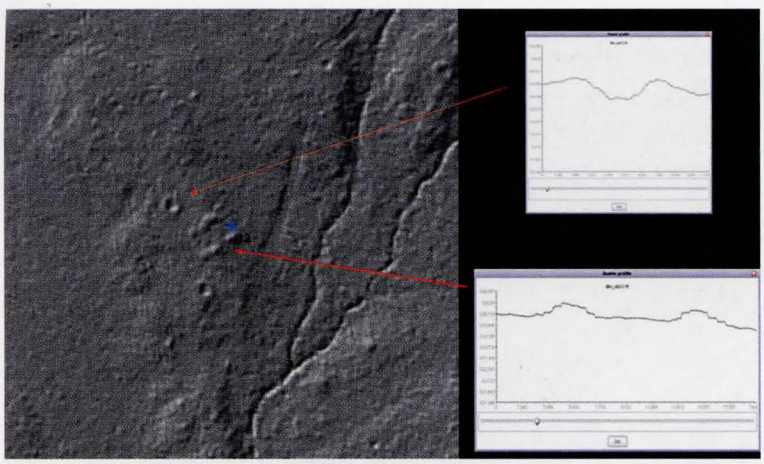


Figure 10. Horizontal sections through one of the charcoal pits (above) and through the iron production site (below).

A ditch for tar production was found in another part of the test area by visually analysing the DTM (Figures 8 and 9). The ditch is visible as an indentation in the surface, indicating a cultural feature.

Further analysis of iron production site No.12 showed interesting possibilities for making horizontal sections through the monuments based on the lidar data. This was done with a charcoal pit and with iron production site No.12, as seen in Figure 10. On the basis of lidar data it is possible to create cross sections and to make measurements of the depth, height and length of features. The measurements obtained in this way on the computer screen were compared with the field measurements. The differences were found to be small.

Conclusions

We find these preliminary results very promising and think that the project has to a great extent fulfilled the goals of the pilot study. The first of our constituent goals – to find cultural remains in forests – is fulfilled. Many cultural remains are actually seen as anomalies on the relief maps. The precision in mapping the features is also satisfactory and seems to exceed the precision of an ordinary GPS. The quoted accuracy is 15-30cm vertically and 0.5-1m horizontally. The last constituent goal – defining the structures – is so far the biggest challenge. Some of the structures,

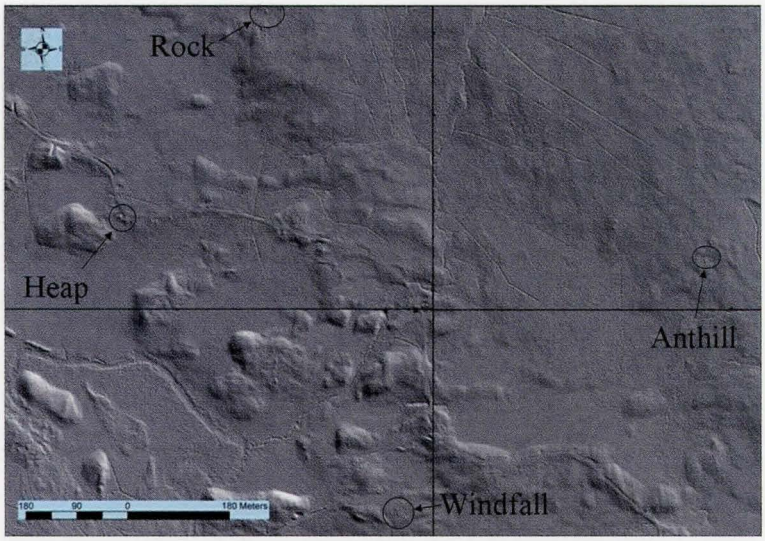


Figure 11. Some of the natural features and how they appear on the relief model.

such as the charcoal pits, are quite distinct while slag heaps for instance are less visible. A major question on which to focus in the continuation of the project is to determine why some structures are more clear than others. Is it only due to the size and distinctiveness of the structures themselves or does forest density also play a role?

As mentioned earlier, another key challenge is to distinguish cultural features from natural ones. Both kinds of feature appear as concave or convex anomalies on the relief maps. Figures 11 and 12 show a selection of the anomalies that were investigated during the fieldwork and which turned out to be natural: a windfall, a natural mound, an anthill and a rock.

In the continuation of the project a section of the test area will be subjected to in-depth analyses where the main challenges will be followed up. For instance we will try to use a pattern-recognition programme to determine if it is possible to replace visual interpretation of the maps with a technical procedure.

The laser-scanning method seems to be an efficient way of collecting survey data, especially in areas with forest or other

Figure 12. Some of the natural features that were investigated in the field. (a) a windfall, (b) a natural mound, (c) an anthill and (d) a rock.

12 a

12 b

kinds of vegetation. In this respect the method is useful for the cultural heritage sector, both for management and for research. This method is also interesting in connection with land-use planning and the preparation of Environmental Impact Assessment. And finally, in projects monitoring cultural landscapes,

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environments and monuments, different remote measurement methods such as aerial photography and satellite imagery are in use but usually fail when it comes to monitoring structures hidden beneath vegetation. The use of lidar undoubtedly brings an improvement in this situation.

We have just started to get a glimpse of the potential, and the project has uncovered a wide range of questions and problems which make it worthwhile to develop the use of lidar further in both forest and outfield archaeology.

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