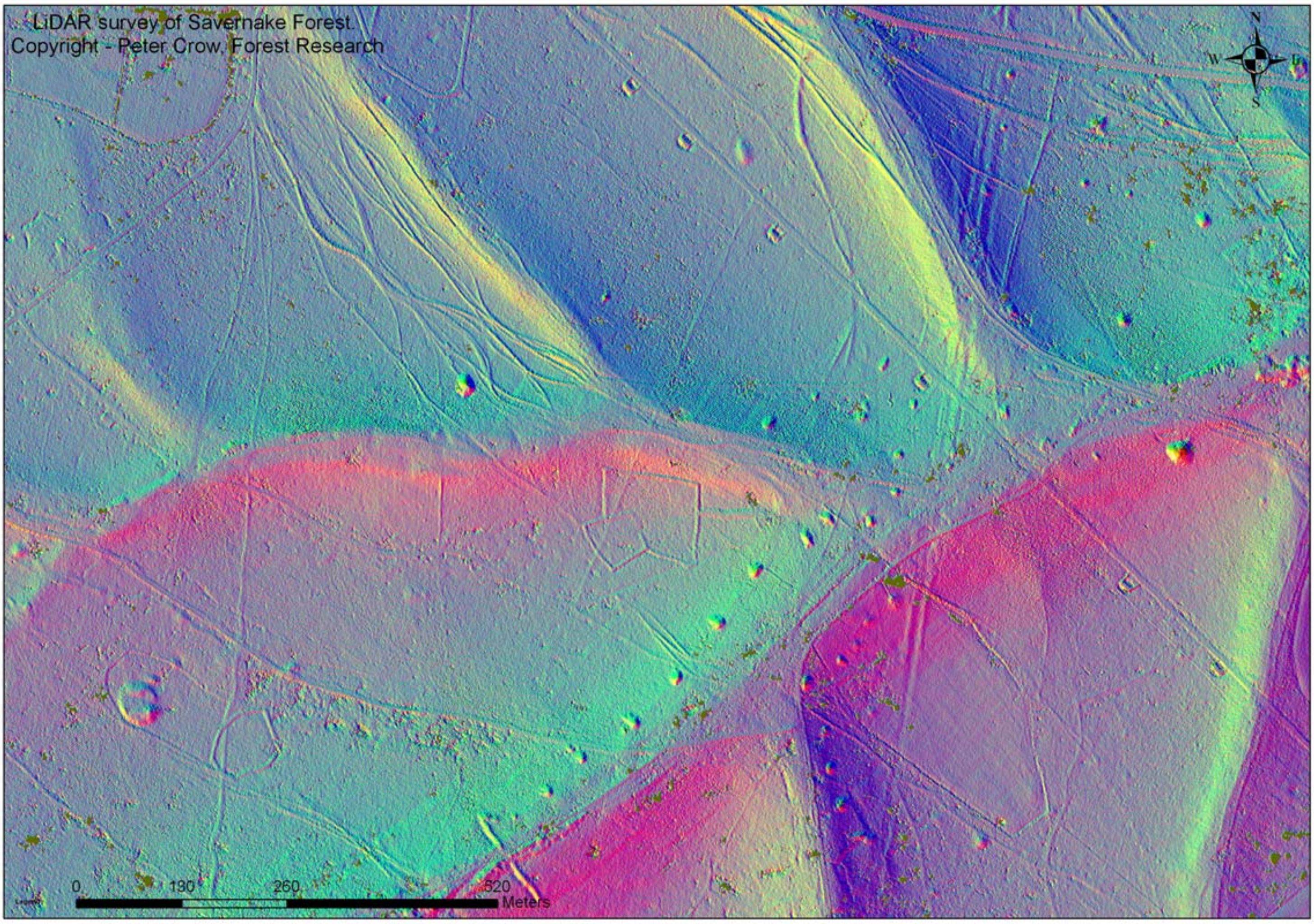
Historic Environment Surveys of woodland using LiDAR



Objective

This note outlines the recent developments of Remote Sensing technology to reveal the Historic Environment by ‘seeing through’ the woodland canopy and considers its application in mapping, with direct relevance to forest management. This use of LiDAR has significant potential to greatly enhance the cultural value of our woodlands and is discovering previously unknown archaeological sites. However, there are limitations to what the technology can show and over what types of woodland it is best employed. These limits are discussed, along with other potential, non-heritage, uses of the data.

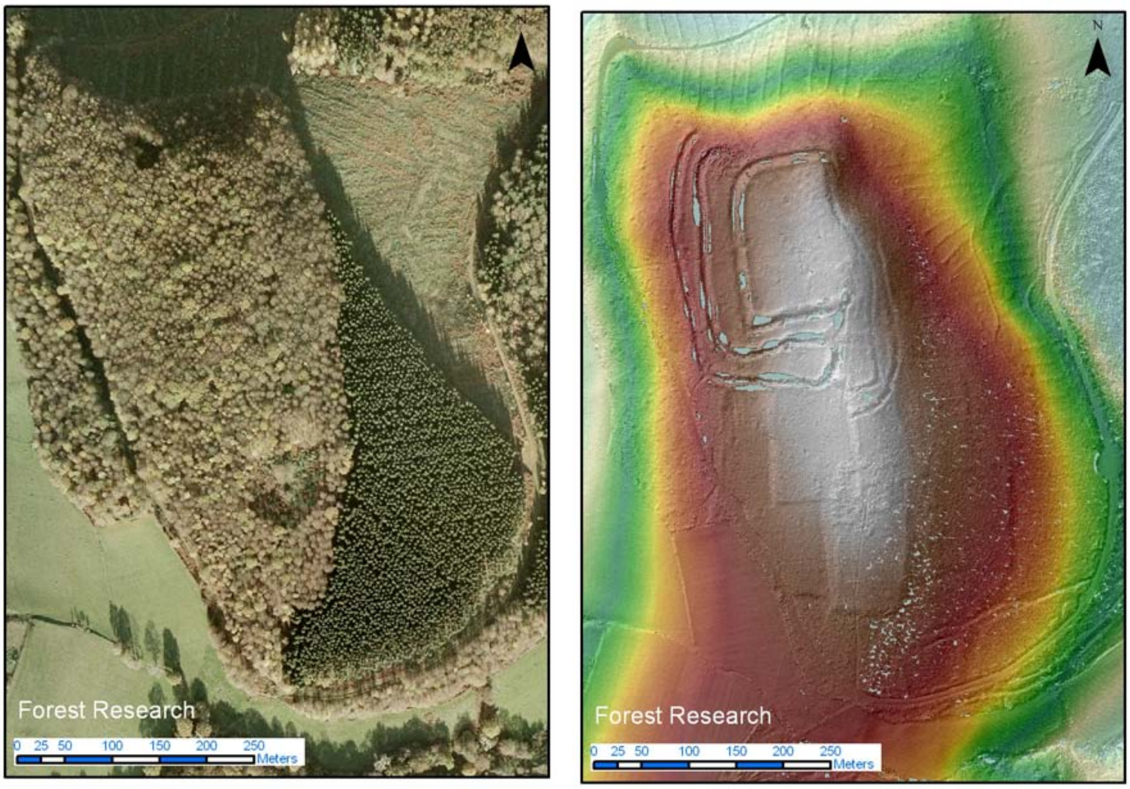


Figure 1. A typical aerial photograph and a LiDAR modelled ground surface of the same area.

What is LiDAR?

Ever since the first aerial photographs were collected early in the 20 century, they have shown many archaeological features in agricultural and other landscapes. However, woodland has always been a hindrance to this process, preventing a clear view of any archaeological evidence hidden beneath. The archaeological resource within UK woodlands is often therefore, poorly understood. There are exceptions to this rule and some woodlands have been subject to archaeological survey, typically in the form of ground-based survey. However, this is time consuming and often difficult in woodland due to uneven terrain and limited visibility. Woodland has therefore recently been identified as one of the UK's last potentially untapped, archaeological resource. For this reason, there is considerable excitement at recent developments with the Remote Sensing technique of Light Detection And Ranging (LiDAR).

The survey uses an aircraft, flown over an area of woodland where a laser is fired in rapid pulses (thousands of times a second) back towards the earth below. When the laser strikes a solid object, such as a building, it is reflected back to a detector built into the LiDAR system on the aircraft. Because light travels at a known speed, differences in the reflected signal time to the aircraft flown at a constant altitude will be directly related to changes in the height of the ground surface (or objects on it) below. Whilst it is not possible to fly at such a precisely fixed elevation, sophisticated navigational and flight sensors on board the aircraft combined with the times collected from the LiDAR system, allow a 3-dimensional co-ordinate to be calculated for the surface that reflected the laser. Millions of these co-ordinates can be joined together to form 3-dimensional models of the ground surface.

When the LiDAR is used over a porous surface (such as woodland) some of the laser energy is reflected back from the canopy, but some passes through, creating reflections from further down the canopy, understorey vegetation and potentially the forest floor. The LiDAR detector on-board the aircraft therefore receives a series of reflected signals from any single laser pulse. At the time of writing, systems used for historic environment surveys have only stored the time taken for the first part of the reflected signal (typically from the canopy) and the last part of the reflection (potentially from the ground surface).

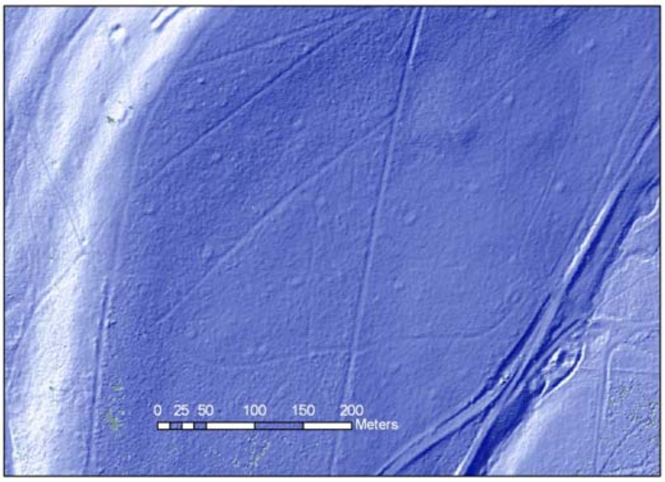
The combined data can be analysed by computed software that filters out the data points derived from the porous vegetation to create a 3-dimensional model of the forest floor. With a sufficiently high number of data points (a high resolution survey) archaeological features previously hidden from aerial reconnaissance can be revealed.

Survey specifications and suitability

In order to gain the most from any LiDAR commissioned for historic environment analysis, surveys to date were flown at a higher resolution than that required for open ground and during the winter months when laser penetration to the forest floor would have the greatest likelihood. Many other existing LiDAR data may not be ideal for analysis, as it may have been collected during the summer and often of a lower resolution than the optimum required for historic environment analysis under woodland. Equally, if considering a new survey, it must be emphasised that not all wooded areas are suited to this technique. Because the survey is dependant upon laser penetration of the forest canopy and understorey vegetation, significant areas of dense, young regeneration or unthinned conifer plantation will greatly restrict the potential of the survey and may prevent it from being a viable option (also see *current LiDAR limitations* below).

LiDAR strengths

The technology allows the survey of large areas of landscape (both open and wooded) and is most cost-effective when applied to continuous blocks rather than small, fragmented areas of wooded landscapes. The best results are obtained from mature broadleaf canopy with little understorey vegetation. For example, a beech woodland with bluebells, where the winter survey time would ensure that the vast majority of the laser energy would reach the forest floor uninhibited. Under these optimum conditions, the surveys can reveal some very subtle changes in ground surface allowing many archaeological features to be seen. The method is most effective at revealing linear features and even very subtle earthworks can be shown, many of which are difficult to see on the ground. Examples include earthworks of field systems, other boundary banks, lynchets, route-ways and drainage channels. When used over optimum vegetation types, smaller, more discrete features such as charcoal platforms have been mapped.



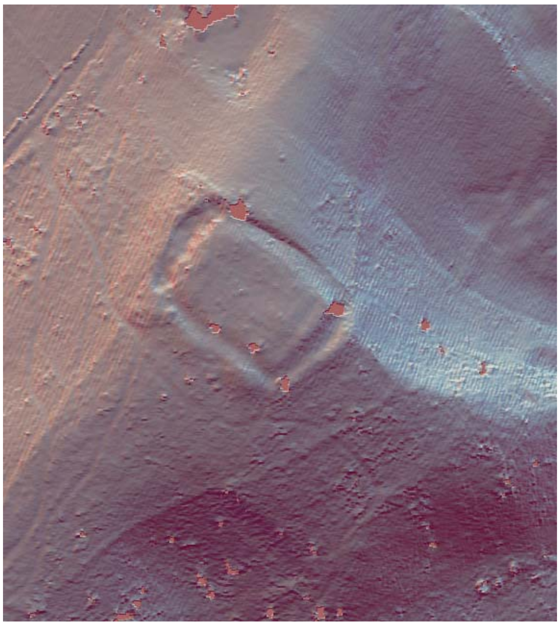


Figure 2. Examples of circular charcoal platforms (left image) and a hilltop enclosure (right).

Current LiDAR limitations

LiDAR will not show every historic environment feature and will not work in all woodland types. Whilst the technology will work through mature, thinned conifer and has shown linear earthworks, quarries and pits under such conditions, younger, dense conifer plantations will greatly reduce the quantity of energy able to penetrate to the forest floor. However, even where canopy penetration is perceived to be good, dense layers of understorey vegetation such as bramble, bracken, gorse or holly can still inhibit the laser from reaching the true ground surface. Indeed gaps in the LiDAR derived computer generated ground model caused by understorey holly have been used to map its distribution. A knowledge of the vegetation types through which the survey is expected to work is therefore essential in considering potential areas for LiDAR survey, targeting efficient use of resources and providing confidence in the resulting data interpretation. Whilst LiDAR has shown discrete features such as charcoal platforms, these tend to be several metres in diameter. However, there is no guarantee that all platforms of this size will be resolved and circular features of less than 5m diameter may be missed completely. Part of the problem with the identification of small features, is that whilst the LiDAR may have detected them, they may only be displayed by a few pixels in the resulting image and distinguishing them from any noise or patches of vegetation can be difficult.

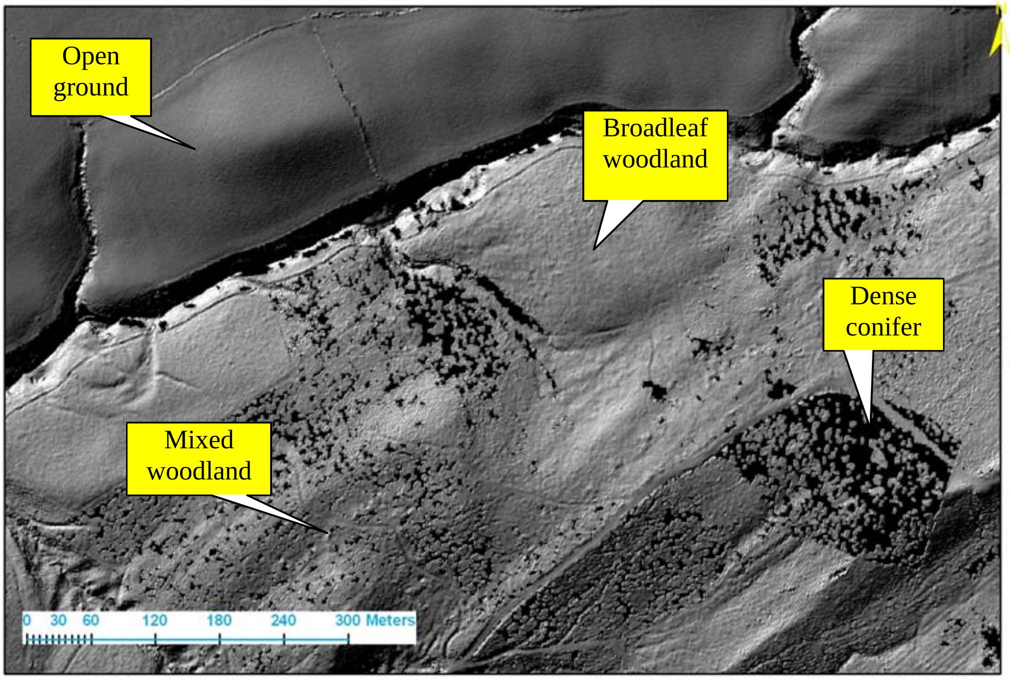


Figure 3. Examples of the effects that different types of vegetation have on the LiDAR survey.

Identifying features

Arguably, the most useful product of a LiDAR survey are hillshaded images. These are created from the LiDAR surface models by artificially lighting them in the same way that the sun will create highlights and shadows on the landscape. Lighting the model from a low elevation angle allows subtle changes in the surface model to become apparent. These images can be loaded into a GIS environment. (Further information on hillshaded images is given in the technical information towards the end of this document). LiDAR is indiscriminate in the features it will detect. The hillshaded images will show many (but not necessarily all) archaeological features but will also display roads, paths, buildings, forest residue, timber stacks and a host of other modern objects. Additionally, changes in ground vegetation can create patterns that look like features of archaeological potential. Distinguishing between the genuine and artificial historic environment is therefore an important and necessary process, although it is likely to be a long-term project.

Figure 4. Examples of 'false earthworks'. The bracken fallen over a wire fence can create an artificial bank, whilst the small mound shown in the right-hand image results from a modern tree-throw.

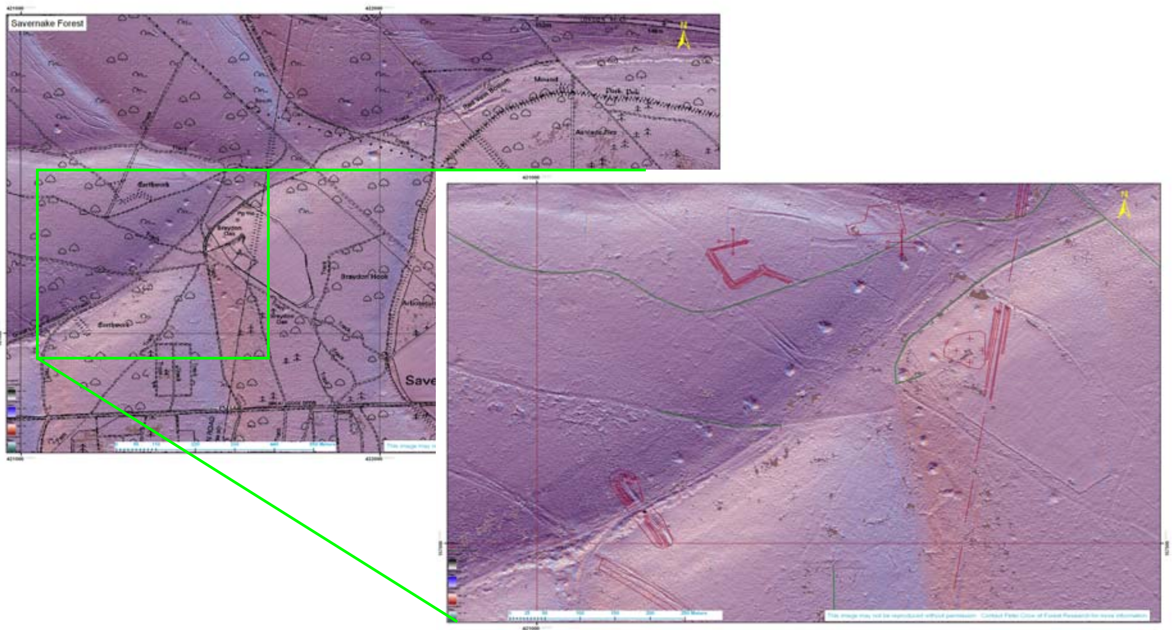


Figure 5. Within the GIS environment, it is possible to add other data as a method of identifying recorded features.[1]

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Eliminating the known

The ability to place hillshaded images into GIS allows other layers to be overlain. Placing aerial photographs, modern and historic maps and forestry data (such as roads) will directly identify many features and may provide an indirect explanation for others. This process should help to eliminate many objects and draw attention to those remaining. Many archaeological features within a survey area will already be known and occur as entries on the local authority's Historic Environment Records (HER), formerly Sites and Monuments Records (SMR). The HERs are increasingly GIS based and it may be possible to obtain a copy to overlay on the hillshaded images. Even where features are identified within the HER, their full extent may not be mapped and the LiDAR can add valuable information to this record. Where readily available, historic maps may also identify features no longer shown on modern maps. Only once known information has been examined and these features interpreted on the hillshaded images will previously un-recorded features become apparent.

Ground-truthing

Where objects seen in hillshaded images are not identified from other sources of information, the only reliable method of identification is by on-site examination. Whilst this may not allow identification of the archaeological feature or its age, it will at least confirm that it is an earthwork or similar structure rather than a fence or pile of forest residue.

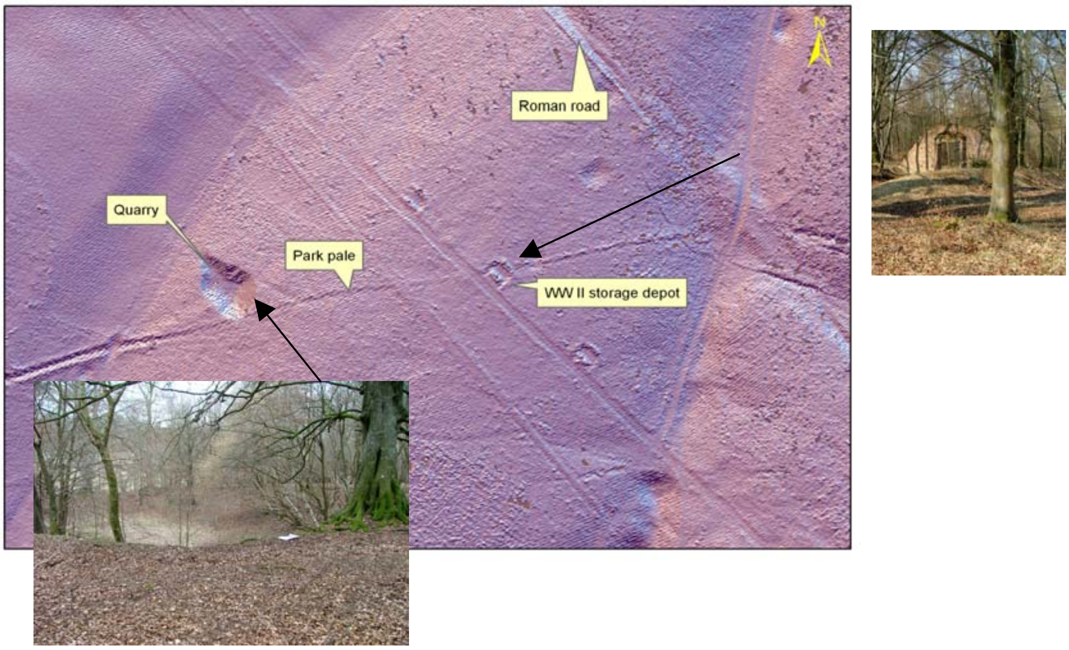

Figure 6. Simple photographic evidence taken during routine site work can be very informative for feature identification and management.

It is likely to be impossible to ground-truth the whole area in a short time-span and to do so would remove the value of commissioning a LiDAR survey in the first place. However, longer-term projects are possible. It is likely that the hillshaded images have been passed on to the local authority or project archaeologist who will themselves identify areas or features of priority for any site investigation. This they may undertake themselves, in conjunction with woodland managers or possibly utilise local volunteers. Indeed, there is the potential for engaging with local groups or communities to conduct some of this ground-truthing. Additionally, forest staff routinely working within the survey area may be in the position to examine features. Given time, many areas will become investigated.

Managing the Historic Environment

Important historic environment features located within a forest need to be identified and actively managed to inform forest operations and prevent accidental damage. However, advice on how to manage different types of Historic Environment feature is beyond the scope of this document. It is likely that a new LiDAR survey will have shown a variety of features perceived to be of historic environment potential and interest. Unless these features are known from the HER or site visit, it may be difficult to determine their relative importance. Close collaboration between forest managers and the local authority archaeologist is essential and a site visit may be considered necessary. Nonetheless, even in areas where no site visit has occurred prior to the commencement of operations, the hillshaded images can still be used to raise awareness of potential features and allowing staff to avoid possibly sensitive areas. Equally, some surveys to date have mapped landscapes of many small, but deep pits and quarries. Here the LiDAR data also provides a potential map of some on-site hazards and can be used in conjunction with on-site assessments to help reduce the risks of injury to staff or damage to equipment.

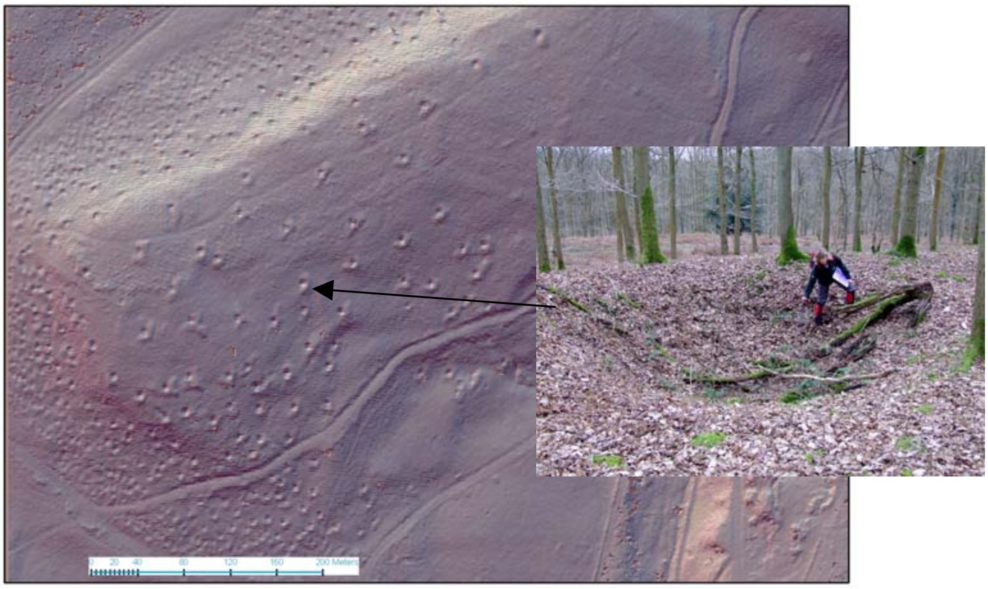

Figure 7. LiDAR derived models can also be useful in mapping difficult terrain.

Forest Design Planning

LiDAR derived data, models and indeed any mapped features from them, offer a very powerful tool for the forest design planner. Because the survey produces 3-dimensional surface models of a forest, that can be manipulated within mapping software, forest views can be examined and planned from all angles. This has the benefit of being able to view archaeological features as they may once have looked in an earlier landscape. This allows planners to consider the possibility of visually connecting associated historic environment features within the landscape, or changing the setting of individual features. Recreational access routes to and around historic environment features can be sensitively planned to increase their value and profile within the woodland, thereby enhancing its cultural value.

Figure 8. A 3-Dimensional model with an aerial photograph draped over it can be a very useful planner's tool.

Protecting important features during routine forest management

The most important method of protecting important historic environment features, is through mapping and increasing awareness. As such, it is essential that features interpreted from the LiDAR are digitised on to GIS to allow addition to management and operations maps. Because of the high accuracy of the LiDAR data, the hillshaded images produce very reliable maps for any site work that may be planned. As such, any features highlighted for protection should be easily distinguishable on site prior to operations. Once located on site, sensitive areas are usually marked and brought to the attention of forest workers. To what extent the management of a sensitive area will differ from that of the surrounding woodland will be site specific and not considered further in this document.

Looking beyond archaeological remains

LiDAR data and modelled outputs have potential uses in many areas. For example, the differences between the first part of the reflected signal and the last when surveyed over woodland, can be used to calculate tree height (providing the laser was able to penetrate to the ground). The models of the forest canopy can be used to map individual trees (although this works best on well-thinned or mature woodland). Hedgerows and small areas of woodland can also be mapped to show ecological corridors. When a survey is carried out over a mature broadleaf woodland with little understorey, there should be little to prevent the laser from reaching the forest floor. Under such conditions the large boles of any ancient trees present (standing or fallen) can block the laser, allowing them to be mapped (although standing ancient trees may also be evident from models of the forest canopy). With further developments in LiDAR technology, it may soon be possible to map dead wood, understorey and eventually, full forest structure, with potential applications in biomass calculations and carbon storage.

Data types

The LiDAR survey produces a variety of data types, some more useful than others. Many are immediately usable within a GIS environment however, they can be very large data files that will significantly slow the performance of the average computer. Some types of data processing and analysis require specialised software and will not be available to many users. These surveys produce large quantities of data and storage and back-ups facilities should be considered.

Point Cloud Data

This is the raw data derived from the laser reflections. In most cases, this is in the form of a simple text file, with each row containing the X, Y, Z co-ordinates of the first and last part of the reflected signal. Because these are simple X, Y, Z values, they can be displayed as points and coloured to show changes in height (Z). One useful analogy for visualising a point cloud in 3-dimensions, is to imagine a fresh, heavy snow fall over a landscape and then mentally remove everything except the snow, suspended upon invisible trees, roofs, fences etc.

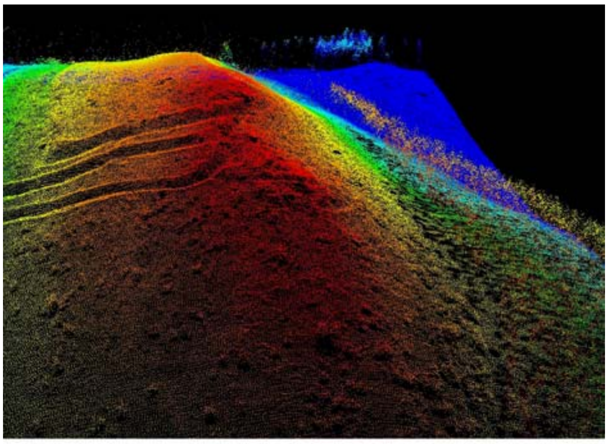

Figure 9. A 2-dimensional image of a 3-dimensional point cloud.

Digital Elevation Models

For every LiDAR survey, 2 Digital Elevation Models (DEMs) are usually provided. The Digital Surface Model (DSM) is created from the first part of the reflected laser pulse and thus maps the surface of the woodland canopy. In many respects, this is a 3-dimensional version of what is visible below the survey aircraft and therefore provides the perfect elevation model over which an aerial photograph can be draped (see Figure 8).

Conversely, a Digital Terrain Model (DTM) is created as an output of the vegetation removal process and is designed to show the ground surface located beneath a woodland canopy. Objects with vertical faces such as buildings are also often removed during the processing.

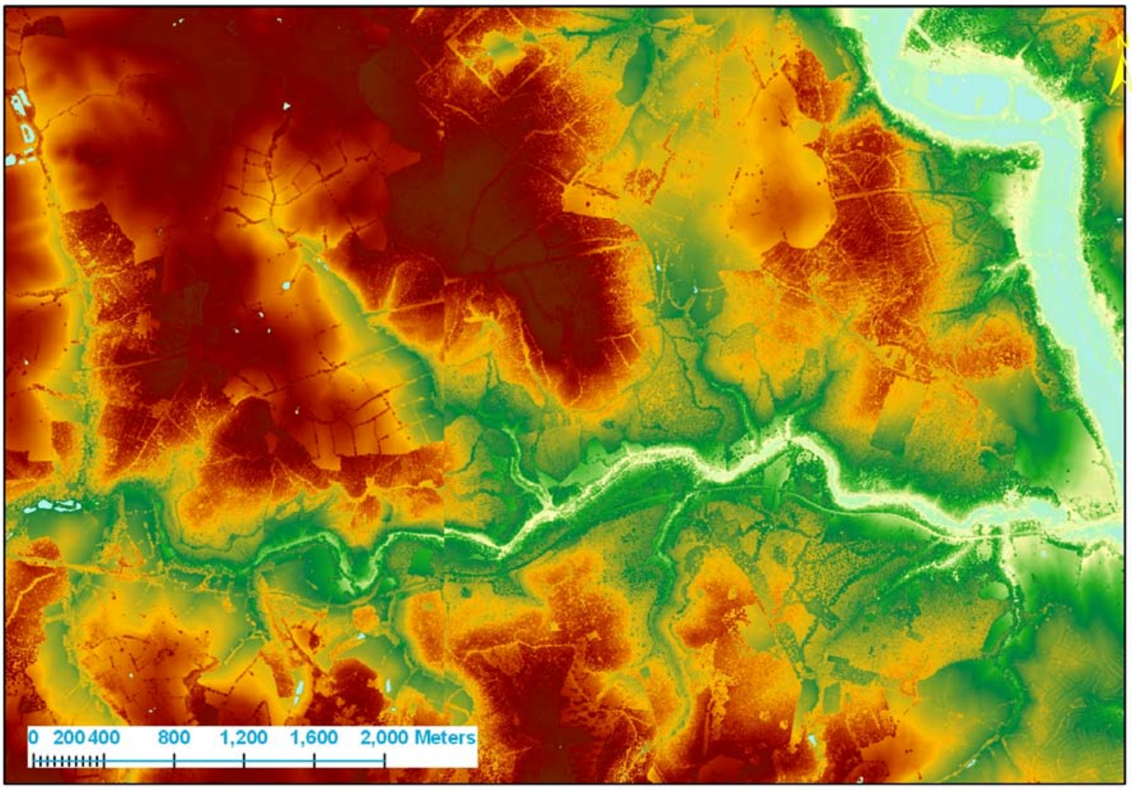

Figure 10. A vertical view of a DSM. Each cell in the raster was given a colour to indicate the height value.

Hillshaded images

These are generated by computer as a method of viewing digital elevation models and contain no elevation data. Elevation models, when viewed from above, show little detail in any surface changes. To make topographic features more apparent, an artificial sun is created within the computer and placed at a low angle to recreate a sunset or sunrise event. Any upstanding feature on the surface of the model is then disclosed by the creation of highlights on the face closest to the illumination source and shadows on the features opposite face. The opposite effect shows sunken features such as ditches. When hillshaded images are provided as part of a LiDAR contract, unless specified otherwise, they are typically provided as north-west illuminations. However, viewing only one hillshaded image of a given area can result in some features remaining hidden. For example, a linear ditch with a NW-SE orientation will only have a small surface area exposed to the light source, providing little highlight or shadow. Additionally, if located on a south-east facing slope, the feature would also fall in the shadow of the hill. An example of this effect is shown below. It is therefore necessary to create additional hillshaded images. A minimum number of 4 is recommended.

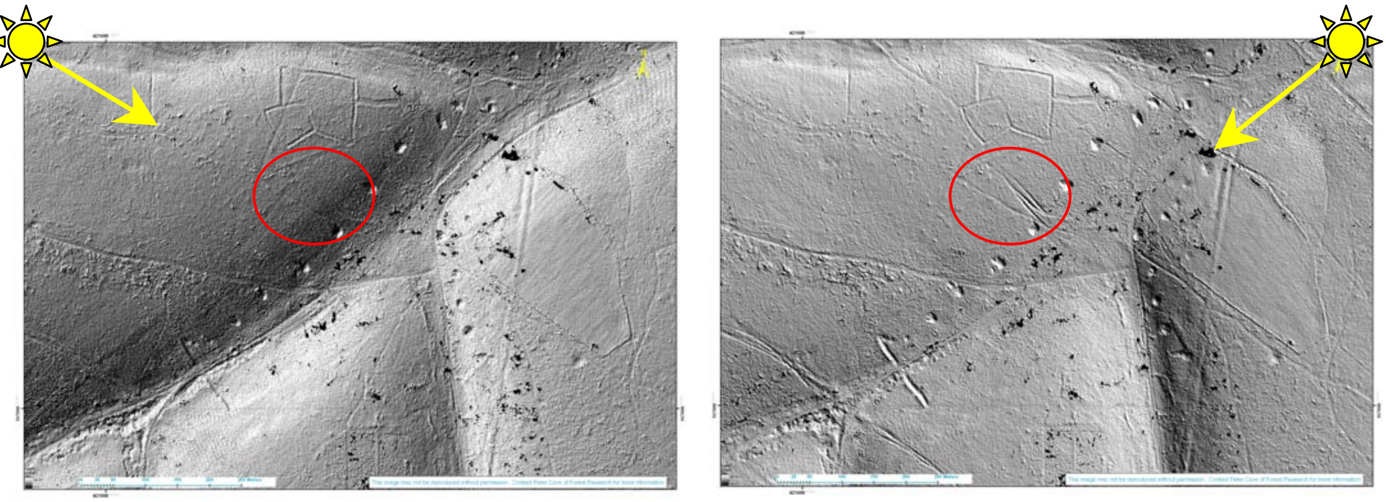

Figure 11. Two examples of the same are of DTM, but illuminated from different directions to produce the hillshaded models.

Summary

LiDAR is a very powerful tool and when applied to appropriate wooded landscapes has the potential to map both known and previously unrecorded historic environment features. Nonetheless, is not an instant solution to discovering every aspect of a woodlands heritage and is best employed in combination with other sources of information. Because it is most economical to apply the technique at the landscape scale, costs of commissioning surveys will inevitably be considerable. However, such surveys should be looked upon as a long-term investment as the data, models and images can be useful for a wide range of planning, management and public engagement activities.

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Glossary

DEM – Digital elevation model. A grid of squares (cells) with a height value assigned to each square. This type of grid is a called a raster by most GIS software.

DSM – A digital surface model. A digital elevation model of the land surface. This includes the woodland canopy.

DTM – A digital terrain model. A digital elevation model of the ground beneath any vegetation.

GIS – Geographical Information System. Computer-based mapping software.

HER/SMR – Historic Environment Record. Slowly replacing Sites and Monument Records. Both are systems are held by local authority archaeologists.

Hillshaded image – a computer generated image to show subtle changes in the topography of DEMs. An artificial sun position is defined and used to illuminate the DEM. Highlights and shadows are created by changes in the relief, a process which allows features present to become evident.

LiDAR – Light Detection and Ranging.

Point cloud – The raw data format from the LiDAR survey. Millions of X, Y, Z co-ordinates in the form of text. Some software packages allow this data to be plotted as 3-dimensional points.

Vegetation removal – A computer-based process to filter out data from the point cloud derived from vegetation, to allow the creation of a DTM.