KEYWORDS: ***Rock art – Digital data processing – 3D laser scanning – Visualisation***

DIGITAL ROCK ART RECORDING: VISUALISING PETROGLYPHS USING 3D LASER SCANNER DATA

I. Trinks, M. Díaz-Andreu, R. Hobbs and K. E. Sharpe

Abstract. This paper presents digital data processing techniques for the recording of rock art. 3D laser scanning and photogrammetry allow the rapid creation of digital models of rock surfaces with very high accuracy. Virtual digital models offer great advantages over traditional methods for recording rock art, such as rubbing, tracing and conventional or digital photography. The application of automatic 3D data processing algorithms permits the objective recording of petroglyphs. We present spatial data processing and visualisation algorithms that may be used to colour the virtual rock surface according to physical properties, such as relative and absolute elevation and maximum curvature rendering. Presentations in the form of colour and grey-scale images or as contour line plots in 3D and as 2D projections are discussed. Data from rock art sites at Rombalds Moor (West Yorkshire) and Lordenshaws (Northumberland) are used to illustrate the methods.

Introduction

The development of new technologies for the digitisation of 3D surfaces with millimetre and sub-millimetre accuracy, such as laser scanning (Barnett et al. 2005) and photogrammetry (Chandler et al. 2005) allow for the application of digital data processing techniques to the recording of rock art. The 3D laser scanning method is conventionally used in the manufacturing of mass products and in topographic surveying, for example to create 3D computer models of sport shoes, to capture the facades of historic buildings or to generate high-resolution digital terrain models.

Alternatively, photogrammetry with suitable software is a low-cost technique to generate 3D models of high accuracy (Rivett 1983). Precision digital cameras with known optical properties allow the photographing of 3D objects from various view points. Through the identification of identical points in the overlapping images it is possible to construct a digital 3D model of the captured object. Digital 3D models obtained through laser scanning, or photogrammetry, are similar to the virtual worlds seen in computer games, with the difference that these models are highly accurate copies of the real world. 3D laser scanning technology and photogrammetry are versatile tools for archaeologists, opening up exciting new possibilities both in the field and in the laboratory. The methods have been used in the topographical recording of sites such as the Seahenge timber circle and the Grimes Graves flint mines (Archaeoptics 2004), human and animal bones (Roberts pers. comm. and Dobney pers. comm.), medieval sculpture and inscriptions (Ahfeldt 2002), Australian rock art (El-Hakim et al. 2004), Upper Palaeolithic (Robson-Brown et al. 2001) and other pre-Historic art (Eklund and Fowles 2003; Goskar 2003; Johansson and Magnusson 2004). In the field of rock art recording the advantages offered by digital recording methods over traditional techniques, such as rubbing, tracing and photography, are many (see below). The technique most commonly used in Great Britain is rubbing, usually combined with tracing: the rock is covered with a sheet of paper and the features carved into the rock surface are then felt through the paper and traced with a wax crayon. In addition, the crayon is rubbed over the paper to capture the surface texture of the rock, similar to the brass rubbing technique. Until recently, this method was the best available, and useful for a basic visualisation and recording of rock art. The archive of Stan Beckensall containing rock art photographs and traditional recordings from Northumberland, UK, was made publicly available under *http://rockart.ncl.ac.uk.*

In this article we argue that the acquisition, processing and visualisation of digital rock art models offers obvious advantages over traditional rock art recording methods, despite the initially higher cost of the instrumentation (costs of precision digital cameras, specialist software; price of laser scanner or price of buying laser scanning service). The accuracy and repeatability of these recent methods render them the only techniques that would, for example, allow for the monitoring of such small changes as those caused by weathering. Photogrammetry and laser scanning techniques offer clear advantages over rubbing, tracing and photography, with benefits relating to the fields of recording, preservation and management of rock art and its presentation, both to the public and to a scholarly audience. Whilst rubbing requires surface contact and may produce results that depend on the experience of the interpreter (Simpson et al. 2004: Fig. 1), the digital recording tech-

Figure 1. *Photograph showing the Minolta laser scanner used for the recording of the data presented in this article. The portable operated scanner was placed under a tent in order to exclude interference from external light sources.*

niques are non-invasive (if the rock surface is too large or too high, a scaffold may be required) and their results are not subject to the interpretation skills of the archaeologist in the field. The new technologies have the great benefit of very high accuracy in terms of measurement precision and point density.

The digital data presented in this article were acquired using 3D laser scanning, since this method results in digital 3D models with very high point densities and model accuracy. The data processing methods described below for laser scanner data may similarly be applied to digital models obtained with other methods of comparable spatial resolution, for example through high-resolution photogrammetry.

The laser scanning technique is very fast and the data can be used to generate a photo-realistic model: several thousand points per second may be digitised and colour information about the rock surface may be recorded in addition to the spatial point data using a digital camera or colour filters. The data obtained with laser scanning are reproducible. Moreover, sophisticated software algorithms may be used to outline and visualise faint petroglyphs found on rock surfaces, which may not become apparent through more traditional methods (Goskar 2003). The high-resolution results obtained with the laser scanning or photogrammetric techniques provide managers and rock art researchers with a detailed digital copy of the stone surface, which may be viewed and manipulated comfortably on a computer at home or in the office. Using the Internet or CDs and DVDs, it is easy to share the data by sending digital 3D rock art models to colleagues for study, comparison and publication. This facility also has an obvious value for the presentation of the pre-Historic rock art to the public as well as for teaching purposes. The digital 3D model may be viewed interactively on a standard computer screen, as stereo projection in full colour using auto-stereoscopic monitors, or in virtual reality within an immersive visualisation environment using polarisation or shutter glasses. Fly-by animations may be created for data analysis, for lectures or for presentations. Finally, spatial data acquired through digital recording methods open up other fields of enquiry to researchers, such as investigations into the type of tools used to create the motifs and the different techniques employed depending on the geology of the stone. Digital 3D models obtained through laser scanning are detailed copies of the real world with the advantage that no subjective interpretation process is involved in their creation. In order to visualise rock art, the digitally recorded data can be processed using automated filters. In the following sections we will briefly describe the laser scanning method and then outline in detail different visualisation techniques that may be used for the recording and mapping of rock art. Internet links for additional information on the software tools used for the processing of the data are provided in the Appendix.

Laser scanning

3D laser scanning is based on a laser light source emitting a laser pulse that is then reflected from a surface. The laser scanner calculates the distance to the reflecting point by measuring the travel-time of the light pulse. With the knowledge of the azimuth and inclination of the laser beam it is possible to determine the relative *xyz* co-ordinates of the reflecting point. These relative co-ordinates may be turned into absolute co-ordinates through Geo-referencing using differential GPS measurements. Laser scanners record up to 8000 points per second. The entire laser scanning process is completed in a matter of minutes. The measurement accuracy of laser scanners is between 5 mm and below 1 mm, allowing for overview scans of, for example, stone circles and for high-resolution recordings of individual rocks. In addition to the 3D point locations it is possible to measure the reflection intensity. Some scanners work in combination with a digital camera that records true colour values and assigns this colour information to the point data, permitting the creation of photo-realistic digital models. Other scanners allow the recording of colour information via the use of separate colour filters. The scanner used for the recording of the data presented in this paper is shown in Figure 1.

The raw data obtained through laser scanning are the *xyz* co-ordinates of reflection points, the reflection intensity and the colour values. In addition to the point-cloud data some scanners and their associated software provide a triangulated surface mesh. This mesh is needed in order to present the surface of a rock as a 3D object. If such mesh information is not provided, it may be generated us-

Figure 2. *Photographs of the Horseshoe Rock in Northumberland, England. The rock is a horizontal slab located on a grassy hillside (left). Cupules, concentric rings and a groove that resembles a horseshoe are engraved into the rock surface (right). Link to external site with additional information:* http://rockart.ncl.ac.uk/panel_detail.asp?pi=534

ing surface reconstruction software. Often it is not possible to scan a rock surface from one single scanning location. This may be due to the size of the rock or to the fact that the surface topography of the stone may cause shadow zones in the region of interest. In such a case the rock is scanned from different scanner locations. The resulting 3D data sets have to be merged into a single 3D point cloud or surface object. Typical laser scanner data sets consist of 10 000 up to 50 million points. The size of such data files varies between 10 Megabytes and several Gigabytes. The data presented in this paper were scanned with the Minolta 910 laser scanner. Due to the size of the decorated stones several overlapping scans of the rock surface were required to achieve full coverage. The reduced data of the Rombalds Moor stone (Fig. 3) consisted of 37 000 scan-points, while the raw data of the Lordenshaws site (Fig. 2) contained 12.5 million points (ASCII file size approx. 880 MB). The data of the individual scans were merged by members of the Department of Computer Sciences at the University of Bristol.

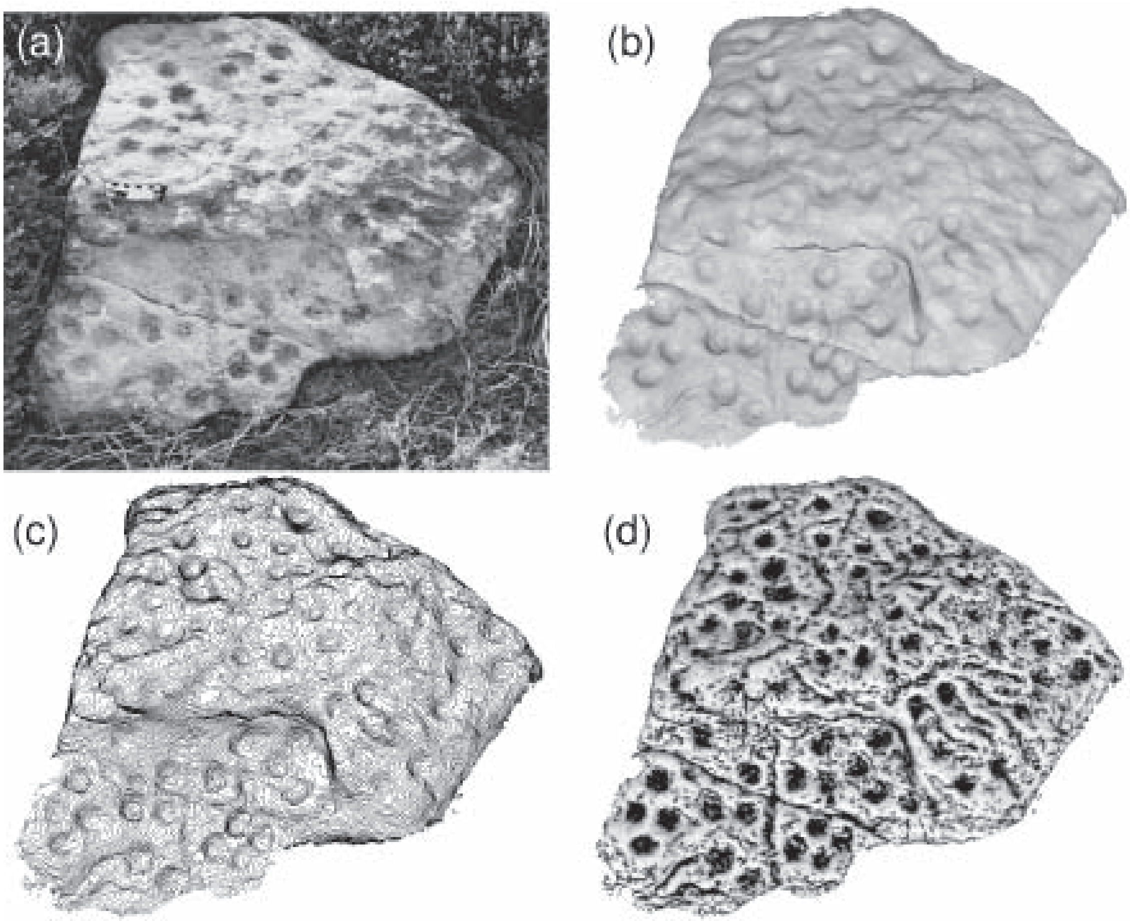

Figure 3. *(a) Photograph of site 105 from Rombalds Moor showing cupules. (b) Surface rendering of triangulated and smoothed 3D scanner point cloud. (c) Absolute elevation contour plot. (d) Maximum curvature colouring.*

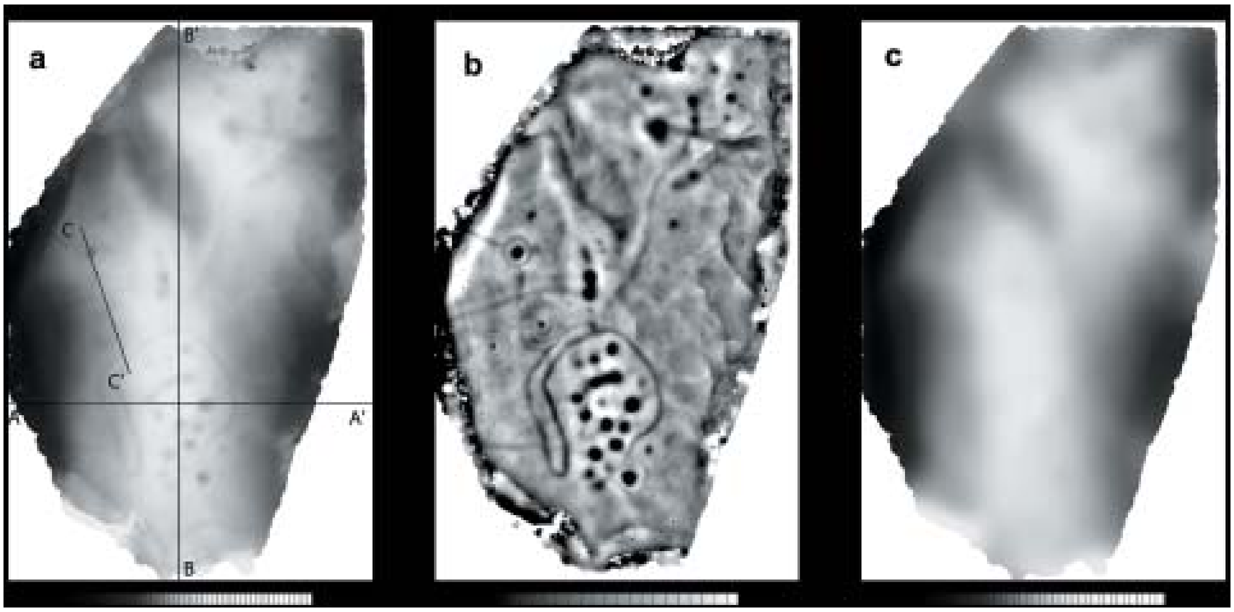

Figure 4. *(a) Map view of Horseshoe Rock as grey-scale image showing the absolute elevation of the rock surface projected into the xy-plane. The data are only plotted in a small region surrounding every data point. Profiles of the cross-sections shown in Fig. 6 are marked. (b) Map view of surface texture of the rock, that is, the local or relative elevation of the rock surface. (c) Map view of the underlying rock topography, calculated as difference between (a) and (b).*

Data processing

Generally, the first step in processing laser scanner data is to convert the raw data into a 3D object format. It may be necessary to reduce the data in this process in order to keep them in a manageable size. The large size of the data sets involved in processing and visualisation of 3D laser scanner data requires computers with at least 512 MB memory. CD or DVD writers are desirable if data are to be shared. Both Windows and Linux operating systems are suitable for the range of software products available. Laser scanner data files in ASCII (text) format normally consist of a number of columns describing the *xyz* co-ordinates of each scan point, the reflection intensity and possibly RGB colour values (intensity values for red, green and blue varying between either 0 and 1, or 0 and 255). When creating a 3D object file only some of the columns in the raw data file may be of interest (e.g. while the *xyz* co-ordinates are needed for surface meshing, reflection intensity is not used in the processing described here). Spreadsheet programs may not be able to deal with the large numbers involved in 3D laser scanning. Instead, software tools, such as *Gawk*, may be used to extract columns from a text file, or to extract, for example, every tenth data point. Data sets of up to 500 000 points should cause no problems or substantial delays during processing and rendering. The 3D data format used here is the *Visualisation ToolKit* (VTK) 3D data format. In the process to convert the xyzRGB text file into a 3D object format, a header is assigned to the point co-ordinates and point properties, such as colour or reflection intensity, are defined for each point. If surface grid information is available from the raw data it is necessary to specify which three points are used to describe each single triangle. This is done by listing the three indices of the corresponding points. Such 3D point cloud, or 3D surface, files may then be read and displayed with a 3D viewer. For this purpose we use the free-ware *Paraview* that is based on the VTK library.

Surface reconstruction from 3D point data

It is possible to visualise simple point data. However, many filter and visualisation methods require that the individual scan points be meshed into a surface grid. This process is either performed by the scanner software or separately with a triangulation and surface reconstruction program. The scanner 'knows' about the azimuth and inclination of the laser beam during the scanning process. Thus, the scanner software should, in principle, be able to simply connect neighbouring scan points to triangles, based on the knowledge of the in-line and cross-line scanning indices. If the raw scan data do not contain any grid information, the surface may be reconstructed using triangulation software. This process is not simple, since there are many ways to connect several thousand 3D points. 3D surface triangulation would need to be performed in respect to a reference surface. Software that is able to reconstruct surfaces through point cloud data is, for example, the freely available software *Cocone* (Dey et al. 2001).

Data visualisation

Once the data are converted into a 3D object it may be viewed with a 3D visualisation software. Unless an auto-stereoscopic display or an immersive environment is available, the 3D character of the data will be best visible when the object is moved. 3D data viewers offer mouse-based functionality with zoom, rotation and panning assigned to the three mouse buttons. A function to create animated fly-bys over and around the 3D object is very useful for generating AVI- or MPEG-animations for presentations or web-

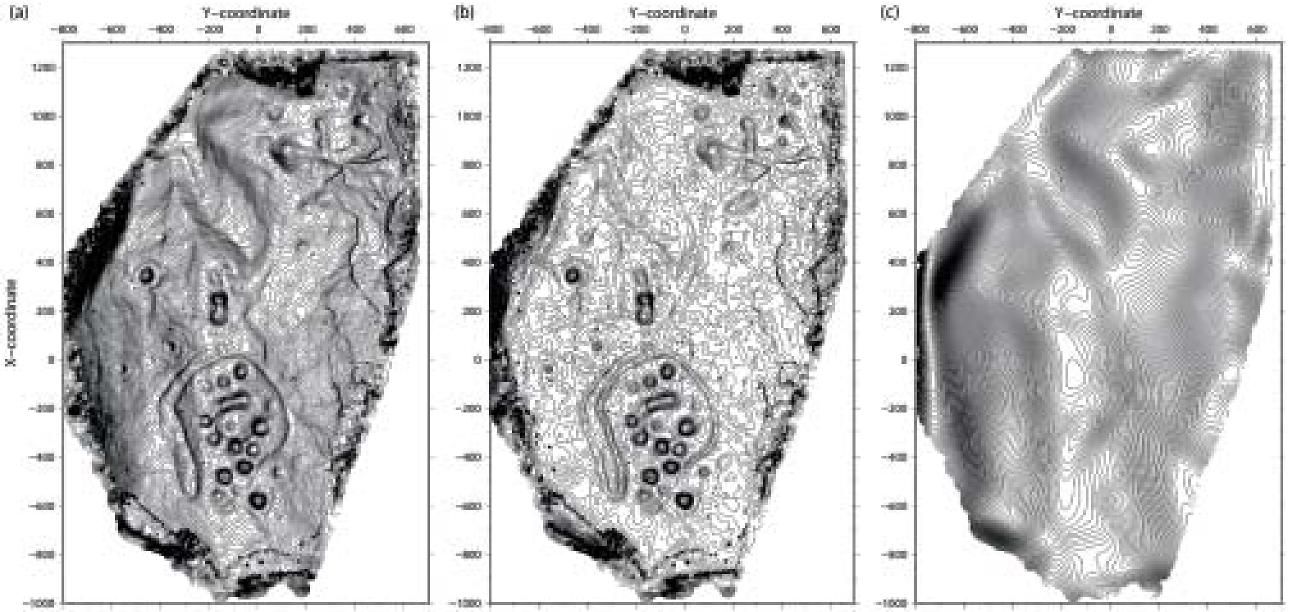

Figure 5. *(a) Map view of Horseshoe Rock as contour line plot showing the absolute elevation of the rock surface projected into the xy-plane. The data are only plotted in a small region surrounding every data point. (b) Map view of surface texture of the rock, that is, the local or relative elevation of the rock surface. (c) Map view of the underlying rock topography, calculated as difference between (a) and (b).*

pages. Animations of the rock art presented here may be viewed at *http://www.dur.ac.uk/prehistoric.art/visualisation.html.*

One of the advantages of digital laser scanning for rock art recording over traditional recording methods is that automatic mathematical filters may be applied to visualise the structures carved into the rock surface. These processes are repeatable and not subject to interpretation. Several possibilities for highlighting rock art structures in digital data are described in the following sections. The examples presented here are scans of the Horseshoe Rock in Northumberland and of the Rombalds Moors site 105 in Yorkshire (Figs 2 and 3a).

Shadow and light

A classic method to visualise rock art is to illuminate the 3D object using a spot light source at a shallow angle. By animating the light source and changing its position and direction it is possible to highlight different regions on the rock surface. This method gives good results for stone surfaces that have relatively little natural curvature (e.g. Milstreu and Prøhl 1999). However, the shadow and light technique may cause shadows to be cast by outstanding regions of the model and is therefore very much dependent on subjectively chosen light conditions. A method that is able to deal with the problems of direct light and shadow zones was described by Mark (1992), who suggested the generation of shaded-relief images using multidirectional, weighted oblique illumination. This method makes use of the computerised combination of shaded relief images that are illuminated from different directions at shallow angles. Thereby it is possible to visualise more detail in regions that otherwise would be hidden in shadow zones or that would be illuminated by direct light.

Curvature colouring

A possible criterion for the colouring of the rock surface of the digital model shown in Figure 3b is the curvature of the rock. Each triangle in the triangulated surface grid may have a normal-vector assigned that is oriented perpendicular to the area of the triangle. These triangle normal-vectors may be used to analyse the difference in orientation between neighbouring triangles. Where this difference is largest the curvature of the surface is at maximum. Colouring the surface according to its curvature may result in an image that highlights the artificial petroglyphs due to the high local surface curvature (Fig. 3d). This method depends on the size and density of the triangles. A data set with too large triangles will fail to represent the small-scale petroglyphs adequately, while an over-sampled surface with too many small triangles will fail to show sufficient contrast between neighbouring triangles. Therefore, various grid densities should be tested to achieve an optimal relationship between curvature contrast and smooth surface representation. The format in which the results are displayed (Fig. 3d) resembles the result obtained with traditional methods.

Elevation rendering

In contrast to the real world, where elevation has a fixed meaning, it is possible for a 3D model in virtual reality to choose any vector to describe the maximum and minimum elevation. The surface of the 3D rock model may be coloured in relation to this elevation vector, for example black for the lowest parts, white for the highest regions and a continuous grey scale in-between (Fig. 4a). In the case of a flat rock surface with rock art carved into it, this method would highlight the carved structures in black with the natural rock surface appearing white. Since most investigated rocks are not flat but show considerable natural

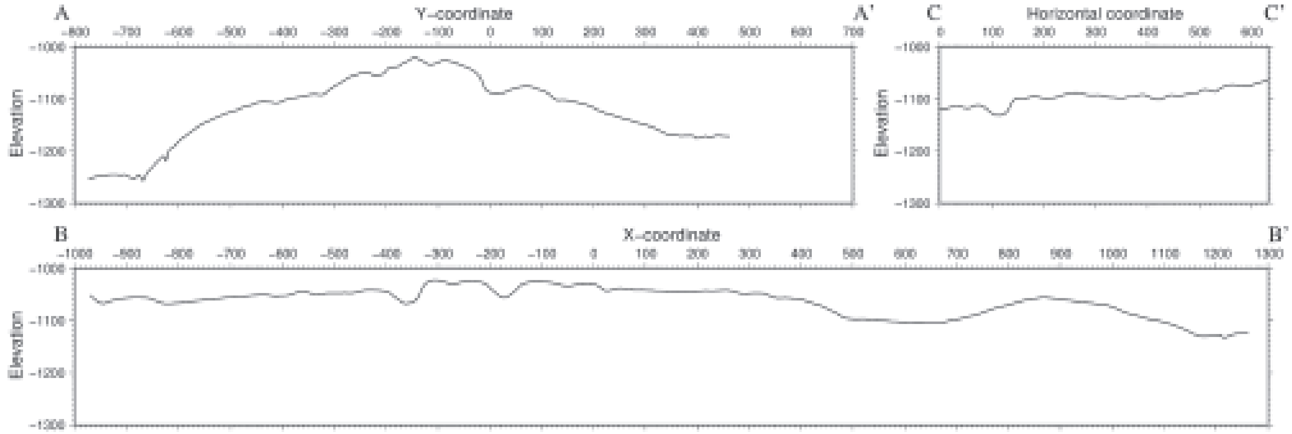

Figure 6. *Cross-sections taken from the Horseshoe Rock 3D model. The location of these cross-sections is marked in Fig. 4a.*

curvature (Figs 2 and 4a) it is difficult to use the overall elevation as criterion for colouring the rock. Instead, the local (or relative) elevation should be used. This may be achieved by applying a spatial high-pass frequency filter to the 3D point data and removing the low frequency (long-wavelength) curvature of the natural rock surface, thereby flattening the model of the rock artificially. The surface may then be coloured according to elevation (Fig. 4b), since the remaining elevation differences are solely due to the short-wavelength, artificial markings or natural fissures in the rock surface. Once the surface is coloured according to local elevation, the long-wavelength curvature of the rock, displayed in Fig. 4c, may be added again and the petroglyphs will be visible on the digital 3D model (Fig. 7). Since the petroglyphs stand out relative to the local rock curvature this method is called *local elevation* or *relative elevation colouring*.

Grey-scale shading is preferable over colour-scale shading since the change in elevation may be displayed best as change of intensity, varying gradually between black and white. Any colour representation would display the structures as function of colour value and colour intensity, which may overload the information content of the figure and distract from the inherent structure.

It is possible to display absolute and relative elevations as contour-line plots (Figs 3c and 5a-c). Contour-line presentations depend on the contour-line interval, that is their density, and on the elevation vector chosen. The contour-line plot (Fig. 5a) gives a better impression of the 3D curvature of the entire rock than the grey shaded image (Fig. 4a). However, the grey scale image showing the relative elevation (Fig. 4b) contains much more information than the corresponding contour-line plot (Fig. 5b). The contour-lines may be displayed in a uniform colour or coloured according to elevation using a colour scale.

The 3D nature of the surface data permits the simple generation of cross-sections. An example of cross-sections cutting the Horseshoe Rock along its short (A-A') and long

Figure 7. *Perspective view of the Horseshoe Rock 3D model coloured corresponding to relative elevation after high-pass frequency filtering. The small black spots with surrounding white halo are due to outliers in the data.*

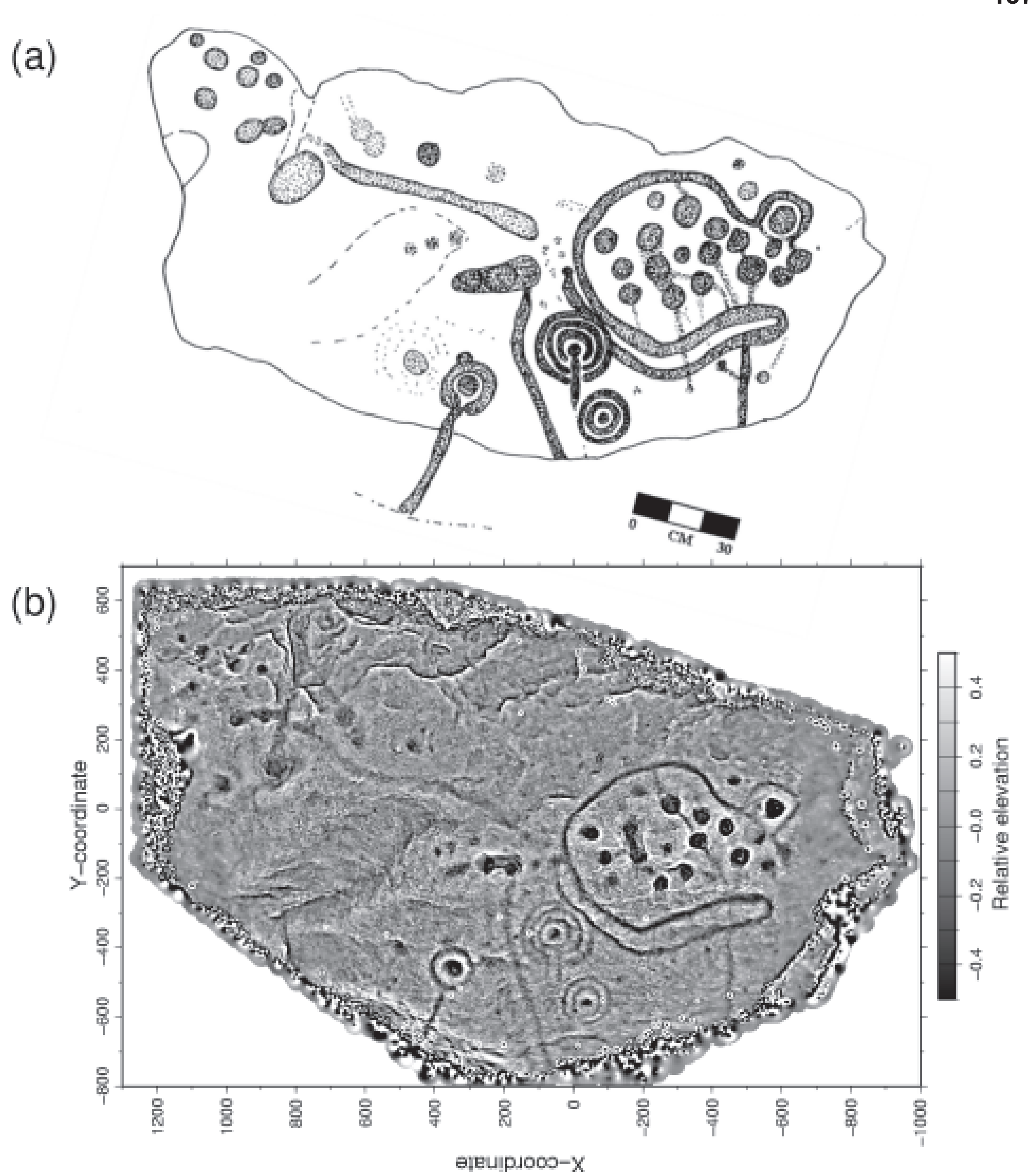

Figure 8. *Comparison of recordings of the Horseshoe Rock produced using (a) the rubbing and tracing technique (by courtesy of Stan Beckensall 2001) with (b) the digital mapping technique showing variations in relative elevation. The high-pass frequency filter used in the generation of (b) had a higher cut-off frequency than the one used for Fig. 4b and 5b, leading to more pronounced structures. The small black spots with surrounding white halo in (b) are due to outliers in the data.*

(B-B') axes is shown in Figure 6. The section C-C' is taken across two ring structures with central cupules. The location of these cross-sections is marked in Figure 4a.

Comparison of digital rock art recording with traditional methods

The comparison between recordings of the Horseshoe Rock made by Beckensall (2001) (Fig. 8a) with the results obtained through 3D laser scanning and subsequent relative elevation mapping (Fig. 8b) demonstrate the potentials of the digital data processing method. In Figure 8a it can be seen that the traditional rubbing and tracing method causes a large degree of abstraction, which requires a trained and talented interpreter. The new method based on digital data processing removes this subjective element in the recording process and results in a more detailed record of the rock surface (Fig. 8b). In addition to providing the flexibility of being able to work with the data off-site it has now become possible to investigate those deteriorated elements of petroglyphs and to interpret them using a larger tool-box than was previously available.

Recently, Simpson et al. (2004) presented an approach towards three-dimensional rock art recording based on a photogrammetric technique using the Horseshoe Rock as an example. Their technique required the layout of marker points on the surface of the rock in a regular grid, the capturing of several digital images with a camera with known optical specifications and *Photomodeler* software for the 3D surface reconstruction on a computer. Their method proved to be suitable for generating an approximate 3D model of the larger features, however, the accuracy is limited since the surface between the locations of the placed marker points has to be interpolated.

The laser scanning method has a lateral point density on the rock surface in the order of millimetres and is therefore a very accurate method. 3D laser scanning currently appears to be the only technique that would allow the monitoring of the small changes caused by weathering.

Conclusions

We have demonstrated that digitisation of rock surfaces, using 3D laser scanning and appropriate data processing and visualisation, offers advantages over traditional rock art recording methods. None of the analogue methods is able to provide the same amount of data and information with a comparably high level of accuracy in the same space of time.

We have shown how rock art may be visualised using maximum curvature and local elevation colouring. The relative elevation colouring technique allows the rendering of pronounced and weak surface features alike. Grey-scale map views that are rich in contrast and interactive 3D visualisation of rock models permit high-resolution recording of the rock art and the use of enhanced imaging and interpretation methods for analysis.

The relatively high costs of the equipment needed for digital rock art recording should be put into perspective to the greatly increased possibilities for data analysis and visualisation. The entire software used to process the data and generate the images presented in this article is freely available on the Internet. All mentioned software can be run under the common operating systems (Windows using Cygwin, MacOSX, Linux/Unix). The automation of the processing would allow an experienced user to create a final image or animation from the raw laser scanner data in 1–2 hours.

From this study we have learnt that the correct georeferencing of the 3D data during the recording process, which allows the orientation of the rock in space and in relation to other objects at a later point in time, is very important. This is of particular significance when considering repeated measurements for monitoring decay processes of the rock surface.

A point that was not investigated in greater detail in this paper is the possibility for statistical analysis of rock art on the basis of digital data. It should be possible to use the digital 3D rock models to differentiate between artificially carved grooves and natural fractures in the rock using spectral analysis. Natural cracks should show a fractal spectral distribution while artificial grooves should display a band-limited spectrum due to the characteristics of the tools and techniques used in producing petroglyphs.

The relative elevation rendering technique presented here would be perfectly suited to visualise and image rock art at such sites as Tanum, Sweden, Valcamonica, Italy, and many other significant sites where the 3D data has already been recorded (Johansson and Magnusson 2004; Rock Care n.d.).

Digital rock art recording will develop to become the scientific standard in the coming years. We hope that this paper is helpful in illustrating possible ways that show how digital 3D data of rock surfaces can be used to generate more detailed and accurate images of rock art.

Acknowledgments

The 3D laser scanning was undertaken in May 2004 by Gavin Ellis, Pete Longhurst and Richard Gillibrand of the Department of Computer Sciences at the University of Bristol under the supervision of Dr Alan Chalmers. The data acquisition of the Horseshoe Rock took place within the framework of the AHRB Innovation awards project 'Breaking through rock art recording', and the Rombalds site data set was taken from the British Academy small grants 'Fading rock art landscapes project' (Projects PI M. Diaz-Andreu). Richard Hobbs is funded as a NERC Advanced Research Fellow (NER/J/S/2002/00745). The data were processed and presented using the free software *Generic Mapping Tools* developed by Wessel and Smith (1991), the software *SuperCocone* and *TightCocone* (Dey et al. 2001), *Gawk*, *Paraview*, and the *Visualisation ToolKit (VTK)* library.

Dr I. Trinks and Dr R. Hobbs
e-Science Research Institute
University of Durham
Durham DH1 3LE
United Kingdom

Dr I. Trinks now at:
National Heritage Board
Department for Archaeological Excavations
Box 5405
114 84 Stockholm
Sweden
E-mail: *immo.trinks@raa.se*

Dr M. Díaz-Andreu and Dr K. E. Sharpe
Department of Archaeology
University of Durham
Durham DH1 3LE
United Kingdom
E-mail: *m.diaz-andreu@durham.ac.uk*

Final MS received 15 July 2005.

Appendix

Software used for the processing and visualisation of the 3D laser scanner point cloud and surface data presented here:

Visualisation ToolKit (VTK) (open source, freely avail-

able software system for 3D computer graphics, image processing, and visualisation):
http://www.vtk.org

Description of the VTK 3D object format:
http://www.vtk.org/pdf/file-formats.pdf

Paraview (free-ware 3D viewer based on VTK):
http://www.paraview.org

Cocone (***SuperCocone***, ***TightCocone***) (free software for surface reconstruction, triangulation of point cloud data):
http://www.cse.ohio-state.edu/~tamaldey/cocone.html

GMT Generic Mapping Tools (free software for mapping and filtering of 2D and 3D data):
Linux/Unix: *http://gmt.soest.hawaii.edu*

Gawk (free pattern scanning and processing language for Linux/Unix and Windows):
Linux: *http://www.gnu.org/software/gawk/gawk.html*
Windows: *http://gnuwin32.sourceforge.net/packages/gawk.htm*

REFERENCES

AHFELDT, L. K. 2002. Individual variability in rune carving on rock. A comparison between individuals and workshops. *Journal of Nordic Archaeological Science* 13: 79–101.

ARCHAEOPTICS 2004. Recording the past for the future. *http://www.archaeoptics.co.uk* (Nov. 2004 version).

BARNETT, T., A. CHALMERS, M. DÍAZ-ANDREU, G. ELLIS, P. LONGHURST, K. SHARPE and I. TRINKS 2005. 3D Laser scanning for recording and monitoring rock art erosion. *International Newsletter on Rock Art* 41: 25–29.

BECKENSALL, S. 1983. *Northumberland's prehistoric rock carvings: a mystery explained*. Pendulum Publications, Rothbury, Northumberland.

BECKENSALL, S. 2001. *Prehistoric rock art in Northumberland*. Tempus, Stroud.

CHANDLER, J. H., J. G. FRYER and A. JACK 2005. Metric capabilities of low-cost digital cameras for close range surface measurement. *The Photogrammetric Record* 17(109): 12–26.

DEY, T. K., J. GIESEN and J. HUDSON 2001. Delaunay based shape reconstruction from large data. *Proceedings, IEEE Symposium in Parallel and Large Data Visualization and Graphics (PVG2001)*, 19–27.

EKLUND, J. and P. S. FOWLES 2003. Three-dimensional recording by laser scanning of the petroglyphs at Rombald's Moor, West Yorkshire. *Conservation and Management of Archaeological Sites* 6: 11–22.

EL-HAKIM, S., J. FRYER, M. PICARD and E. WHITING 2004. Digital recording of Aboriginal rock art. 10th International Conference on Virtual Systems and Multimedia (VSMM), Ogaki City, Gifu, Japan, 17–19 Nov. 2004, pp. 344–353.

GOSKAR, T. 2003. The Stonehenge laser show. *British Archaeology* 73: 9–14.

JOHANSSON, S.-O. and J. MAGNUSSON 2004. Developing new techniques for 3D documentation of rock art. In U. Bertilsson and L. McDermott (eds), *The Valcamonica Symposiums 2001 and 2002*, pp. 125–133. Riksantikvarieämbetet 2004: 6 / National Heritage Board of Sweden.

MARK, R. 1992. Multidirectional, oblique-weighted, shaded-relief image of the Island of Hawaii, U.S. Geological Survey, Open-File Report 92-422, *http://pubs.usgs.gov/of/1992/of92-422/*

MILSTREU, G. and H. PRØHL 1999. Documentation and registration of rock art in Tanum No 2 — Fossum and adjoining Areas, Rock Art Research Centre in Tanum, Tanums Hällristningsmuseum Underslös, SE-457 91 Tanumshede.

RIVETT, L. J. 1983. *The application of photogrammetry to the recording of rock art and archaeological sites in Kakadu National Park*. Australian National Parks and Wildlife Service Special Publication 10: 87–126.

ROBSON-BROWN, K. A., A. CHALMERS, T. SAIGOL, C. GREENAND and F. D'ERRICO 2001. An automated laser scan survey of the Upper Palaeolithic rock shelter of Cap Blanc. *Journal of Archaeological Science* 28: 283–89.

ROCK CARE N.D. Intressanta uppdrag. *http://www.metimur.se/sidor/intresantaupdrag_Hallristningar.htm*

SIMPSON, A., P. CLOGG, M. DÍAZ-ANDREU and B. LARKMAN 2004. Towards three-dimensional non-invasive recording of incised rock art. *Antiquity* 78(301): 692–8.

WESSEL, P. and W. H. F. SMITH 1991. Free software helps map and display data. *EOS Transactions of the AGU*, 72 (441): 445–6.

RAR 22-724

AURANET main homepage

http://mc2.vicnet.net.au/home/aura/web/index.html

Rock Art Research (journal)
http://mc2.vicnet.net.au/home/rar1/web/index.html

IFRAO (Australian page)
http://mc2.vicnet.net.au/home/ifrao/web/index.html

AURA Congress
http://mc2.vicnet.net.au/home/congress/web/index.html

Rock art dating
http://mc2.vicnet.net.au/home/date/web/index.html

Palaeoart epistemology
http://mc2.vicnet.net.au/home/epistem/web/index.html

Cognitive archaeology
http://mc2.vicnet.net.au/home/cognit/web/index.html

The EIP Project
http://mc2.vicnet.net.au/home/eip1/web/index.html

Cave art research (CARA)
http://mc2.vicnet.net.au/home/cara13/web/index.html

Interpretation of rock art
http://mc2.vicnet.net.au/home/interpret/web/index.html

Rock art recording
http://mc2.vicnet.net.au/home/record/web/index.html

Rock art conservation
http://mc2.vicnet.net.au/home/conserv/web/index.html

Rock Art Glossary
http://mc2.vicnet.net.au/home/glossar/web/index.html

Save Guadiana rock art
http://mc2.vicnet.net.au/home/guadiana/web/index.html

Save Dampier rock art
http://mc2.vicnet.net.au/home/dampier/web/index.html

Human behaviour and rock art research
http://mc2.vicnet.net.au/home/behav/web/index.html

AURA Español
http://mc2.vicnet.net.au/home/auraesp/web/index.html

Portable palaeoart of the Pleistocene
http://mc2.vicnet.net.au/home/portable/web/index.html

The First Mariners Project
http://mc2.vicnet.net.au/home/mariners/web.mariners.html