Editorial Introduction

Although emphasis is usually placed on our increasing ability to visualise imagery, the past two decades have seen enormous advances in ways by which image data can be captured.

In this Case Study Paul Carey, Stephen Trew and John Meneely illustrate the combination of a series of by now relatively standard tools in the creation of some impressive visualizations of an archaeological site in Ireland. First, their study shows how image data can be rapidly acquired using conventional aerial photography. In terrain that would otherwise be difficult to survey conventionally, these images were geo-rectified (i.e. placed onto a standard spatial co-ordinate system) using the global positioning system. Second, a digital photogrammetric workstation was used, together with the scanned and rectified imagery to produce a variety of visualization of the site and its stone circles. These include conventional two-dimensional maps of the stones known as block diagrams, and fully navigable 3D representations. All of these results can be made available to other archaeologiests as digital files or via the WWW and create for posterity an invaluable archive of the newly-excavated site.

Although the techniques employed and the contet are highly technical, we suspect that the general methodology employed will become increasingly used in a variety of other academic contexts. Indeed, we can think of numberous applications including many outside archaeology.

The Application of Digital Photogrammetric Techniques and Aerial Photography to the Preservation of Archaeological Detail.

Case Study: The Copney Stone Circle Complex, Co. Tyrone, N. Ireland.

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Abstract

The Copney Stone Circle Complex, Co. Tyrone, N. Ireland, is an important Bronze Age site forming part of the Mid-Ulster Stone Circle Complex. The Environment Service: Historic Monuments and Buildings (ESHMB) initiated a program of bog-clearance in August 1994 to excavate the stone circles. This work was completed by October 1994 and the excavated site was surveyed in August 1995. Almost immediately, the rate at which the stones forming the circles were breaking down was noted and a program of study initiated to make recommendations upon the conservation of this important site. Digital photogrammetric techniques were applied to aerial images of the stone circles and digital terrain models created from the images at a range of scales. These provide base data sets for comparison with identical surveys to be completed in successive years and will allow the rate of deterioration, and the areas most affected, of the circles to be determined. In addition, a 2D analysis of the stones provides an accurate analysis of the absolute 2D dimensions of the stones for rapid desktop computer analysis by researchers remote from the digital photogrammetric workstation used in the survey.

The products of this work are readily incorporated into web sites, educational packages and databases. The technique provides a rapid and user friendly method of presentation of a large body of information and measurements, and a reliable method of storage of the information from Copney should it become necessary to re-cover the site.

1 Introduction

Digital photogrammetry is being adopted throughout the mapping industry because of the ease with which it may be applied to small and large-scale studies to generate both accurate and repeatable analyses and user-friendly visualisations of large datasets. For example, the detailed surveying of an archaeological site can produce significant amounts of spatial data including the geographical co-ordinates of the site, it's extent, the position of objects of interest and their dimensions. This is routinely represented on a surveyed map with associated scales. The process of surveying even a small site and generating accurate maps is labour-intensive. Digital photogrammetric techniques can be applied to aerial photographs of such a site to generate the same information in a fraction of the time and generates data sets and images that are readily transferred to other software packages, incorporated into reports and presentations and posted to WWW sites.

Furthermore, aerial techniques may be applied in regions where access is limited or detailed examination of the site may cause damage to delicate artifacts.

The rapid development of digital photogrammetry and photogrammetric workstations in the last decade, and more so the increased availability of these systems to research establishments presents an extremely powerful tool to researchers in all spheres. This technique, using modern computing systems, is applicable at all scales of observation from the processing of satellite-acquired images to electron photomicrographs. The power of the technique lies primarily in the ease with which large amounts of data can be generated and recorded to a very high degree of accuracy in readily accessible formats. Additionally, the ease of data generation, representation and storage facilitates later cross-referencing of image derived data with subsequently recorded datasets of the same area. It is therefore possible to measure the change in terrain quantitatively through time and the changes determined can be ascribed to particular processes depending on their degree and style.

Aerial photography presents the most rapid method of image acquisition for medium-sized (metres across) and large-scale archaeological sites. The main benefits of such a survey are:

- Image acquisition and processing of the entire area of interest is rapid and non-destructive.
- Photogrammetric techniques can be employed to give a high degree of accuracy.
- Ground surveying is minimal.
- A single user can carry out all of the image processing, analysis and output on a single system.
- The technique is ground-condition independent.
- The technique can be rapidly repeated at specified time intervals and data sets easily archived for later comparison.
- The final products are readily transferable to other software packages.

This case study will elucidate the power and ease of use of digital photogrammetry and image processing techniques in the recording and processing of data from a Bronze Age stone circle complex recently excavated in Northern Ireland: the Copney Stone Circle Complex. This site was chosen for examination using this technique because it presents unique problems to routine surveys. Specifically:

- The complex nature of the site, with large numbers of stones of highly variable dimensions and arrangements within each stone circle requires very detailed and time-consuming ground surveying.
- The use of aerial photos avoids the highly detailed ground-based photographic techniques normally employed on sites comprising such small artifacts.
- The subject area is situated in waterlogged peat bog. This makes access by any vehicles impossible and manipulation of heavy surveying apparatus difficult.

2 Site details and aims of the study

Northern Ireland has a wealth of archaeological sites, which reflect human activity in the region from the earliest Neolithic. The earliest sites comprise individual standing stones and stone circles, and some of the most important and complex of these have been excavated from beneath peat bog. The Copney Stone Circle Complex (CSC), County Tyrone, N. Ireland (H599782, Figure 1) is an important Bronze age site forming part of the Mid-Ulster Stone Circle Complex. The complex is situated on the northern slope of Copney Hill and runs down-slope along a NW-SE axis. The CSC was first noted in 1979 and surveyed in 1981. It became a scheduled monument in March 1993 and was taken into State Care Guardianship in 1990, at which point the site, located in peat bogs, was still un-excavated. The Environment Service: Historic Monuments and Buildings (ESHMB) initiated a program of bog-clearance in August 1994. This work was completed by

October 1994 and the excavated site was surveyed in August 1995. Only two of the circles (of a total of nine) and a quarter of a third were excavated at this time. The present visible site comprises these circles (designated circles A, B and C, a stone alignment between circles B and C and a standing stone (Plate 1).

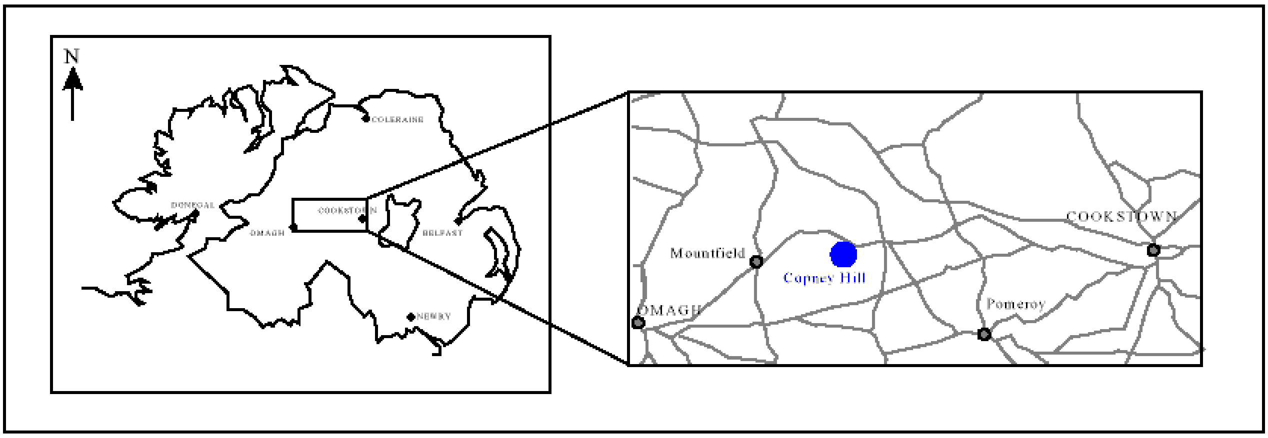


Figure 1. Schematic location map for the Copney Stone Circle Complex, N. Ireland

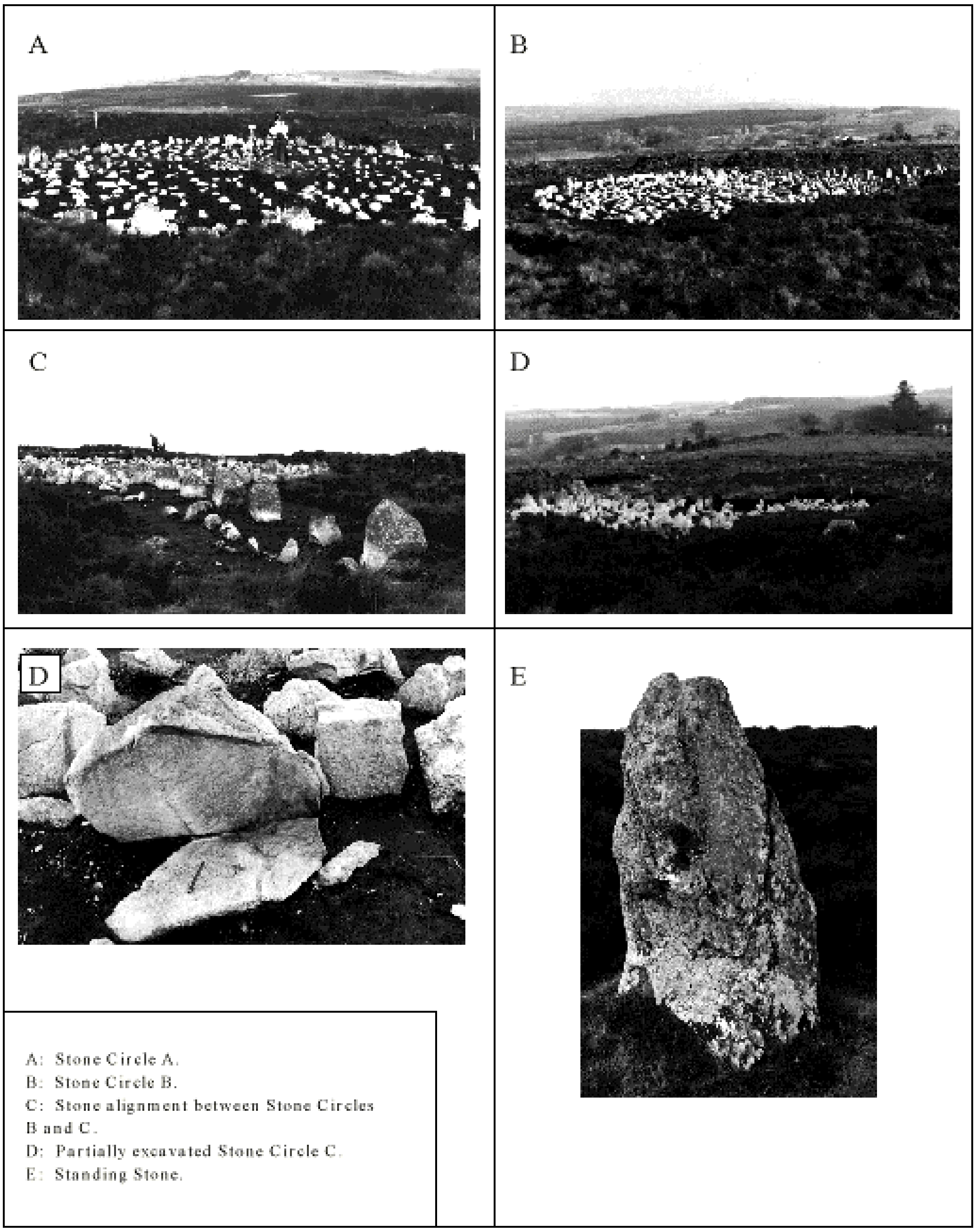
The complexity of the CSC makes it unique amongst the Mid-Ulster stone circles. As a result, the accurate recording of the details of the site and its components is essential. This requirement became even more important in light of the survey reports following the initial site survey report (MacDonagh, 1995). In this report, the surveyors remarked upon the condition of the stones making up the Complex, particularly their apparently high rate of decay since excavation. The decay of such a site represents a significant loss to both the archaeological record and to the public. For this reason, excavation of the site was paused to allow examination of the stones, surveying and the construction of conservation pathways for the site. The surveyors therefore recommended monitoring of specified keystones within the complex to estimate decay whilst decisions regarding conservation were considered by EHSMB.

At this point, a program of study was initiated in the School of Geosciences, The Queen's University of Belfast to investigate decay features and the effect burial in peat has on the structure and mineralogy of the stones as a means of informing management decisions for this site. The report generated from the first phase of this study (Curran *et al*, 1997) highlighted the following problems:

- The stones comprising the CSC are significantly altered by hydrothermal processes that have generated individual stones that are cross-cut by extensive fracture networks and veins. The ingress of fluids through these networks has permitted the rapid decay of the stones by weathering processes (freeze-thaw, leaching etc) since their excavation. The penetration of the weathering processes through the body of the stones has resulted in a very weak artifact that is decaying at a very significant rate.
- Present environmental conditions at the site are exacerbating the effects of the weathering processes and deterioration of the site is set to continue at this high rate unless remedial action is taken.
- Perhaps Curran *et al.'s* most significant observation relates to the processes of chemical weathering of the site. There is a correlation between the rate of decay of the stones and their total surface area exposed to attack. Thus, whilst monitoring of keystones will give some estimation of ongoing decay, once the stones begin decay, the overall rate of stone decay is constantly accelerating as smaller and smaller fragments are produced.

As a result of this preliminary study, a number of remedial actions were suggested to the EHSMB ranging from preservation of the stones using chemical treatment and/or cover to reburial

Plate 1. Currently excavated Stone Circles at Copney Hill, County Tyrone, Northern Ireland



A: Stone Circle A.
B: Stone Circle B.
C: Stone alignment between Stone Circles B and C.
D: Partially excavated Stone Circle C.
E: Standing Stone.

of the site after site preparation to preserve the stones. In choosing how to best preserve the information in the CSC, the EHSMB require an accurate determination of the projected decay rate of the site as a whole and of individual features within the site. Furthermore, development of the site including construction of access routes such as elevated walkways, and covering the site from prevailing winds has been suggested. Thus a rapid method of visualizing the effects of development on the site both from a structural and aesthetic point of view would be beneficial. More importantly, a permanent record of site details through time facilitates examination of changes to the site.

The aims of this study were therefore to evaluate the use of aerial photographic and photogrammetric techniques to the characterization of the Copney Stone Circle Complex and specifically to provide:

- A base-line digital terrain model of the site for calibration of future site surveys and for use as a measuring tool for the efficacy of conservation techniques. For example, if the recommendation to erect shielding structures (such as walls) is followed, it would be possible to measure the change in the stones after the shield has been placed and comment upon its efficacy.
- A rapid method for the acquisition and storage of site measurements and stone dimensions.
- A visually impressive method of presenting large amounts of data to the public.

To highlight the usefulness of this technique in both detailed and more landform-based applications, two sets of images were treated:

- A standard aerial stereo pair purchased from the Ordinance Survey of Northern Ireland (scale 1:10000). The images were commissioned by the OSNI and collected by BKS Surveys of Coleraine in July 1997. This format is typical of commercially available aerial photographs and it was considered beneficial to examine the efficacy of digital photogrammetry within these limitations. It is obviously financially more attractive to purchase images rather than commission lower level flights over archaeological sites. The problems inherent in processing images at this altitude with regards to small-scale features are well known, specifically that at this altitude it is very difficult to resolve small-scale structures. The GSD (Ground Sample Distance) for the 1:10000 scale imagery is 20 cm. For this reason, aerial photography at this altitude is usually confined to larger structures.
- A privately commissioned stereo pair collected by BKS Surveys of Coleraine in April 1998 (scale 1:2000). Whilst a more expensive option, the 1:2000 scale imagery allows the resolution of much more detail on the ground and is essential in the detailed survey of the CSC. The GSD for1:2000 scale imagery is 5cm

2.1 Photogrammetry and the Leica-Helava Digital Photogrammetric Workstation

The Helava Digital Photogrammetric Workstation (DPW) represents a powerful tool in the analysis and generation of data from digitally scanned images. The DPW is equipped with two high resolution monitors and a stereo video card. One monitor is used for viewing the software package and the other (extraction monitor) is used to see the imported images as they are overlapped. Using a pair of stereo glasses, the overlap area may be observed in 3D and features examined for analysis. Furthermore, this capability of the system allows the accurate placement of ground control points onto the surface rather than floating above the image.

The Copney Stone Circle Complex, like many similar sites in Northern Ireland, is surrounded by waterlogged peat bog which makes human access difficult and vehicular access impossible. Therefore, it is not possible to acquire initial photography of the site by conventional means (using scaffolding or crane) but necessitates the use of aerial photographs. The DPW was applied to the calibration and rectification of aerial photographs acquired of the CSC. Aerial photography facilitates the capture of the entire site in a single image (and a considerable amount of the surrounding terrain). Processing of this image allows the rapid and precise recording of data from this complex site and enables the creation of a baseline against which the success or failure of conservation treatments may be compared. Additionally, it allows the graphical presentation of information in formats that are easily examined and presented to researchers and the public.

3 Methodology

3.1 Data source

The scanned aerial photographs were transferred onto CD in the Helava Vitec Tile format (1:10000 scale) and standard Tiff format (1:2000 scale). These images were imported directly into the (DPW). The DPW runs a software package called Socet Set that is used to carry out all of the image manipulations and digital terrain model generation detailed in this study.

3.2 Ground Survey

Accurate control points are needed to tie the pair of stereo images to each other and to facilitate the construction of an accurately constrained product for spatial measurements. For the 1:10000 scale imagery Ground Control Points were identified from the aerial photographs and were surveyed in the field using a Leica Wild GPS 200 (differential GPS system). For the 1:2000 images, it was possible to place marker sheets in specific positions around the site that were included in the acquired images. The absolute positioning of these sheets was measured prior to image acquisition. GPS data was processed and geographic latitudes, longitudes and elevations generated using Leica SKI v 2.01 software. The values for each GCP were then input into the DPW to allow accurate calibration and rectification to be carried out on the images. In preparation for the more detailed examination of the stone circles, relative heights of selected stones were also recorded for comparison with the digital terrain models to be generated.

The main strength of the DPW method is that ground control can be constrained with a minimum number of measurements. For this study, eight points were collected in total that lie within the overlapping area of the stereo pair of aerial photographs. These points were obviously centered around the circle area to give the tightest fit for the DTM in this area. To give some idea of the relative sizes of the areas we are dealing with, and also to give some feel for the detail of the work being carried out, Figure 2 shows the original untreated images at 1:10000 and 1:2000 scales. Figure 2 shows the total area of coverage possible with 1:10000 imagery, and its application in topographic modelling as well as the finer detail possible at the 1:2000 scale for detailed spatial analysis.

3.3 Image Preparation (orientation)

When images are obtained by photographic techniques, aberrations in the lens can distort the image. Clearly, these distortions give a significant error to any measurements made upon the images and prevent the accurate registration of the images that allows three-dimensional viewing. These are removed by the DPW by inserting the details of the lens distortions provided in the lens calibration report that accompanies the image files. Using the lens calibration files this first stage in image preparation was carried out. This procedure is referred to as Interior Orientation and is a basic procedure in image processing. The next step in image preparation (Exterior Orientation) includes two distinct processes (triangulation and rectification) that are used to prepare the images for stereoscopic examination and data extraction

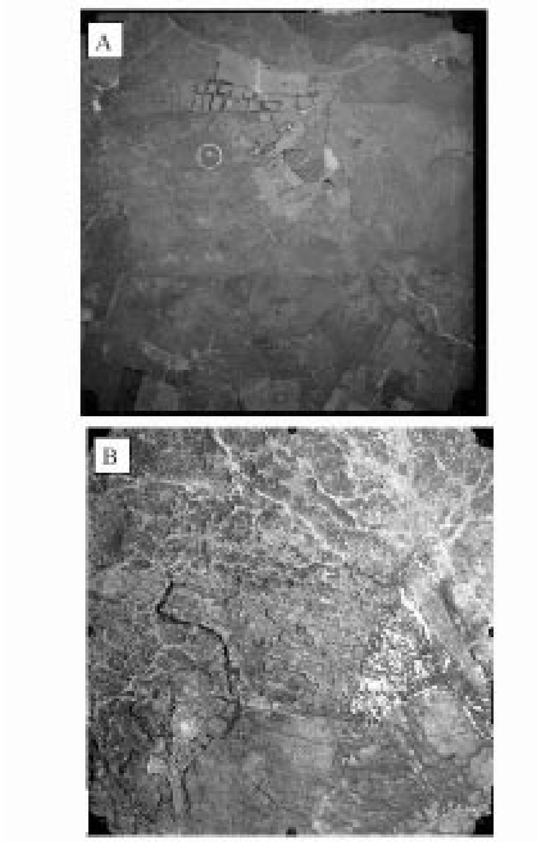


Figure 2. 1:10,000 (A) and 1:2,000 (B) untreated scanned images of the CSC site and surrounding area. Stone circles in the 1:10,000 image are highlighted in a yellow circle

3.4 Triangulation and Rectification

The images were registered to the ground using the Helava Automatic Triangulation System (HATS) component of Socet Set. Initially, the DPW creates a number of points on each image and finds the corresponding points in overlapping areas of both images (these are called Tie Points).

When this is completed, the latitudes, longitudes and heights for each of the surveyed ground control points are entered into the system and the position of each pinpointed on both images. The HATS module then highlights points where the system is not satisfied with the correlation between specified points on the images (expressed as a RMS statistical measure). Further processing of the image is carried out necessary until the system automatically locates all of the tie-points and ground-control points within threshold accuracy limits.

The images are rectified further to remove any small distortions in the images caused by slight changes in the flight path between capture of each image.

With interior orientation, triangulation and rectification complete, the stereo image is in a suitable condition to generate the digital terrain model and examine the site.

3.5 Generation of the Digital Terrain Model, Orthophoto and Perspective Scene for the Copney Site using 1:10000 scale imagery

The DPW's Automatic Terrain Extraction Feature was used to produce a digital terrain model for the Copney section of the images. The digital terrain models may be generated at a range of accuracies, controlled by the selection of post spacing by the user. A dense post spacing (say 1m) will produce a very detailed and accurate three dimensional model of the terrain. The DTM forms the basis of all further processing of the image. It is critical, therefore that this be as accurate a representation of the terrain as possible. Once generated, the DTM is readily storable for further comparison with successively generated DTM's of the same area to allow determination of change in the area through time. Furthermore, once the DTM is generated, Socet Set allows the user to generate a range of visually dramatic and accurate representations of the site, as well as generating extremely accurate base maps of the site. Some of the features available to the researcher at this point are:

- Contoured base map generation. It is possible to generate contoured maps of the site, or it's underlying terrain, with very accurately places contours (the spacing of the contours is controlled by the spacing of the post spacing on the DTM).
- Orthophoto generation. An orthophoto represents the image that would be observed on the area if the observer were looking at the site from an infinite distance away. In a normal aerial image, the position immediately beneath the camera focal point is undistorted, but as we travel across the image away from the camera's focal point, the image becomes increasingly distorted. Over a large area, the effects of this distortion can dramatically reduce the accuracy of measurements made on the image. Orthorectification removes this distortion and generates a true image on which we can base spatial measurements. Additionally, the process removes some of the shadows cast by the stones that can cause problems during further image processing. The orthophoto is generated not from the image, but from the DTM. There is less of an effect visible in the small area we are dealing with but the process is essential if spatial measurements and positions are to be accurately constrained.
- Perspective Scene generation. Socet Set allows the generation of Perspective Scenes from any angle or height in the area of interest. Further, it is a relatively simple process to add structural features to the DTM using the feature extraction and editing facilities of the DPW. For example,
  a) the suggested elevated walkway to allow visitor access to the site can be added to the DTM and viewed using the Perspective Scene feature to decide on architectural design and engineering considerations
  b) a full or partial screen over the site can be added to show the visual impact of such a structure on the surrounding terrain etc.

The Perspective Scene module can also be used to generate fly-throughs of the area along specific flight paths and heights to give visitors who cannot access the site some feel for its structure and beauty. Perhaps the most interesting possibility from this technique is the generation of a 3D model that can be added to web sites for remote access to the site. The basis of 3D reconstruction is the provision of images from specific heights and angles of the intended area to be modeled. The Perspective Scene module can provide all of these images from a single set of aerial photographs. Export of images from the system is a simple procedure and can be carried out in most main image formats.

3.6 Orthophoto manipulation and image analysis

At 1:5,000 resolution, the components of the stone circles are understandably poorly resolved, even when DPW processing is completed, but enhancement of the images using standard filters can dramatically improve both image quality and definition. Filtering is a standard image processing tool that essentially overlays a standard mathematical matrix to each pixel in the image or to groups of pixels to enhance specific features. Although it is possible to carry out this process using the DPW, it is also possible to use some standard graphics and image analysis packages (e.g. Adobe Photoshop, ENVI, HLImage ++, NIH Image (freeware Mac), Image Tool (freeware PC)) to obtain the same effect. There is little difference in the end product from these packages, although some (including the DPW) allow you to define your own matrix to overlay on the images, therefore giving more control on the final image produced. Fewer enhancements are needed on the 1:2000 scale images, as most image processing packages can readily distinguish between the stone and the base topography at this scale. Image analysis was carried out on a desktop system-based PC software package (HL Image++) to demonstrate the ease of transfer of information from the DPW and the results possible on desktop systems. The purpose of image analysis in this project was to provide a second and more readily transferable method of characterizing the stone dimensions and morphology to researchers using more routinely available systems. The two-dimensional image that is generated in the orthophoto generation stage of the DPW analysis is calibrated very accurately and the individual co-ordinates of the stones can be extracted on the DPW very rapidly. Image analysis packages can use this accurately calibrated image to produce a binary image of the stones themselves, without the associated terrain, which can be used in ground-based site surveying and examination. Furthermore, standard image analysis packages can carry out object analysis, extracting each stone and measuring a series of parameters that can be stored in a flat 2D database for correlation purposes with similar datasets generated at later times. This opens a significant number of avenues for routine data storage, comparison and processing to the remote researcher (i.e. one who does not have access to the DPW) and for the graphic representation of this data on intranets, WWW sites and integration into databases. In summary, for the purposes of spatial measurement and analysis of the individual stones the two processes of DTM generation and 2D image analysis provide two products:

- True 3D representative model of the stones and terrain. The full details of the model can be rapidly extracted using the DPW and subsequently generated DTM's subtracted from the base model for accurate topographic change measurement.
- 2D object analysis that rapidly demonstrates the change in overall 2D shape and size of the stones. This process can be carried out on a desktop computer system. The advantage in this output is that the end-user does not need the highly specialized DPW to carry out meaningful measurement and dimensional analysis on the stones.

4 Results and products

4.1 1:10000 scale imagery

The 1:10000 imagery produced the orthophoto shown in Figure 3A. Clearly, although this image is a dramatic improvement on the original, it is less than satisfactory from a measurement point of view. The stones are discernible but it is difficult to distinguish individual stones below a certain size threshold. This can be improved somewhat by filtering the orthophoto as shown in Figures 4A and 4B.

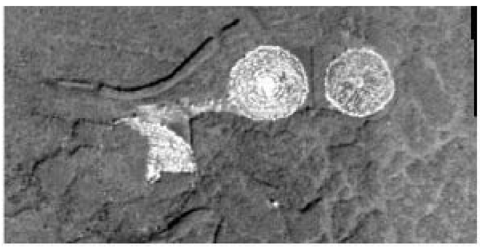


Figure 3. Orthophoto of the Copney Stone Circle Complex from 1:10,000 scale imagery.

Whilst absolute resolution of the stones was not achievable, the DTM generated facilitates an accurate contour map of the site and it's surrounding environment. This base map is very useful in further site examination and correlation between the position of these stone circles and others still to be excavated. It must be remembered that this image is very accurately constrained, with a ground accuracy of *c.* 17cm. This may be used to generate a very accurate contour, with contour intervals of as little as 50cm.

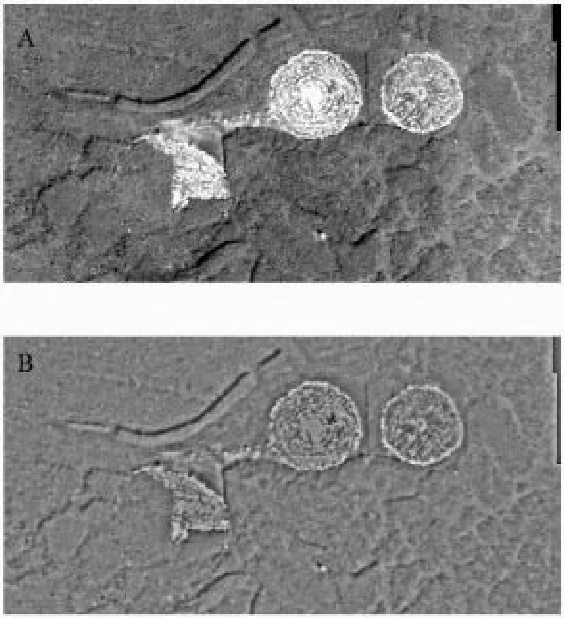


Figure 4. Samples of typical image enhancement filters applied to elucidate detail in the CSC 1:10,000 images. A.Sharpen filter applied.Note the marked improvement in the definition of the stones. Although they are not absolutely distinguishable below a certain threshold size, the shadows obscuring their edges have been removed somewhat. B.High Pass Filter applied. This filter removes shading in a selection by retaining the areas where sharp color transitions occur and by suppressing the rest of the image. It emphasizes very bright areas and highlights and removes low-frequency detail in an image. The pixel radius for this pass was 10.

Thus, even with this relatively low-resolution imagery, it is possible to generate a significant record of the Copney site. Although the ground resolution at a scale of 1:10000 precludes the accurate measurement of the stones themselves, there are still valuable data generated from this survey. Primarily, the accurate generation of the DTM and subsequent processing of the image allows the generation of the orthophoto. This is available as a very accurate base map for future work in the area. Furthermore, the orthophoto represents, in an easily accessible form, the most effective way of storing detailed information on the Copney site. Simply passing the cursor over the stones in the DPW allows the user to immediately get accurate positioning details (as geographic latitude/ longitude or in the grid system of their choosing) and altitude details for any point of the site.

It is also possible to generate a Perspective Scene from this scale of imagery. Whilst the stones themselves are not particularly prominent as features, the image can still be used to generate a visually impressive image of the site and can be incorporated into web-based flythoroughs. A Perspective Scene from the 1:10000 DTM is illustrated in Figure 5.

4.2 1:2000 scale imagery

The much better resolution at this scale facilitates the more accurate representation of the Copney site.

Digital terrain models were constructed at a range of post spacings from the imagery when orientation and rectification were completed. There is no significant difference in the processing techniques for the different scales of imagery.

Figure 5. Perspective Scene, generated from the hill above the CSC illustrating the visual impact of images generated by this technique even at a 1:10,000 scale.

The DTM's generated from the 1:2000 scale imagery are detailed in Table 1 and Figures 6A to 6C. Larger scale (15m post spacing) DTM's are rapidly generated and form the basis of accurate base maps. These are effectively identical to the base contour maps that could be generated from the 1:10000 scale imagery, as the post spacings are comparable. Finer scale DTM's allow better resolution of the circles, and ultimately the stones themselves. For the purposes of illustration, a 1m spacing DTM is detailed in Figure 6C. This DTM is constructed on an area within Circle B to illustrate the significant resolution of the stones themselves at this scale. This and finer scale DTM's form the basis of the final record of the site.

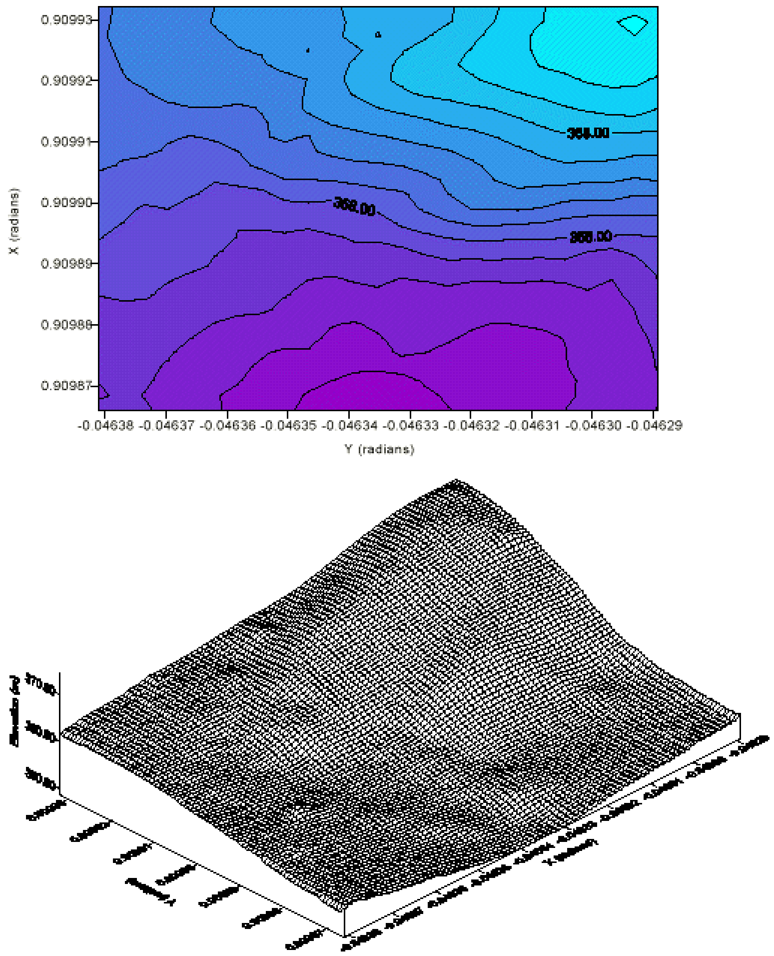


Figure 6A. 15m post-spacing DTM generated from 1:2000 scale imagery.

Figure 6B. 5m post-spacing DTM generated from 1:2000 scale imagery.

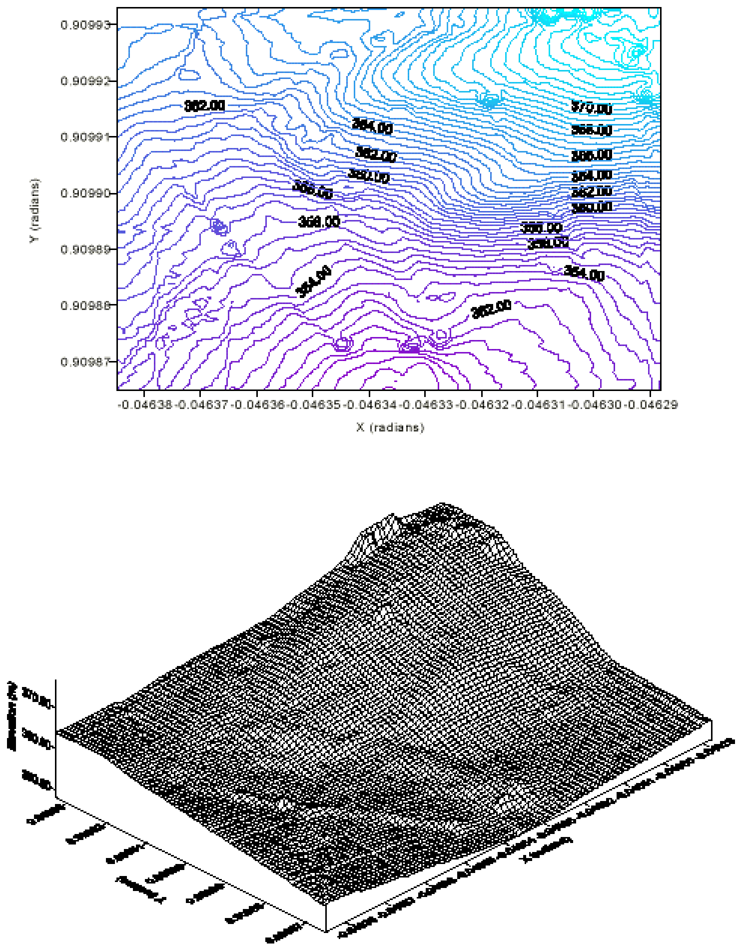
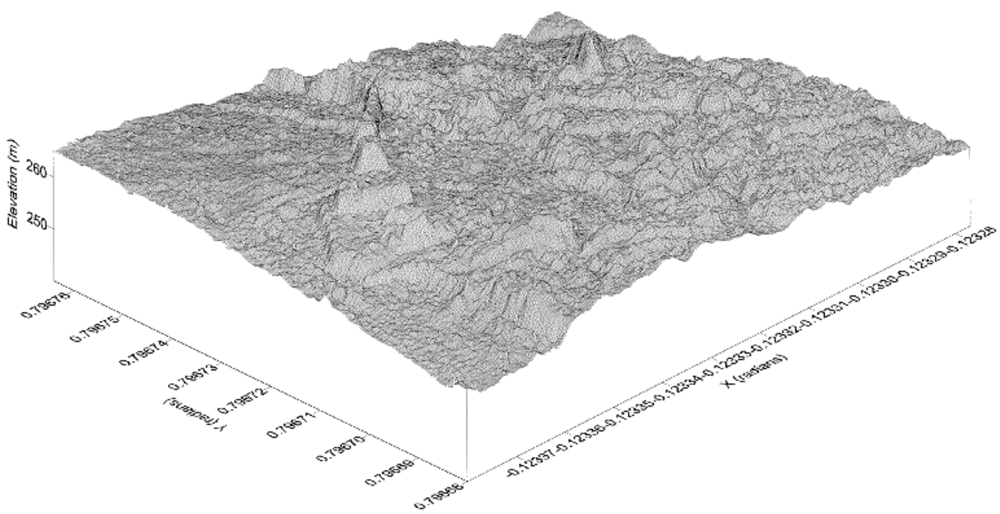


Figure 6C. 1m post-spacing DTM generated from 1:2000 scale imagery from the CSC.



DTM	X (radians)	Y (radians)	X grid interval (radians)	Y grid interval (radians)	Grid
15 m	0.046385	0.909864	3.823352×10^{-6}	2.352832×10^{-6}	26 x 30 = 780 points
5 m	0.046385	0.909864	1.274451×10^{-6}	7.842774×10^{-7}	77 x 89 = 6853 points
1 m	-0.123380	0.796680	2.238874×10^{-7}	1.570326×10^{-7}	461 x 541 = 249401 points

Table 1. Specifications of the digital terrain models constructed on the Copney 1:2000 scale images.

The finer scale DTM's form the basis of the orthophotos generated for the site. The orthophoto generated is illustrated in Figure 7A. Since this orthophoto was generated from a DTM with much more dense post spacing and from a higher resolution image, it is possible to extract ortho-images of the stone circles individually and to analyze these using standard image processing techniques. An example of an extracted orthophoto is shown in Figure 7B.

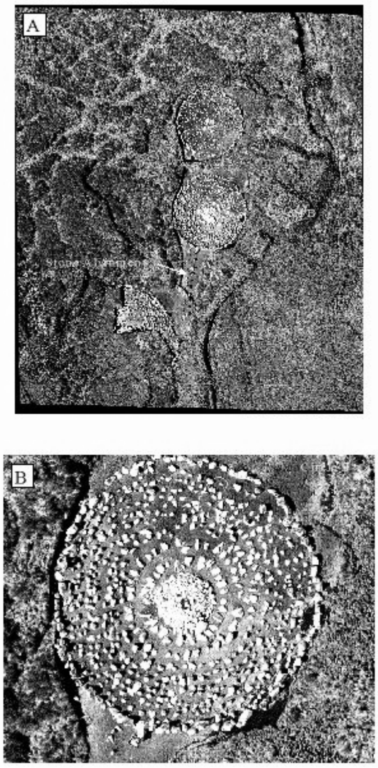


Figure 7. Orthophoto generated from 1:2000 scale imagery, Copney Stone Circle complex. A. Untreated orthophoto. Individual stones are discernible at this scale. Furthermore, it is possible to extract higher magnification images from this ortho that are suitable for image analysis techniques. B. Extracted section of 1:2,000 scale orthophoto.

The digital terrain maps and orthophotos provide accurate base maps and 3D models against which later surveys can be compared. These images, stored in standard file formats within the DPW can be rapidly recalled for regeneration of images, comparison with newer surveys on the area, generation of specific Perspective Scenes and lines of sight images, addition of man-made features for visual examination of their effect etc. The DTM's are a very effective method of storage of a significant amount of data relating to the Copney site. All of the spatial data relating to the site and the individual stones is rapidly accessible and can be output in a graphically impressive form for illustration of features to specialists and non-specialists alike. Furthermore, the powerful data and image export facilities of the system allow export to most major imaging packages and GIS software for more specialized spatial and statistical analysis. Perhaps the most significant value of such a compact and accessible data storage method is that the accuracies and reliability of data can be readily calculated for implementation into modeling programs and statistical analysis.

4.3 Image Analysis and spatial data measurement

As a final stage in this study, thought was given to researchers who may have temporary access to the DPW but generally carry out research on desktop systems. These systems, whilst powerful, lack the processing capabilities of the DPW so routine 3D spatial analysis and dataset comparison can be slow. To illustrate the use of such systems in manipulating DPW-based data, the orthophotos generated from the 1:2000 scale images were exported to a standard image analysis package (HL Image++). It is possible to carry out image analysis of DPW orthophotos on any desktop system that runs imaging software capable of calibration. An area of the DPW orthophoto of Circle B was exported to a PC system and the 2D images of the stones examined. Blob analysis of the image rapidly identified and outlined the individual stones and the spatial measurements of each were determined by the system. In all, this procedure takes less than 5 minutes on a mid-range Pentium PC with 32MB RAM. The output from the analysis is a large dataset including stone axis lengths, perimeter lengths and positional measurements that lend themselves to graphical presentation. Figure 8A illustrates the images exported and processed using HLImage++. Figure 8B illustrates some useful parameters of the stones generated by image analysis that can be visually represented on standard plots.

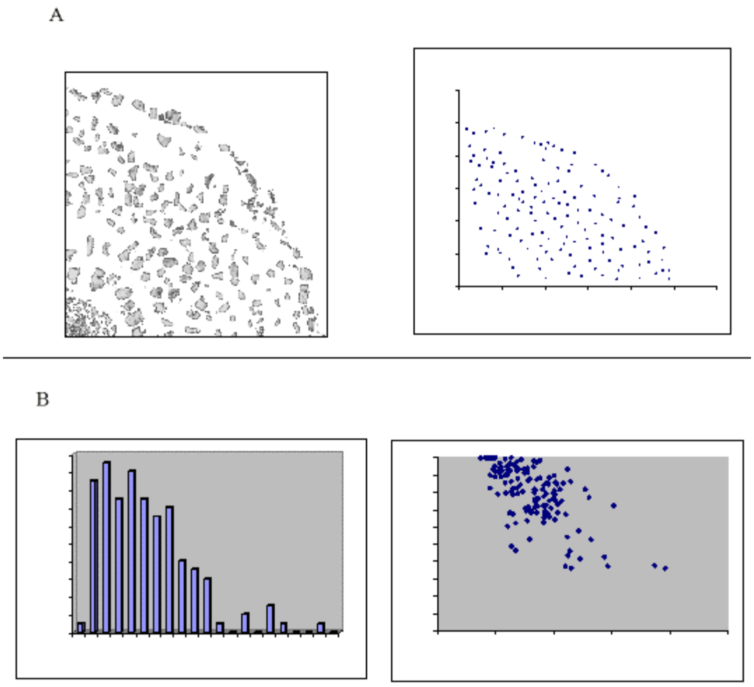


Figure 8. 2D Image analysis of a section of Circle B. A. Transferred image after blob analysis and identification of individual stones. The plot shows the identified centroids of each stone and is recorded for future comparison. This allows identification of any stones moved by human intervention, cattle, storm processes etc. B. Sample data plots from spatial measurements generated within a standard image analysis package (in this case, HLImage ++). The total area histogram sh ows a sample set that has a fairly even spread of stone dimensions. As decay proceeds, the mean will shift towards smaller values and the histogram should become progressively more skewed or polymodal. The roundness/ perimeter plot facilitates a simple representation of the degree of roundness of the stones, a characteristic produced by certain forms of weathering.

5 Conclusions

The application of digital photogrammetry and aerial photography to the Copney Stone Circle Complex has provided a valuable dataset that can be easily stored, transferred and compared with data generated from similar surveys in the future. The DPW provides a rapid tool for visualization of the data and easy measurement of spatial relationship, absolute dimension and elevation of the stones. The accuracy of the data generated by the DPW is highly dependent on the scale of the imagery and the quality of the ground control points.

The data generated by the DPW are readily transferred to image analysis, visualization and GIS software that can be run on standard desktop systems.

The Perspective Scene capability of the DPW facilitates not only visually impressive representations of the CSC (Figure 9) but also the generation of specific height and angle views compatible with the generation of 3D walkthroughs using VRML (and therefore is very www-friendly).

The accurate construction of DTM's allows:

- Generation of accurate base maps, with fine-scale contouring for surveying.
- Accurate orthophotographs for surveying, visual presentation and image analysis
- A permanent record of spatial and dimensional characteristics of the CSC.
- A baseline for comparison in stone weathering surveys. Each stone can be compared, through time, against the base line constructed in this study. This avoids the complication of accelerated breakdown of smaller stones confusing the rate of decay calculated for two or three marker stones.

Simple image analysis of the orthophotos generated from the DPW allows rapid characterization of the 2D stone dimensions and their positions.

Figure 9. Perspective Scene of a section of Circle B. Image is generated from the 1:2000 imagery and from a position just south of the central mound. Similar images can be generated from any position or height in the area.

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