DISCOVERING ARCHAEOLOGICAL CROPMARKS: A HYPERSPECTRAL APPROACH

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ABSTRACT:

For the last half century aerial photography has been considered to have made the single most important contribution to archaeological site discovery in temperate latitudes, as subsurface features can produce cropmarks detectable in aerial imagery. But it is well established that successful aerial photographic reconnaissance for cropmarks relies on dry weather and well-drained soils in arable agriculture. There is, thus, in Scotland, a bias in the discovery of known archaeological sites in favour of drier eastern districts, supporting arable agriculture, compared to the west with its wetter climate focussed on pastureland. Cropmarks are linked to moisture stress in growing plants and, thus, are potentially detectable in bands both outside and within the visible part of the electro-magnetic spectrum. So, although cropmark detection has used film, whose sensitivity closely approximates the human eye, hyperspectral scanning allows consideration of a wide range of different wavelengths, beyond the visible spectrum, many of which are sensitive to changes in vegetation status. The main objective of the research partially reported here is to test whether an enhancement of archaeological site discovery can be achieved by augmenting cropmark detection rates through the use of hyperspectral remotely sensed imagery.The research uses two case studies (one in eastern Scotland and the other in the west). One case study of an area of arable farmland in eastern Scotland using data provided by one sortie of two airborne scanners (a digital camera was also provided) is summarised herein. Following processing and analysis, these data supported the discovery of as many cropmarks as had been detected in the aerial photographic data acquired over several decades.

1. INTRODUCTION

Over several decades air photo interpretation has become well established in the UK, and increasingly across Europe, as a means of discovering archaeological sites. One of its most important contributions was to locate cropmarks, indicating archaeological sites beneath the agricultural soil. Indeed, it is accepted that in excess of 50% of all archaeological sites known in the UK were discovered from the air   [Bewley 2003]. Cropmarks form because crops usually grow thicker, taller or ripen later (or all three) where there is relatively more moisture and nutrients (e.g. above filled in ditches) and grow less well (i.e. thinner, shorter and ripen earlier) where they are deprived of water and nutrients (e.g. above a buried stone wall). Thus archaeological remains beneath the surface have the potential to affect crops and become visible as patterns of differential crop growth [Wilson 2000].

Cereal crops on a well-drained shallow soil with low rainfall in the growing season seem to provide the best conditions for detecting cropmarks. Least favourable has been permanent pasture on deep, poorly drained soils with high levels of rainfall in the growing season. This leads to a considerable bias in the visibility of cropmarks [Hanson 2005], arising from a range of variables: moisture availability; the availability of dissolved nutrients to the crops at crucial growing times; crop type; soil type; and soil depth [Evans and Jones 1977]. Most important of these is the differential availability of soil moisture, directly linked to precipitation levels. Thus, archaeological cropmarks may be seen in some areas but not in others, simply because rainfall, crop or soil conditions are not conducive to cropmark production and subsequent detection by traditional panchromatic aerial photography. Accordingly, the apparent distribution of archaeological cropmarks is as much a reflection of these factors as it is of the real presence or absence of archaeological sites.

Aerial archaeology has been limited by this differential visibility of cropmarks. It has been generally recognised that multi-spectral imagery has the potential to address some of these problems because it is potentially more sensitive to changes in vegetation status than the visible or panchromatic ranges [Jensen 2000; Chen 1985; Server 1998]. More specifically, Shennan and Donoghue (1992) recommended ATM bands 5 (red), 7 (near infrared), 10 (short wave infrared), and 11 (thermal infrared) for the detection of cropmarks. They showed that red and infrared images provide good definition of soil and cropmarks and that near and short wave infrared wavebands are particularly sensitive to plant health and can affectively detect water stress in vegetation [Donoghue 2001].With the increasing availability of hyperspectral imagery, as well as thermal imagery, it is recognised that this presents an even greater potential. The main objective of this paper is to present an example of the enhancement of archaeological data achieved by augmenting cropmark detection rates through the use of thermal and hyperspectral remotely sensed imagery, revealing buried archaeological remains invisible to both human eye and standard photography.

2. AREA SELECTION

Two test areas, each dimensioned 2km x 2km, were selected, one in the east and one in the west central lowlands of Scotland.

The imagery discussed in Section 3.1 was obtained. This paper considers the results from the eastern area around Inveresk, Midlothian (centred at about 334000E, 670000N British National Grid) which is well known for its high quality cropmark record covering sites from the Neolithic period (c. 3500 B.C.) onwards, including a ritual cursus monument, several Iron Age settlement enclosures, field systems, a pit alignment/land boundary and Roman temporary camps [Brown 2002]. This area has been extensively photographed over a number of years providing an excellent baseline of known archaeological sites against which to compare both the hyperspectral and thermal imagery obtained as part of this programme. Additionally, some sites have been excavated [e.g. Hanson 2002] providing useful additional data.

3. DATA & INSTRUMENTATION

The main data source for this project is the NERC ARSF (The Airborne Research & Survey Facility managed by the UK's Natural Environment Research Council) [NERC 2008]. Two sorties were carried out: the first in Sept. 2005, the second in July 2006. Both consisted of the following data:
- ATM (1268 Airborne Thematic Mapper, by Argon ST but formerly Deadalus);
- CASI 2 (Compact Airborne Spectographic Imager, by Itres); and,
- vertical photographs taken with a Rollei medium format digital camera.

These data were acquired simultaneously to facilitate comparison, allowing conclusions indicating what further archaeological discoveries can be made using hyperspectral and thermal data compared to photographic data. (The imagery from 2005 was acquired too late in Scotland's agricultural growing season for the detection of cropmarks and this 2005 sortie is not discussed further here.)

Cropmarks present as a relative variation in fertility – either more or less fertile than the surrounding vegetation. Thus, intuitively, they present as contrast rather than as characteristic spectra. This, as will be shown in Section 4, has led us to consider contrast enhancement rather than image classification as an image processing tool.

3.1 Imagery

CASI 2 is a pushbroom imaging spectrometer based on a 512 x 288 area array CCD [Babey and Anger 1993]. The instrument detects over a spectral range from 405 nm (visible blue light) to 950 nm (near infrared) and has a 54.4-degree across track field of view. The CASI 2 has three operational modes:
- spatial;
- spectral; and,
- enhanced spectral.

In spatial mode all 512 pixels are recorded in up to 18 wavebands. Spectral mode records data in 288 bands with 39 pixels across the swath. Enhanced spectral mode is a compromise between spatial and spectral mode. The combination of bands and pixels is determined by the ambient light at the time of imaging [Jensen 2000]. Spatial mode has been applied in this work using 512 pixels and 16 wavebands. Different wavebands reflect different spectral signatures. For instance, bands 1, 4, 5, 12 and 14 are typically used for vegetation indices and to simulate popular satellite channels; channels 5, 7, 8, 10 and 12 analyse vegetation density

(http://arsf.nerc.ac.uk/documents/casi2.pdf last viewed 23/04/08). The manufacturer has now replaced CASI 2 by CASI 1500 providing a 1500 pixel swathe (www.itres.com/Sensor_Products last viewed 23/04/08).

The Argon ST 1268 Airborne Thematic Mapper or ATM (www.argonst.com/capabilities/capabilities_sensors.htm last viewed 23/04/08) is a passive sensor with 11 fixed spectral wavebands, which cover visible bands, and near, short and thermal infrared bands. CASI 2 and ATM data cover most of the visible, as well as near and thermal infrared spectrum.

Thus, as the sensors used in this work cover much of the infrared spectrum to which vegetation is more responsive, then they should be sensitive to the vegetation changes introduced by cropmarks.

4. DATA PROCESSING

Data received from the imaging sensors (CASI 2 and ATM provided by NERC ARSF) on the airborne platform contained distortions. Good geocorrection to level 3b (NASA definition) is necessary in order to build up an error free archive of cropmark location, for comparison with imagery captured over time, or to overlie these with other spatial data sets, typically in the GIS environment, to aid understanding. To rectify these distortions, which included atmospheric and solar illumination influences on the recorded signal, line dropout, striping and errors in the relative positions of pixels [Erdas Field Guide 2006], a variety of processing techniques was applied. NERC ARSF data is level 1b. Thus some radiometric correction and also limited geometric correction, based on in-flight GPS and IMS recordings and synchronised ground based GPS recordings by the researchers, had already been applied.

GPS data (position and elevation/altitude) as initially ECEF (Earth-centred, Earth-fixed) Cartesian coordinates are processed to provide ECEF coordinates at level 1b. It is possible to convert level 1b data into level 3b (fully geo-corrected to Britain's National Grid, in this case) using Azgcorr [Azimuth Systems, 2005] software. One of the intermediate steps is Level 3a which presents the image data on a regular grid in a recognised map projection coordinate *without* taking account of relief displacement. Thus Level 3a will not always match the map and a Digital Elevation Model and ground control points were used to achieve an accurate orthoimage. DEM data were provided by NERC ARSF. To get accurate geo-corrected images a geoid-ellipsoid separation file was used, also provided by NERC ARSF. Azgcorr combines hyperspectral (and other) image data with post-processed navigation data, producing geometrically corrected data. Azgcorr converts the raw image data to HDF format, which was reformatted (to geo-tiff) for import to ERDAS Imagine software for further processing.

The second step was to extract the maximum archaeological information using various image enhancement techniques. Principal component analysis (PCA) transforms a series of correlated variables into a smaller number of uncorrelated variables and is thus a way of identifying patterns in multispectral data where there may be some correlation between bands. PCA is widely used to aid interpretation of hyperspectral/multi-spectral data and has been used to detect cropmarks [Winterbottom and Dawson, 2005]. It is a useful tool because it identifies change in surface variability, which helps to detect differences in vegetation and, hence, archaeological patterns. PCA compresses the data by reducing the number of

dimensions, without much loss of information. Normalized Difference Vegetation Index (NDVI) quantifies the density of plant growth using near-infrared (NIR) and visible (VIS) wavelength bands. It was applied to the data and helped to locate varying growing conditions and indicate areas for closer examination for the discovery of cropmarks.

4.1 Interpreting the Images

Cropmarks are not only produced by ancient subsurface features but also more modern ones, such as various agricultural practices, including field drains, tractor turning circles and rig cultivation (a system of medieval land use practised in northern and western Great Britain characterised by alternating "runs", or furrows and "rigs", or ridges which continued in use in some areas into the 19th century). Thus finding archaeological cropmarks requires visual interpretation by an archaeologist of images where cropmarks show clearly.

This means that a contribution that Remote Sensing can make is to ensure that the image data is processed in such a way as to **maximise the contrast** created by the imaged cropmarks and to show as many cropmarks as possible. The archaeologist then needs to interpret these processed images. Current research has not extended to the automated recognition by historic period of cropmarks. In other words, cropmarks created by 2nd century subsurface features are not inherently distinguishable from 20th century ones except on the basis of their archaeological interpretation.

5. DALKEITH PARK TEST SUB-AREA

Dalkeith Park is part of the eastern test area; archaeological remains recorded from the air since reconnaissance began in the area in the 1980's (Figure 1) was transcribed by the Royal Commission for Ancient and Historical Monuments of Scotland (RCAHMS) and presents the extent of knowledge up to 2002. Figure 1 shows several prehistoric enclosures and associated pit alignments, a number of isolated pits and pit clusters and quite extensive areas of medieval rig cultivation. The character of the oblique photographs used in the 1985-2002 period is illustrated in Figure 2 provided by RCAHMS.

Figure 1. The Dalkeith Park test area, showing all recorded archaeology interpreted from photography dated 1977-2002, overlaid on © Ordnance Survey Great Britain data

5.2 ATM data

ATM band composites, enhanced with a variety of filters revealed many archaeological features. For example, Figure 3 generated from bands 4,3 and 2 and a 7x7 standard deviation filter shows pit alignments, a pit cluster and D-shaped and rectangular enclosures. Figure 4, which used bands 8, 7 and 6

and a 5x5 standard deviation and sharpen filter showed further small enclosures.
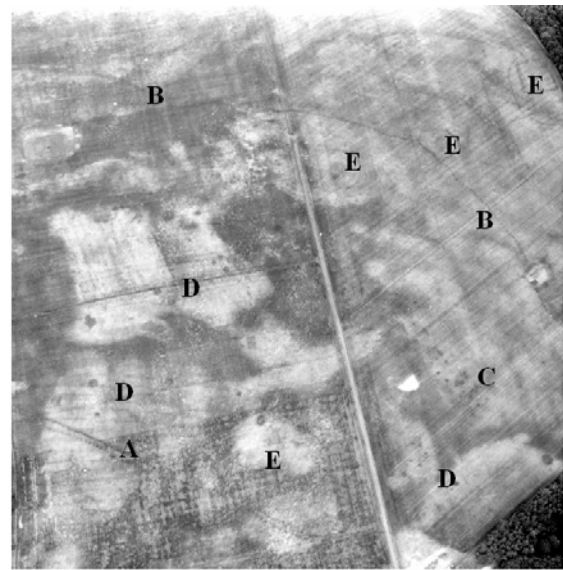

Figure 2. Oblique photo of Dalkeith Park from WSW showing a double pit alignment (A), a single pit alignment (B), a pit cluster (C), scattered pits (D) and 4 enclosures (E). © RCAHMS

Figure 3. Generated from bands 4, 3 and 2 and a 7x7 standard deviation filter shows 2 pit alignments (A), a pit cluster (B), D-shaped and rectangular enclosures (C), a small enclosure (D) and scattered pits (E).

Figure 4. Generated using bands 8, 7 and 6 and a 5x5 standard deviation and sharpen filter showing a double pit alignment (A), Pit alignment (B), pit cluster (C), a small enclosure (D), a D-shaped enclosure (E) and some rig cultivation (F).

5.2 CASI 2 data

The geometric character of the rectified CASI 2 data, with a topographic map overlay, is demonstrated in Figure 5. The correction method applied was, thus, deemed sufficiently accurate to prevent 'double counting' of crop marks, and other errors, when integrating data sets. Figure 6 shows CASI 2 bands 14, 12 and 10.
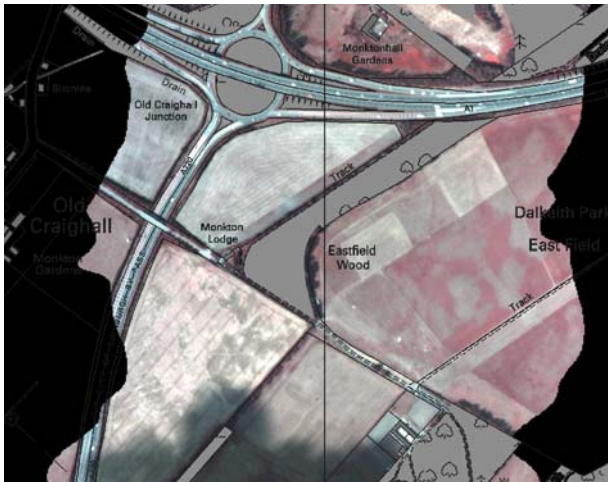

Figure 5. CASI 2 rectified image of Dalkeith Park, with topographic map overlay © Ordnance Survey of Great Britain, showing a good match.

Although not predicted to be a viable process in the search for cropmarks (because contrast was considered to be the most important characteristic of the images), unsupervised classification of the CASI 2 hyperspectral data to 5 classes was investigated. (Figure 7) results were not very successful.

Given that crop marks appear as a consequence of vegetation stress, several vegetation indices were examined, including NDVI. One resulting image is shown in Figure 8, but this seemed to enhance the modern features more than the potentially ancient ones.
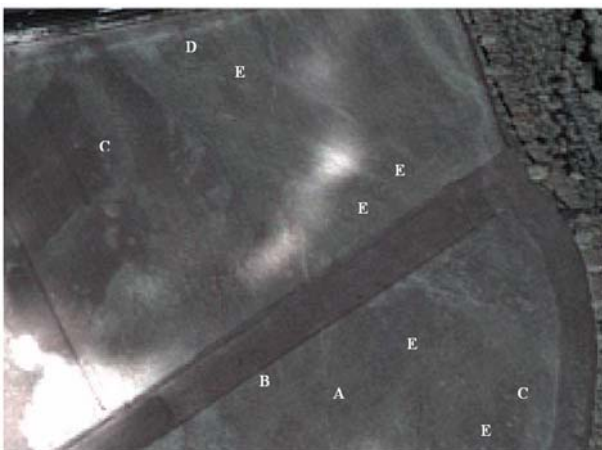

Figure 6. CASI 2 bands 14, 12, 10, Dalkeith Park/Eastfield, showing a pit alignment (A), an enclosure (B), scattered pits (C), a possible double ditched enclosure (D) and further possible archaeological cropmarks (E)

Also considered was Principal Components Analysis (PCA). Figure 9 shows an RGB image (the first frame in the montage) of principal components (PCs) 2, 3 and 4, and the first sixteen
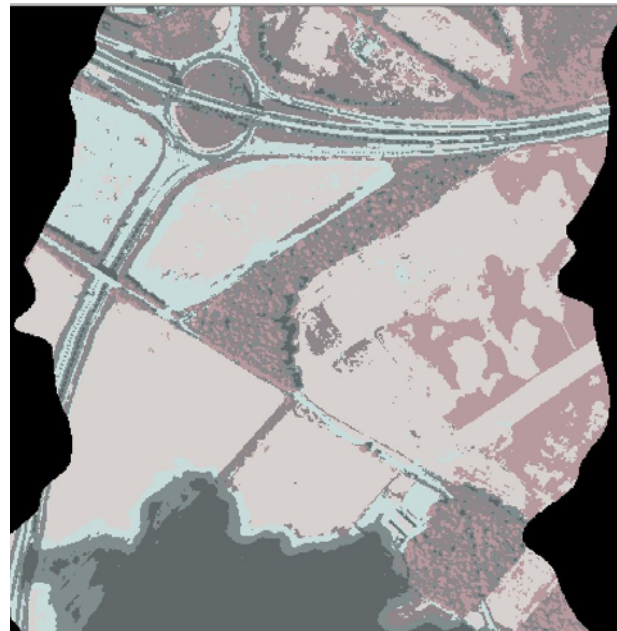

Figure 7. CASI 2 image of Dalkeith Park. Unsupervised classification, 5 classes.

principal components (the next 16 frames). From these it can be seen that very little information is present in PCs 7 to 16. Figure 10. comprises the first Principal Component in pseudo-colour.

Figure 8. CASI 2 NDVI image in Monktonhall Farm (near Dalkeith Park)

6. CONCLUSIONS

Most of the band combinations in the multispectral and hyperspectral imagery provide some archaeological information and most further information can be established through the use of PCA. Normally in any band combination some archaeology

is apparent but some is not, with different parts of landcover responding better in different bands. So it is a matter of experimenting with a wide range of possible combinations to achieve maximum results for the recovery of archaeological cropmarks. The band combinations in the near infrared part of the spectrum tended to give the best archaeological results.

The implementation of different contrasts and filters also plays an important role in the recovery of archaeological cropmarks. In CASI 2 and ATM imagery, detail in many 'washed out' fields become more apparent by adjusting the various contrasts and filters, and (although not discussed here) the same effect was found with the Rollei digital panchromatic photography.
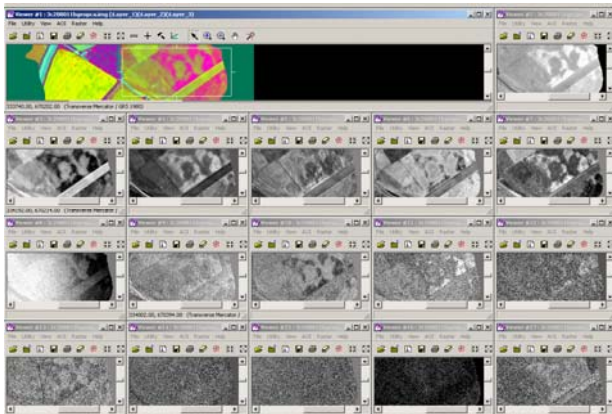

Figure 9. Principal Components Analysis. The first frame (coloured) shows PCs 1, 2 and 3 as RGB. The remaining sixteen frames are PCs 1-16 in order.

In the eastern area of interest there were three sub-areas. That discussed here (Dalkeith Park) is one of the richest in terms of archaeological cropmarks and *all* its known archaeology was recovered from this *single* mission's hyperspectral and ATM data. Also a few possible previously unidentified cropmarks have been identified using these data. This compares very favourably with the output from 25 years worth of aerial photography, and this level of success for hyperspectral and thermal bands provides us with hope for discovering many more sites than heretofore, in the wetter western test area. A major, current, disadvantage, however, is the poorer resolution of the hyperspectral and ATM data compared to digital photography.
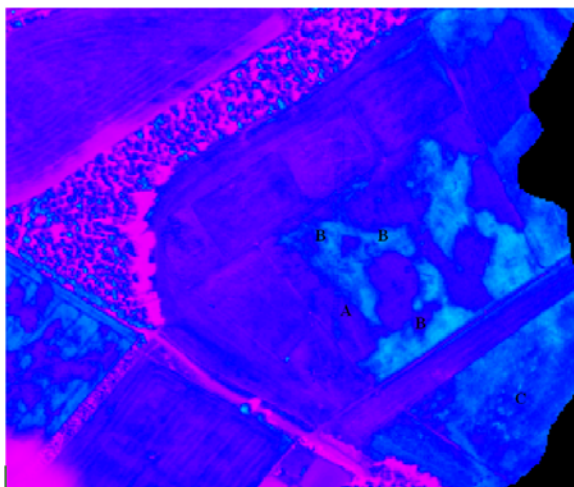

Figure 10. First principal component in pseudo-colour of Dalkeith Park, showing a pit alignment (A), three small enclosures (B) and a pit cluster (C).

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