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RECORDING ABORIGINAL ROCK ART USING CHEAP DIGITAL CAMERAS AND DIGITAL PHOTOGRAMMETRY

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ABSTRACT

Archaeologists, conservators and rock-site managers need simple and cost effective methods to record and document rock art, including both petroglyphs and pictographs. Combined laser scanning and photogrammetry can be effective but equipment remains expensive, is difficult to transport into the field and requires some expertise to use successfully during data capture. What is required is the development of a methodology that enables the inexpert, perhaps volunteer, field worker to acquire imagery suitable for photogrammetric measurement using cost effective digital sensors. This paper describes the desired alternative in which a cheap digital camera costing just US$300 is used to generate both accurate and dense DEMs and orthophotographs. These data are able to record detailed morphology, generate three dimensional visualizations and the ubiquitous fly through model. The methodology was developed and tested using a series of case studies, representing a diverse selection of aboriginal rock art. Imagery was acquired using a 3 Megapixel Nikon Coolpix 3100 costing US$300 and compared with imagery obtained using a Kodak DCS460, which originally cost US$ 30,000. Fieldwork was conducted at six field sites in Australia, including both petroglyphs and pictographs. Digital photogrammetry was carried out using the Leica Photogrammetry System and an external self-calibrating bundle adjustment; the combination generating medium accuracy (±3mm), high-resolution DEMs and orthophotos. The petroglyphs were small, typically 1-2m in length and located on horizontal sandstone outcrops. Simple stereopairs acquired using the Nikon Coolpix and simple scaled control in the form of a survey staff, generated dense DEMs (5mm), appropriate to record detailed morphology. An image processing technique implemented in the form of an Erdas “Spatial Model” tool allowed identification of the pecked and engraved grooves from the surrounding rock surface. The pictographs sites were located on vertical and curved rock faces within rock shelters, typically 2-4m high. 3D control was provided using a reflectorless Total Station and rotation of the control coordinates enabled the LPS software to function correctly. Lower resolution DEMs (50mm) proved sufficient to record the simplified morphology. Colour orthophotographs could be generated and multiple images mosaiced together to allow 3D dimensional visualization and fly through generation. The merits of the developed approach will be discussed and implications arising from adoption outlined.

1. INTRODUCTION

Archaeologists, conservators and rock-site managers need to use simple and cost effective methods to record and document rock art. Combined laser scanning and photogrammetry can be effective but equipment remains expensive, is difficult to transport into the field and requires some expertise to use successfully during data capture. What is required is the development of a methodology that enables the inexpert, perhaps volunteer field worker to acquire imagery suitable for photogrammetric measurement using cost effective digital sensors. There are three main methods of recording rock-art currently in use today: drawing, tracing and photography (Stanbury and Clegg, 1990). Although of increasing sophistication, all suffer from various limitations. Free hand drawing or sketching is simple and easy to conduct in the field but provides only a two-dimensional record and is generally inaccurate (Brayer et al., 1998). Direct rubbing using paper or tracing using plastic sheets is commonly adopted but the method creates large volumes of media, which have to be photographically reduced for more efficient storage. It is also invasive, requiring the physical touching of the art and requires extensive field time (Taçon, 2004). The placing of a grid over the object and transferring detail one square at a time solves the physical reduction problem directly, but again requires time and patience in the field and inaccuracies are inevitably introduced. The use of photography remains universal, particularly for simple recording and qualitative use, but the extraction of quantitative data using imagery is less common. Donnan (1999) identifies the potential of digital image processing for recording rock-art in Northumberland, UK and Clogg et al., (2000) provide a review. In their UK based study, a digital filter and simple thresholding methods are used to identify pictographs from the surrounding rock surface using spectral information alone (Clogg et al., 2000). In Australia, David et al., (2003) cite how simple manipulation of saturation and contrast of digital imagery representing pictographs located in Dauan, (near Papua New Guinea) revealed “previously invisible motifs”. This paper describes the development of a methodology to record rock art using cheap digital camera technology combined with the Leica Photogrammetry System (LPS) software and an external self-calibrating bundle adjustment to generate both accurate and dense DEMs and orthophotographs. The approach was tested and refined on a variety of rock art sites in NSW, Australia which demonstrated the efficacy of the approach.

1.1 What is rock art and why is it important?

A twofold classification is often used to differentiate between the additive and subtractive forms of creating images on rock surfaces (Rosenfeld, 1988). The additive form generally involves the painting of natural sediments, generally referred to as “pictographs” (Rosenfeld, 1988). The subtractive form involves the removal of material in an engraving procedure creating “petroglyphs” (Figure 1). Engraved rock art is common throughout Australia and many of the sites visited by the authors consisted of simple figurative representations such as animals (Figure 1). Anthropologist do not fully understand why engravings were made but it is evident that aborigines originally lived close to and were totally dependent upon the land, (Stanbury and Clegg, 1990). The rock engravings were used to pass on tribal knowledge and although the spoken word was crucial; song, dance, ritual and pictures were of equal significance in passing on folklore down through the generations. Aboriginal communities place great symbolic significance to their links with the past, which is visibly reflected in rock art sites (Rosenfeld, 1988). Engravings are not only valuable for aesthetic and scientific reasons, but also they represent a direct line to their ancestors and the land. (Stanbury and Clegg, 1990).

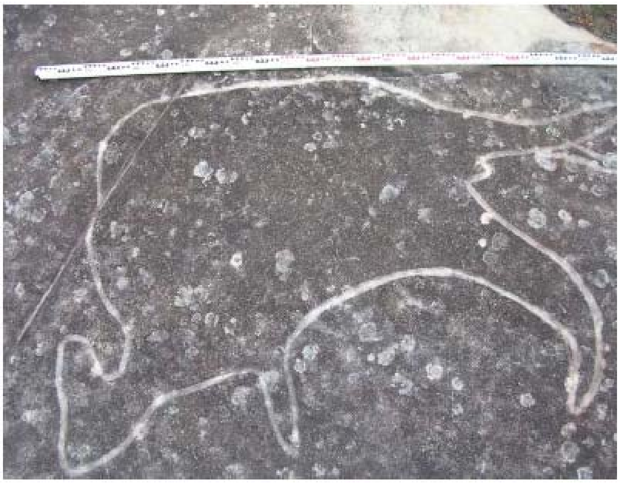

Figure 1- Typical figurative petroglyph

2. PAST USE OF PHOTOGRAMMETRY FOR ARCHAEOLOGICAL AND ROCK ART RECORDING

One of the earliest examples of photogrammetry being used to record rock surfaces was conducted by Atkinson (1968) at Stonehenge in the UK. A special stereo-metric camera system was used to record a small rock engraving from which contours were manually measured using a "Thomson Watts" plotter. Scogings (1978) used a similar method to record petroglyphs at Kinderdam, 300 km west of Johannesburg, South Africa. Features were again represented using contours, generated manually at 1mm intervals on a 1:1 scale plot. In a series of related projects, Rivett (1979) and Ogleby and Rivett (1985) demonstrated the benefits of photogrammetry for recording rock art, both petroglyphs and pictographs. Fieldwork was conducted at a series of sites around Australia, including Kakadu National Park, Northern Territory; Whale Cave, NSW; Quinkin, Queensland; Hawkesbury, NSW; and various cave sites in Western Australia. Their "Handbook of Photogrammetry" (Ogleby and Rivett, 1985) was a key text of its day describing how to conduct a photogrammetric survey for field archaeology. More recently, Ogleby (1995; 1999; 2000) has continued to demonstrate the benefits of photogrammetry to a wider archaeological audience, including the Ayutthaya temple in Thailand (Ogleby, 1999) and Mount Olympus in Greece (Ogleby, 2000). In these two examples, an important final product has been the virtual model, enabling the visualization of the site from any perspective. A similar virtual model was generated by Simpson et al., (2004) who describe the use of the photomodeler (www.photomodeler.com) software package to create 3D models of incised rock-art in Northumberland, UK. Unfortunately their approach requires the painstaking sticking of self adhesive targets over the entire surface area of the rock and also the precise positioning of their digital sensor. Subsequent measurement is also manual and consequently time consuming. The photomodeler package is also widely adopted in the developing field of Archaeological GIS, where it is being increasingly utilised to create virtual reality models (e.g. Hepburn Castle, Gillings and Goodrick, 1996) and assisting archaeological problems that have a spatial component.

2.1 Limitations with traditional photogrammetry

One of the reasons that photogrammetry has not been more widely adopted in the past has been the costs, particularly access to the equipment and skilled labour involved in preparing relevant drawings (Rosenfeld, 1988). Specialized metric cameras costing tens of thousands of US dollars were originally required which needed to be calibrated to enable accurate data to be derived. Traditional instrumentation also enforced strict geometric constraints upon imagery that could be used and also required conventional two dimensional film based maps to be produced. All derived spatial data had to be measured manually and plotted to an average or mean plane, introducing artificial scale distortions into the plotted data (Ogleby and Rivett, 1985). The work described in this paper demonstrates that PC-based computing power combined with automated modern photogrammetric software can overcome most of these traditional difficulties. The International Committee for Architectural Photogrammetry (CIPA) was established to improve the recording of cultural monuments using photogrammetry. One of the important principles adopted has been the "3x3" methods of image acquisition (Herbig and Waldhausl, 1997) to promote acquisition of photography and records that allow photogrammetric measurement. The principles include 3 geometrical rules (control, base/distance ratio, normal photography); 3 photographic rules (constant camera geometry, soft illumination, film type); and 3 organisational rules (sketches, care, checks). It is disappointing that these principles and photogrammetric methods are not more widely adopted. Indeed, one of the tasks identified by CIPA is to "bridge the gap" (Letellier, 2001) between the information user and the information provider. It is recognized (Palumbo and Ogleby, 2004) that the impediment preventing wider adoption of photogrammetry to rock art recording is the unavailability of cheap, portable, automated and easy to use systems. It is believed that work described in this paper will provide a significant step towards achieving that objective.

3. PRACTICAL WORK

Fieldwork was conducted at six sites in New South Wales, Australia but data extraction will be described briefly for just a petroglyph and a pictograph site.

3.1 Fieldwork- petroglyph sites

A variety of petroglyphs were identified in Yengo National Park and at a site near Gosford, New South Wales, Australia. These were all typical of the "Sydney style" of petroglyph (Figure 1), being engraved on horizontal sandstone outcrops in the area north and to the west of Sydney. The petroglyphs were all less than two meters in extent and stereo imagery could be captured simply by raising a handheld camera 1-2 meters above the horizontal sandstone surface using lightweight aluminium steps (Figure 2). Both the cheap (US$ 300) Nikon Coolpix 3100 three Megapixel camera and the more established (Fraser and Shortis, 1995) six Megapixel Kodak DCS460 camera was used, the latter to assess the accuracy of the cheaper sensor. In most circumstances just a single stereopair provided appropriate coverage, the second stereo image achieved through simple lateral displacement of the sensor. A base to distance ratio of 1:6 was desired and while slightly convergent imagery was acceptable it was important to ensure that the camera axes did not cross before the plane of the petroglyph was reached.

Figure 2- Image capture

Control was provided by either a simple scale bar (survey staff) or 6-10 three-dimensional targeted points, their coordinates derived using a reflectorless total station (Leica TC1100). For simple sites the scale bar proved perfectly adequate, although three-dimensional control is generally preferential and easy to provide if a total station is available. Commercial targets were used, temporary adhesion provided by silicon bathroom sealant. Fieldwork was straightforward, requiring ten minutes if scaled control was used; 50-60 minutes if three-dimensional control was installed.

3.2 Fieldwork- pictograph sites

Two main pictograph sites were recorded, both located in New South Wales, Australia. The first site was located near Broke and is the subject of a related paper that compares a laser scanning recording methodology (El-Hakim et al., 2004) with a wholly photogrammetric approach (Fryer et al., 2005). The second site described here is located near Gosford and known as Swinston's cave. This cave site is remarkable because of the extensive and striking hand patterns depicted in the rock-art. It was also more challenging to record because of it's 15 metres length and high degree of cave concavity (radius of curvature < 1m combined with a radial extent of 170°). These physical constraints prevented acquisition of complete stereo imagery within the two hours of field time available. A series of twelve overlapping stereopairs was captured, to provide a sample of the full cave and to identify potential difficulties with a photogrammetric recording methodology. The acute concavity posed particular problems, particularly for vertical imagery of the roof. Here it proved impossible to use the standard camera iewfinder because the camera had to lay on the cave floor. The Kodak DCS460 equipped with a 24mm lens was used throughout, the wide angle coverage and full format proving indispensable for the many short camera object distances necessary. The vulnerable nature of the paintings prevented the use of stick on targets; in many cases fading and degrading pigment could be seen peeling from the rock surface. The only alternative was to use natural features occurring within the rock-art, typically the end of "fingers" within the art and coordinates derived using the reflectorless total station.

3.3 Photogrammetric data processing

Photogrammetric data processing was carried out using the Leica Photogrammetry System (LPS) and consisted of extracting elevation models (DEMs) and orthophotographs from each stereo pair once satisfactory exterior orientations or LPS "triangulations" have been achieved. The procedure was comparatively routine but use of non-metric imagery necessitated the calibration of inner camera geometry. The authors had previously identified difficulties with the self-calibrating routines within OrthoBASE PRO and LPS version 8.7 (Chandler, et al., 2005). An external self-calibrating bundle adjustment (Chandler & Clarke, 1992) was used to derive focal length, principal point offset and radial lens distortion. Subsequent discussions with Leica have resolved the problems with the self-calibrating capabilities of LPS and future releases (LPS Fix: 23825) should be capable of deriving acceptable camera geometry from the imagery acquired (Chandler, et al., 2005). LPS is designed primarily for processing vertical aerial photography and although oblique and terrestrial imagery can be accommodated within the triangulation software module it is not currently possible to extract digital elevation models automatically. This particular difficulty can be overcome if the object coordinate system is rotated so that the average camera axes become vertical (Chandler et al., 2002).

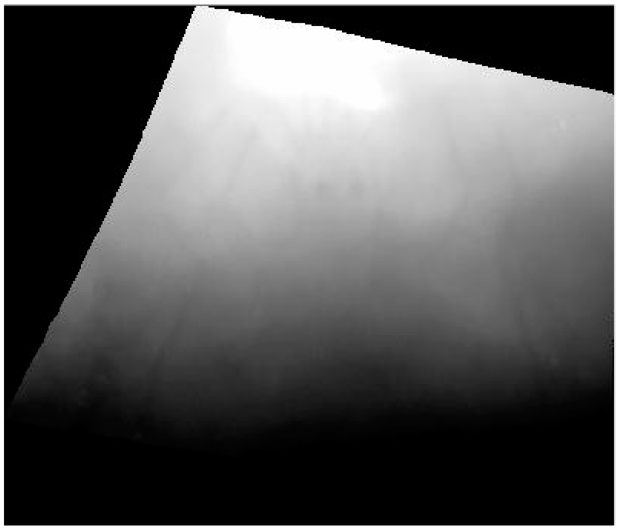

Figure 3- DEM of Big Fella (5mm resolution)

This approach was adopted for imagery of the Swinston cave site but only provides a partial solution. The cave concavity and complexity require camera axes that point in such diverse directions that an "average camera axis" that suited all image pairs did not exist. This inevitably meant that some of the imagery captured could not be used for the production of DEMs and orthophotographs in one single coordinate system.

4. RESULTS

4.1 Petroglyphs

Figure 3 is a greyscale representation of the petroglyph DEM in which white pixels indicate a higher absolute elevation than black pixels. It is encouraging that the engraved features are just visible, particularly two "eyes" which being 7-9 mm deep provide a useful location indicator. However, the remaining engraved features are indistinct and initiatives to accentuate the engraved features using morphology alone were investigated. It was realized that some way was needed to separate the small topographic variations created by the engraving process (elevation range: 10 mm) from the overall topographic variations of the natural rock surface (elevation range: 0.3 m). LPS is a software module within the larger "IMAGINE" package distributed by Leica Geosystems. One of the features of IMAGINE is the ability to write software scripts to perform a sequence of diverse image processing functions. One such "Spatial Model" was developed to identify and accentuate the desired engraved features. In this, (Figure 4) the broad morphology of the rock surface is created by smoothing the original DEM using a large 'low-pass' filter (11 x 11 pixels).

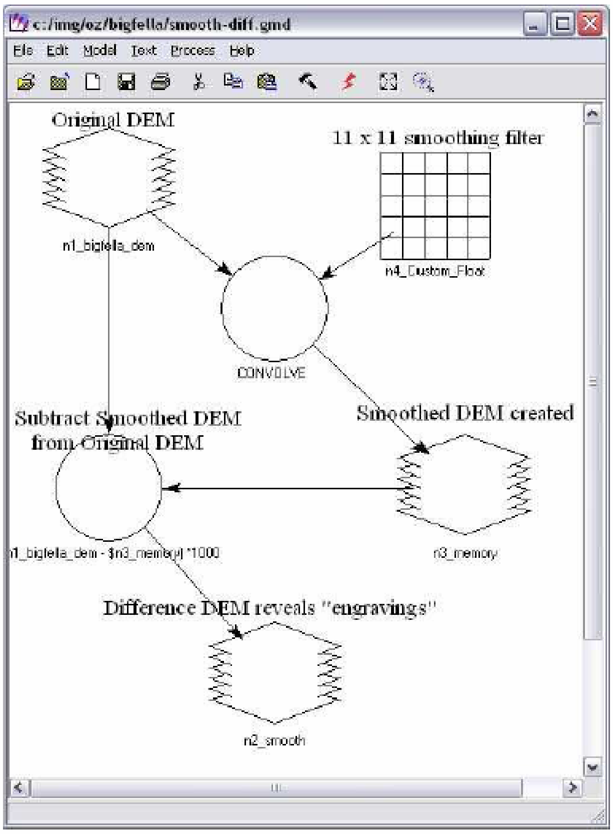

Figure 4- Spatial model to isolate petroglyph

This smooth surface is then subtracted from the original DEM to generate a new DEM image in which the engraved grooves alone represent the dominant morphological features (Figure 5).

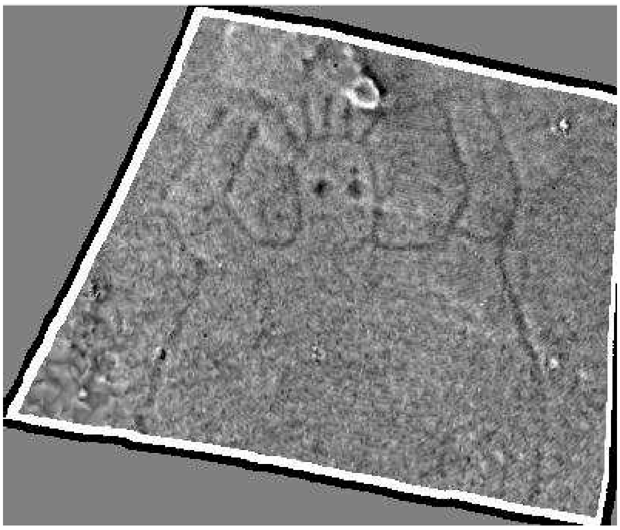

Figure 5- Engraved features identified- Big Fella

The tool effectively isolates data at one spatial frequency (i.e. the engraved rock-art) at the expense of the surface form at other unwanted spatial frequencies (i.e. the general rock surface). Orthophotos were also extracted for the petroglyph site and could be draped on the DEM for three-dimensional visualization. However, the key attribute of the petroglyph were the engraved features, which were recorded in the morphology on the DEM (Figure 5). It is judged that such a "morphological approach" is appropriate for recording this type of rock-art.

4.2 Pictographs

The morphological approach adopted for the petroglyphs was not so suited for recording pictographs because the art is represented by pigment and natural sediments applied to the rock surface (Rosenfield, 1988). A spectral based recording method is therefore necessary, but because the rock surface is not planar but three-dimensional, a combination of a DEM and orthophoto is appropriate. DEMs and orthophotographs were extracted for the pictographs site but because detailed morphology was not critical, DEM resolution could be coarser than those required for the petroglyph sites. The pictographs also covered a larger area and consequently DEMs and orthophotographs derived from individual stereopairs needed to be mosaiced together. Some difficulty was experienced during this process as noticeable "steps" in the DEMs and consequently the orthophotographs were apparent. The steps were located on the boundaries between adjacent DEMs and were caused by slightly inaccurate exterior orientation parameters for individual frames. The fragile nature of the rock-art had precluded the use of stick-on targets and natural features had to be used. Some of these were poorly defined and consequently skewed the photogrammetry models from their true position; manifest by the steps between adjacent DEMs. No such problems were apparent during the processing of another cave site when use of small stick-on targets was permissible.
The mosaiced DEMs and orthophotographs were used to create a virtual 3D model (Figure 6), which illustrates both the striking hand patterns and the level of detailed captured.

5. DISCUSSION

5.1 Accuracy of the Nikon camera

The accuracy of the digital elevation model (DEM) was assessed by comparing the data extracted using the Nikon camera with the Kodak DCS460, the camera with proven photogrammetric capabilities. To allow direct comparison at every sampling point, one DEM was simply subtracted from another, so creating a new "difference surface". Figure 7 represents the comparison, with red pixels indicating negative height differences of 5mm; green pixels representing positive differences of 5mm; white pixels indicating identical elevations; and, lighter colours indicating differences within these limits. Figure 7 indicates that each camera has captured both the gross morphology defined by the rock surface and the engraved grooves, to a similar level of accuracy. The more discerning eye would also detect a minor trend between the different surfaces, although this is less than 5mm across the entire measurement area.

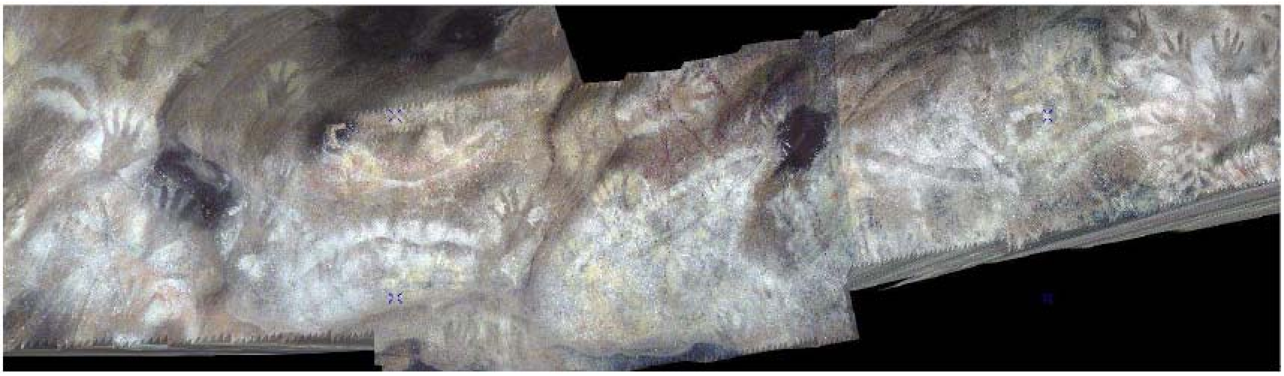

Figure 6- Virtual model of Swinston's cave

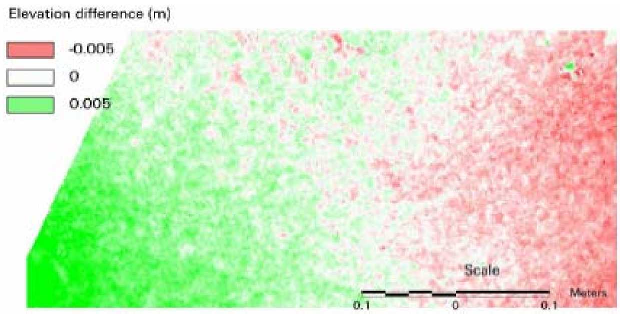

Figure 7 - DEM of difference, Nikon - Kodak DCS460

5.2 Visualisation

Previous authors have recognized the value of producing a 3D model (Ogleby, 1999; Pollefeys et al., Simpson, et al. 2004) and this belief was confirmed in this project. The DEMs and orthophotographs were loaded into a package called VirtualGIS which allows 3D interrogation and inquiry and production of 3D fly through image sequences (Low resolution example: http://civil-unrest.lboro.ac.uk/cvjhc/Images/ bigfella_compressed2.avi). Various light models can be applied and different layers of data visualized from any perspective. The original rock artists took advantage of the natural morphology of their three-dimensional rock canvas and so it seems obvious that rock-art needs to be recorded in three dimensions.

5.3 Software accessibility

An important advantage arising from adoption of commercial software is the widespread availability to users who need access to it. Specialised photogrammetric software has been developed to specifically assist archaeological recording (e.g., Pollefeys, et al., 2003; Mueller, et al., 2004), although these suggest potential, their approach is less favourable to field archaeologists because the software is not widely available. In contrast, commercial photogrammetric software packages have matured significantly since their original development and promotion 10-15 years ago and can be now used by the novice user with minimal supervision. The counter argument is of course cost, commercial packages remain expensive and a single commercial license for LPS used in this project would cost US$ 12,000. One solution is to perhaps invest in a single software license for one informed archaeological/ photogrammetric user who is able to support multiple archaeological recording teams in the field. The benefits of identifying and using such a "champion" cannot be underestimated.

6. CONCLUSION

An efficient and effective method of recording petroglyphs and pictographs using digital photogrammetry has been presented. The approach takes advantage of the new range of cheap digital cameras, which if calibrated can produce accurate 3D data. Appropriate photogrammetric software is capable of generating thousands of surface points fully automatically and orthophotographs, which when combined, can be used to produce accurate virtual reality models. For most petroglyphs the required fieldwork can be conducted by non-photogrammetrists using lightweight, portable and cheap equipment.

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