

8 | Making the most of airborne remote sensing techniques for archaeological survey and interpretation

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Abstract: The use of airborne remote sensing has found increasing popularity in the historic environment sector over the past decade. Many landscape projects across Europe are incorporating the application of archive airborne survey and increasing numbers are commissioning bespoke survey. This is particularly true for Airborne Laser Scanning (ALS), but despite a number of promising applications, digital spectral surveys have been less frequently utilised. Our understanding of the full potential of these rich data sources is still in its infancy. This paper provides a summary of current applications and highlights the need for research in three key areas to improve our applications of airborne remote sensing for research into the historic environment. It concludes by introducing a project established at Bournemouth University to develop a multisensor approach to airborne survey of liminal environments.

Introduction

In the past decade the heritage sector across Europe has seen growth in the application of airborne remote sensing techniques, such as Airborne Laser Scanning (ALS) and digital spectral sensors. High profile projects such as the landscape survey of Loughcrew, Ireland (Shell & Roughley 2004) and the National Mapping Programme of the Stonehenge World Heritage Site (Bewley *et al.* 2005) have brought the application of ALS, based on the principle of light detection and ranging (LiDAR), to national attention, while work in the Vale of Pickering (Powlesland *et al.* 2006) and at Aqueila, Italy (Traviglia 2006; Sterazi *et al.* 2008) have shown the potential of digital spectral imagery, (referred to as either multi or hyperspectral imagery), for identifying archaeological features. It is clear that these sensors have great potential for improving our understanding of the quantity of features of archaeological interest in a landscape but their application poses a number of practical and theoretical challenges. Although often compared favourably with traditional aerial photography survey (see Beck this volume), each sensor by itself captures only a portion of what can be recognised in the shadow, soil, crop marks and earthworks as being of archaeological significance. As no single airborne sensor records all of the indicators we understand to represent archaeological remains, the power of their application has to be in their complementarity.

While the applications of multiple airborne sensors to record data for the same study area are becoming increasingly common, our knowledge of how to combine the vast information content efficiently to form an understanding of the features represented in it can still be regarded as in its infancy. This short paper will briefly review work undertaken to date and look at some of the themes to be addressed in the application of multiple airborne sensors for heritage management,

concluding with details of a project at Bournemouth University that is pioneering multisensor methods for the survey of liminal landscapes in the UK.

Laying the Foundations

In a landscape research context, the appeal of remote sensing techniques such as ALS and digital spectral imaging, lies in great part with their ability to complement the traditional ground-based and airborne techniques of walkover survey and low altitude aerial photography for large survey areas. Walkover survey is defined as the technique of surveying in transects to record archaeological features and can be undertaken with or without concurrent artefact collection (as per Fulford *et al.* 2006; RCHAMW 2009). This type of survey is time consuming, may be restricted by vegetation or land use and is limited to identifying features with noticeable upstanding remains or artefact scatters caused by plough damage (Fulford *et al.* 2006). In contrast, aerial photography can identify features that have no upstanding traces but are typified by near-surface changes in soil moisture content and vegetation composition. However the identification of these features relies heavily on the differences in contrast between the matrix of an archaeological feature and that of its surroundings and/or the impact of this contrast on the structure and growth of vegetation. Additionally, variance of this kind is generally only visible under certain conditions, i.e. in recently ploughed soil or during long dry spells, limiting the time of acquisition and making aerial photographs far less useful for survey of certain environments including pasture and uncultivated land. It is well documented that aerial photographs only capture records of such features in specific circumstances and the visibility of crop and soil marks from the air is heavily affected by underlying soil

type and geology, vegetation, agriculture and seasonal variance (Wilson 2000) and the bias that the interests of the airborne observer brings to the survey process (e.g. Palmer 2005). In addition, it has long been recognised that the infrared region of the spectrum is particularly sensitive to plant health, more so than the red, green and blue reflectance of the visible spectrum (Lillesand *et al.* 2008). The majority of aerial photographs capture only visible wavelengths and the implications of this small spectral window on both the techniques and the results of aerial survey are discussed in detail by Beck (this volume). While digital spectral sensors do not yet boast the high spatial resolution of aerial photography, they capture a wide range of wavelengths and are more sensitive to subtle changes in the spectral response of soil and vegetation.

In addition to variations in vegetation and soil, oblique aerial photography, especially in raking winter light (defined by Wilson (2000) as no more than 20° above the horizon) can be used to identify features with upstanding topography. Often this technique is more effective than observations from ground level, especially if the features are slight or the site covers an extensive area. However due to the bias in visibility introduced by differing illumination angles, mapping complex earthworks requires repeat acquisition in different light conditions and more often than not such repetition is impractical. The high accuracy, high resolution digital terrain and surface models (DTM and DSM respectively) that can be rendered from ALS surveys enable the identification of topographic features and can be artificially shaded from any angle to replicate optimum conditions (Devereux *et al.* 2008).

An increasing body of research has shown that ALS and digital spectral imaging have the potential to redress some of the weaknesses of the traditional techniques detailed above. Their complementarity to existing techniques has been amply illustrated both in the UK and elsewhere in Europe (Bewley *et al.* 2005; Powlesland *et al.* 2006; Campana *et al.* 2009; Gallo *et al.* 2009). Yet the potential of these sensors for improving our understanding of archaeological features extends beyond quantitative identification. In the detailed data that they collect about soil, vegetation and topography is a wealth of information that has the potential to enhance our management of archaeological landscapes, to monitor levels of degradation, to better understand the impact of landuse and vegetation cover on both the visibility and preservation of features and to aid the appropriate targeting of future research resources.

Airborne sensors in archaeological survey

Although the advantages of surveying vegetation, soil and topography from the air for archaeological prospection are well established, very few projects have had the opportunity to acquire contemporary ALS and spectral data for research in this field. This is in part due to the high cost of both deploying these sensors and processing the data collected, but is also a consequence of the restrictions of flying the sensors in tandem. Until recent improvements in the sensors themselves, an uncomfortable compromise had to be

reached between the optimal operating parameters for the spectral and ALS systems, meaning that the best resolutions for either sensor were not attainable (Shell 2005). In addition the processing power required to handle both spectral and topographic data together exceeded the capacity available to many historic environment professionals. Where data from either of these sensors has been used for landscape research it has been predominantly subject to individual visual assessment rather than combined digital processing. Consequently it is important to briefly consider the independent issues surrounding the use and interpretation of spectral and ALS data for archaeological purposes.

Despite first being used to detect archaeological features over 20 years ago (Donoghue & Shennan 1988) and showing some promise for the UK and on the continent (Donoghue & Shennan 1988; Winterbottom & Dawson 2005; Powlesland *et al.* 2006; Traviglia 2006) uptake of digital spectral data for historic environment research has been limited. There are several reasons for this including the cost, spatial resolution and relative scarcity of equipment. In this volume, Beck identifies the issues associated with the application of spectral sensors in more detail, but to date there has been little understanding of the physical, biological and environmental variables that influence the visibility of archaeological features in airborne digital spectral data. Unlike many vegetation mapping and geological applications, archaeological features do not exhibit a spectral signature which can be consistently identified and much work is required to understand fully how and why features are represented in spectral imagery, and equally importantly, why known features may not be represented.

Many of the problems in resolving the physical details of features seen in spectral imagery have been magnified by the use of archive spectral data collected primarily for environmental and hydrological purposes, rather than archaeological survey (Challis *et al.* 2008). As a result, often no simultaneous ground observations or survey exists for the flights. As the spectral response of vegetation cover and soil can change on a daily basis, this lack of control data makes it extremely difficult to link the airborne data closely to either the observed ground conditions or the results of topographical and geophysical survey undertaken at other times. This lack of observational data can and should be, partially mitigated by post-survey field visits and comparison to the known archaeological record. This is essential to verify the archaeological interpretations and feedback iteratively into the process of identifying features from the airborne imagery (see Winterbottom & Dawson 2005). However this can only correct interpretation at a broad visual level, rather than by looking at the physical, biological and chemical properties of the features at the time of survey. While this level of correction might be sufficient depending on the aims of the research being undertaken, there is little doubt that our understanding of the representation of archaeological features in digital spectral imagery could be improved immensely by qualitative links to ground observations, particularly geophysical survey. Fortunately there is increasing recognition of the need

to compare airborne data to ground based spectral, soil and geophysical measurements, culminating in the first Natural Environment Research Council (NERC) supported simultaneous ground-based and airborne data acquisition for archaeological research in the UK in March 2010 in support of the current research project at Bournemouth University and the AHRC / ESPRC funded DART project (see Beck this volume.)

In addition to the complexities of understanding airborne spectral data, there is also the issue of the sheer quantity of data derived from a single flight. Hyperspectral sensors such as the AISA Eagle are typically capable of recording spectral data in 244 bands across the 400–970nm range, but due to the narrow (2.3nm) bandwidth, much of the data in each of the bands is identical. The challenge is to find the bands within the data cube that best represent the archaeological features within the landscape. While of course the data themselves will vary between (and potentially within) landscapes, much progress has been made recently in trialling statistical autocorrelation methods such as Principal Components Analysis (PCA), Moran's I and Gi (Ciminale *et al.* 2009) and separability indices (Cavalli *et al.* 2009) to reduce data redundancy. In addition a number of indices, such as the Normalised Differential Vegetation Index (NDVI) and Tassled Cap Transformation that were developed specifically for vegetation mapping, and which work by targeting the spectral regions that reflect key biophysical properties, have been applied to archaeological research with varying degrees of success (Traviglia 2006; Challis *et al.* 2009).

Despite the challenges, it has been repeatedly shown that digital spectral imagery is of use for detecting sites that are not visible in conventional aerial photographs, particularly in areas dominated by arable farming (Powlesland *et al.* 1997; Rowlands & Sarris 2007; Challis *et al.* 2009). It is less clear how the increased spectral sensitivity can aid our interpretation of sites in liminal areas where the vegetation sensitivity to stress is reduced and pasture or scrub vegetation dominates, although Winterbottom & Dawson (2005) reported good results in machair dominated environments.

In contrast to digital spectral sensors, the application of ALS has enjoyed increasing popularity with historic environment professionals as it enables the creation of high resolution, high accuracy spatial models and the removal of vegetation from these models, allowing below-canopy modelling (Crow *et al.* 2007; Doneus *et al.* 2008). This, coupled with the increased availability of archive data from providers such as the Environment Agency in the UK has seen a surge in the number of research and commercial applications of the data. The explanation of the technique of ALS and examples of its use in a heritage management context are discussed elsewhere in this volume (see Doneus & Briese and Shaw this volume).

To date, studies using ALS for examining archaeological features in the UK have focussed on two main research areas; the potential for last-pulse return to record features beneath forest canopy (Crow *et al.* 2007) and the modelling of alluvial valleys (Challis 2006; Challis *et al.* 2009). While the use of archive data is

still prevalent and provides a relatively simple route to the acquisition of terrain models avoiding the computing requirements of in-house data processing, commissioned surveys are becoming more common. Although these are expensive, it has been calculated that the cost of collecting airborne data is less than the equivalent cost of deploying a ground based survey team and is far more effective for some land cover types (Crow *et al.* 2007). Beyond the recently published English Heritage ALS guidelines (Crutchley 2010), there is still little in the way of guidance for those wishing to commission airborne remote sensing survey however and this is due in part to the fact that the use of these data is still an emerging discipline, changed continually by advances in sensor technology and processing techniques. Although the basic principles remain the same, far more technical research is required before we can confidently state what survey parameters are best suited for prospection, detailed feature mapping, monitoring and conservation purposes and how these may vary between and within landscapes. In this volume, Doneus & Briese discuss many of the issues surrounding survey and processing parameters and the availability of metadata with specific reference to forested landscapes. Even the simplest assumptions regarding ALS survey may not hold true in every circumstance. For example, it is thought that the highest possible spatial resolution will achieve the best results in terms of identifying archaeological features. However in recent work over heavily and uniformly cropped fields in Italy the noise produced by higher spatial resolution survey meant that the archaeological features were only visible when the resolution was reduced (S. Campana pers. comm.).

Like digital spectral imagery (e.g. Figure 8.1), there is little doubt as to the efficacy of ALS as a prospection tool, providing impressive increases in the number of known features even in previously well-researched landscapes (Shell & Roughley 2004; Bewley *et al.* 2005; Doneus *et al.* 2008; Gallagher *et al.* 2008; Weishampel *et al.* 2010). Despite this there is still a sense that the full potential of these data has yet to be achieved for historic environment applications. Although much work has been undertaken on the technical aspects of data processing (see Challis 2004; Challis 2005; Doneus this volume), assessments of digital terrain model accuracy rarely feature in published accounts. If the goal of the research is simply to indicate whether a feature is present or not then it might be considered that an assessment of the accuracy of the model is not a vital piece of metadata. However, given the capacity of modern sensors to produce surveys of high spatial resolution, it is feasible that models created from ALS data could be used to derive basic metrics of archaeological features. If you wish to estimate the diameter of an enclosure, the height of a bank or depth of a ditch from the data (which are feasible aims within the tolerances of the sensor), the accuracy of your model, whether it significantly smoothes or overshoots the original data points and how representative your surface model following vegetation removal is of the actual ground surface becomes more critical. To date projects have mostly used protocol designed for mapping features from aerial photographs, and while this provides an excellent and comparable basis for

recording, given the increasing use of laser scanned data and the additional topographic data it can provide, we should perhaps look to review this.

Recently there has also been a move away from the traditional hillshaded views (Figure 8.2) of LiDAR data that primarily replicate the 'ideal' image that aerial photography might provide in low light levels. These views, though aesthetically pleasing are difficult to interpret and illumination from different angles (which is necessary if the viewer is to see features aligned with a single direction of illumination) provides a multitude of images with a great level of data redundancy. Even if this is reduced through the application of PCA (Devereux *et al.* 2008), visual analysis can still be hampered by the topography of the larger landscapes out-shadowing the archaeological features (Figure 8.3). The processing techniques recently developed in Germany (Hesse 2010; Bofinger & Hesse this volume) mark a move away from the creation of pseudo-aerial photograph views to a method of processing that improves the way we derive information from the data.

Two technical areas where research to date has indicated promising results involve the use of the intensity measurements of the returned laser beam. Challis *et al.* (2008) had some success in using the intensity values to enhance archaeological feature detection and also suggested that intensity data may be a potential proxy for, or comparable to, conventional geophysical techniques, namely earth resistance survey and potentially GPR in its reflectance of soil moisture values. This tentative link to geophysical survey techniques requires further research but is potentially an aspect of

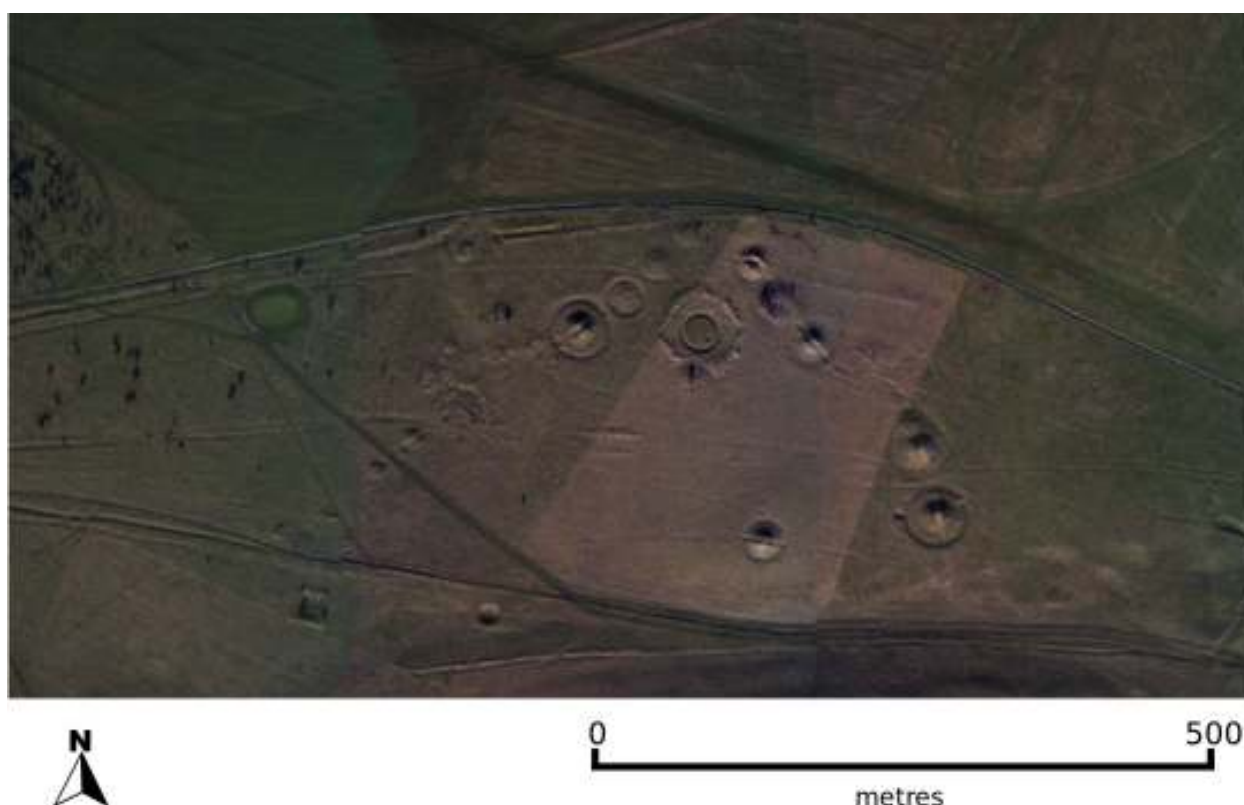
the ALS data that could be used to assess and monitor archaeological features and would provide improved comparability to traditional survey methods.

As the body of research into the technical and archaeological applications of airborne remotely sensed data grows, so too should our understanding of how to apply the data to specific research questions. The potential for the application of this data to heritage management issues, such as the identification and conservation of ephemeral remains, or research questions, such as how the change in upland management is impacting archaeological features, is limited by the lack of research in these areas to date.

Future Directions – Multiple Remote Sensor survey for the Historic Environment

From the work undertaken in the UK and elsewhere in Europe it is possible to outline a number of potential research directions that would improve the usability of airborne imagery for historic environment purposes. The first of these is improving our understanding of the physical, biological and chemical properties that both represent archaeological features in spectral imagery and affect the ALS intensity returns. The second lies in building on the existing body of research which aims to make the vast quantities of data derived from these types of survey more manageable. This should be in part achieved by a better understanding of the representation of archaeological features within the data but also by the continued improvement in processing techniques.

Figure 8.1: A typical 1.5m resolution digital spectral (CASI) image of Snail Down Barrow Cemetery, Everleigh, Wiltshire, UK. © Environment Agency



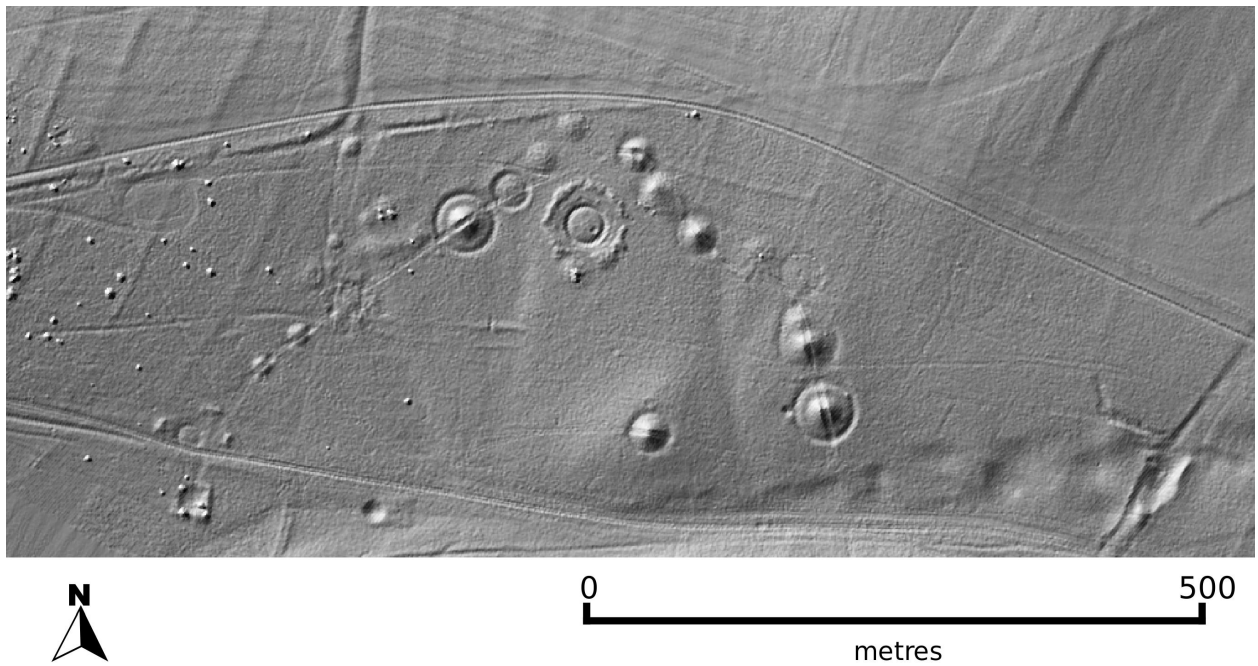


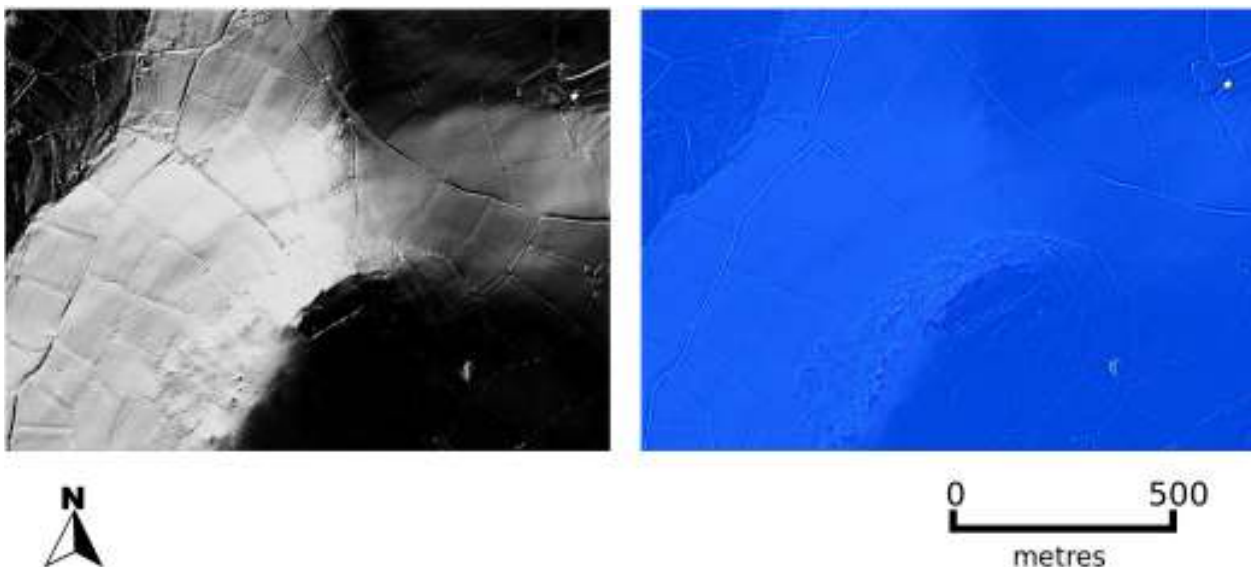
Figure 8.2: A typical 1m resolution hillshaded ALS terrain model of Snail Down Barrow Cemetery, Everleigh, Wiltshire, UK. © *Environment Agency*

From the expanding body of research into airborne sensing techniques, the conclusion is that a combination of spectral and ALS survey has value that surpasses that of each survey alone. Shell notes that 'all imagery can be better employed for understanding landscape context by the use of a digital terrain model' (2005, 282). While seemingly obvious, it is worth emphasising that using all of the data available about a feature improves our understanding of its form, and therefore our interpretation of it. It would seem that there is a need to tackle the amount of data available in a combined spectral and ALS survey in a manageable and semi-automated process while retaining confidence in the

results of the classification and limiting the number of false positives. To date no research of this kind has taken place in the UK, although a similar method combining data from different sensors and exploring the use of filters to extract archaeological features was used in a study on Crete (Rowlands *et al.* 2007).

Finally, there is also a clear requirement to improve our understanding of how both digital spectral and ALS surveys can be applied in areas where vegetation is less prone to stress and the terrain may pose greater challenges to the creation of accurate surface models. These areas are often much more difficult to access

Figure 8.3: Brent Hill Dartmoor, UK showing how macro topography can impede the identification of archaeological features in hillshaded (*left*), visualisations of ALS terrain models when compared with other techniques such as local relief modelling (*right*). © *Environment Agency*



on the ground, so any improvement on traditional survey brought about by using airborne sensors will have a great impact on their management. The project established at Bournemouth University in 2009 seeks to contribute directly to this area of research by closely examining how multisensor techniques can be applied to an area not dominated by arable production.

Beyond the picturesque – analysing the full information content of remotely sensed images

The overall aim of the Bournemouth project is to assess the full information content of airborne remotely sensed data with respect to the detail that can be derived for archaeological features in a number of liminal areas. The initial study is being conducted on the chalk grassland of the Salisbury Plain, Wiltshire, England. Almost 39,000 hectares of the rolling chalk outcrops of the Plain is owned and managed by the Ministry of Defence as the largest training area in the UK. The archaeological landscapes of this area are remarkable both for their location between the World Heritage status prehistoric landscapes of Stonehenge and Avebury and for the outstanding preservation of their archaeological features. Purchased by the War Office following the agricultural depression of the late 19th century (McOmish *et al.* 2002, 6), the Plain is the last area of chalk grassland that remains predominantly unaffected by agricultural intensification.

In addition to the preservation of the upstanding archaeological features, the Plain has been selected as a pilot study for the Bournemouth University project due to the quality of previous and on going investigations, which have characterised the nature of the archaeology through aerial, ground based metric and geophysical survey, providing an excellent baseline record. The area is generally well understood with a number of previous archaeological investigations, including full mapping of the aerial photograph archive by the National Mapping Programme (NMP) and the trial application of airborne remote sensing for environmental conservation (Crutchley 2002; Barnes 2003). Barnes' initial work looking at the application of digital spectral (in the form of CASI) and ALS data established that many known archaeological features could be seen in the airborne data that was collected primarily for vegetation condition mapping (2003, 86). The study area also allowed for the use of a number of archive datasets of different sensor types (Table 1).

The project comprises two areas in the north east of the Plain, south of the villages of Everleigh and Upavon. At 4km² the Everleigh area forms the pilot study, using archive digital spectral and ALS data supplied by the Environment Agency and military 4-band vertical photography. For the larger 12km² Upavon area a successful application to the NERC Airborne Research and Survey Facility allowed the acquisition of hyperspectral data and high resolution LiDAR with parameters tailored for archaeological survey and with contemporary field spectroscopy and geophysical survey.

The principle aims of the pilot study are to investigate the combined use of archive spectral and LiDAR data to enhance the understanding of archaeological features within an area of mixed landuse including scrub, undisturbed chalk grassland, pasture and a single arable field. Spectral data collected with the CASI sensor were available for both January and May 2001. As so little was known about the relevant information content of the spectral data for this type of environment prior to the start of the project, the spectral data were analysed visually by band and in true and false colour combinations and using a series of common vegetation indices (selected for their biophysical rather than numerical basis) for each flight. The LiDAR was also visually analysed using a range of techniques including hillshading, PCA and Local Relief Modelling (after Hesse 2010). The project will focus on trialling a number of digital combination techniques for the remotely sensed data. Combination techniques range from simple addition of derived rasters to trialling of techniques such as pan-sharpening. These will be targeted at the portions of the spectral data identified as having the most information content for the archaeological features in the area.

Features were mapped using a GIS and a number of parameters were recorded for each feature identified including morphology, length, description, interpretation and land use. In this way the data could be analysed not just by the presence or absence of features in a given image but by % recovery. Ancillary data enabled the results of the mapping exercise to be broken down by land use and feature type to give greater insight into the patterns of visibility. By comparing the information derived in this manner to the baseline recorded by the traditional mapping methods of the NMP, we can have some confidence in

Data Type	Resolution	Date Flown	Source
CASI	1.5m	January 2001	Environment Agency
	1.5m	May 2001	Environment Agency
LiDAR	2m	January 2001	Environment Agency
	1m	2005	Environment Agency
Aerial Photography (Oblique)	0.15m	Archive (c.1950–2002)	Wiltshire Sites and Monuments Record
Aerial Photography (Vertical)	0.15m	Modern, yearly summer coverage (2002–6)	Defence Estates
4-Band Aerial Photography (Vertical)	0.15m	Modern, yearly summer coverage (2006–7)	Defence Estates

Table 8.1: Airborne Digital Data Sources for the Everleigh Pilot Area.

whether they provide additional information to current common techniques.

The bespoke data acquired for the Upavon area by the ARSF in early 2010 will enable assessment of a number of key issues surrounding the potential for direct links between airborne remotely sensed data and ground observations. These will focus on the parameter of soil moisture differences measured both directly by the collection of soil samples and indirectly through earth resistance survey. It will also enable the comparison of the full data cube of hyperspectral data with the banded CASI data available for Everleigh and an assessment of whether improvement in spatial resolution has an impact on the useful information that can be derived from the ALS topography and intensity data.

Conclusions

While the individual value of digital spectral and ALS data for the interpretation of archaeological landscapes has been proven beyond doubt, significant work is required to exploit the full information content of these datasets. Only by developing both a robust understanding of what these surveys can tell us about archaeological features in a given landscape and techniques to streamline the combined data processing, will we actualise the full potential of airborne remote sensing for archaeology.

While no single sensor will ever be a panacea for archaeological feature identification it would seem the value of combining both ALS and digital spectral survey is greater than the value of each separate survey. In terms of identifying both the direct and proxy measures of archaeological features in a landscape that combined surveys are powerful tools, and given the ongoing improvement in sensor systems it would seem likely that this type of dual survey will become increasingly common. The combination of vegetation / soil and topographic measurements may prove particularly valid for areas that are hard to survey by traditional means and there is a real need for specific research into the application of multisensor survey in non-agricultural landscapes.

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