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HMS STIRLING CASTLE, KENT
THE STIRLING CASTLE WOOD RECORDING PROJECT. A PILOT STUDY TO COMPARE TRADITIONAL AND INNOVATIVE RECORDING TECHNIQUES FOR WATERLOGGED WOOD

ARCHAEOLOGICAL CONSERVATION REPORT

Angela Karsten and Graeme Earl

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SCIENCE

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HMS *Stirling Castle*, Kent

The *Stirling Castle* wood recording project. A pilot study to compare traditional and innovative recording techniques for waterlogged wood

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SUMMARY
This project was jointly carried out between English Heritage and the University of Southampton. It compares and evaluates traditional and innovative recording techniques for waterlogged timber. The aim is to establish the effect of conservation treatments on fine surface details and to establish the accuracy when using moulding and casting techniques. The results confirm that some changes take place during the conservation treatment.

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KEYWORDS
Methodological Research, Conservation, Wood

ARCHIVE LOCATION
Currently Fort Cumberland, Portsmouth. Discussions are ongoing with Ramsgate Maritime Museum and The Shipwreck and Coastal Heritage Centre, Hastings.

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1 INTRODUCTION

This project was jointly carried out between English Heritage (Archaeological Conservation and Technology Team) and the University of Southampton (Archaeological Computing Research Group).

The recording of wooden remains, where tool marks, constructional and natural features are documented, has long played an important role in archaeology (Morris 1990, Allen 1994, Brunning 1996, Sands 1997). The study of tool marks on waterlogged timbers can answer a variety of questions from wood conversion over the production of the artefact, to the actual tools used.

There seems to be a general consensus in archaeology, that once a timber has been exposed or excavated, fine surface details are extremely vulnerable and can even vanish during prolonged storage (Marsden 1991, 29; Starling 1991, 43). The same is often said for conservation treatments, namely that surface details seem to disappear. Whilst it is out of the scope of this project to investigate the survival of tool marks during storage, it aims to look at what happens to fine surface details following conservation treatment.

So far the recording techniques used were either photography, hand drawings and in some cases the use of moulding materials. Lately the application of digital recording techniques and their use in archaeology is becoming more common. Some projects use digital recording equipment as their first and prime technique (Jones 2009).

The Stirling Castle Wood Recording Project is designed as a trial to compare and evaluate traditional and innovative recording techniques. The potential to document fine surface details and constructional features of wooden objects is being investigated using traditional techniques such as photography, illustration, x-radiography, silicone rubber moulds, and innovative techniques such as laser scanning and Polynomial Texture Mapping (PTM). Some of these techniques are being used as a monitoring tool to track how fine surface details change during the conservation process and how well some techniques capture surface details. All techniques are being evaluated in terms of accuracy, availability, time and costs.

An analysis and interpretation of the tool marks is outside the scope of this study.

2 AIM OF THE PROJECT

The overall aim of the project is to compare and evaluate traditional and innovative recording techniques for waterlogged wood.

To achieve this, the project has the following objectives:

To compare traditional and innovative recording techniques for wooden remains.

To establish the effect of conservation treatments on fine surface.

To establish the accuracy when using moulding and casting techniques.

3 STUDY MATERIAL

The piece of waterlogged wood used in this study was recovered from the protected wreck of the *Stirling Castle* in 2006 by Wessex Archaeology, who undertook an investigation of the site on behalf of English Heritage.

One barrel fragment was selected to carry out the recording project using the techniques described below. This piece was chosen for its small size, tool marks and constructional features. It is either a base or a head piece of a barrel (in the accompanying documentation it is referred to as a head piece, although this must remain unsure as it was a stray find). It is part of a composite base, as two dowels are present at the timber's flat edge. It is 40cm long, 9cm wide and the diameter can be reconstructed to 56.5cm.

4 THE SITE

The wreck of the *Stirling Castle* was discovered in 1979. It is a post-medieval ship, built in 1699 and lost during the great storm of 1703 on the Goodwin Sands, off Kent, Great Britain (Ensor 2004). The wreck has been protected under the Protection of Wrecks Act since 1980.

The recovered artefacts and the remaining hull timbers *in situ* are very well preserved and the archaeological potential of the assemblage is high. The site of the Goodwin Sands is subject to sediment movements, which cover and expose the wreck at intervals. This poses a threat to the stability of the wreck. Furthermore the remains are vulnerable to fishing activity.

5 METHODOLOGY

A variety of traditional and innovative recording techniques were used in this study (Table 1).

Table 1: Overview of recording techniques used

Traditional Recording Techniques	Innovative Recording Techniques
Sketch	Laser Scanning
Hand drawing	
Illustration	Polynomial Texture Mapping
Photography	
X-radiography	
Silicone rubber mould and plaster cast	

To compare and evaluate the methods, the following parameters were chosen:

Access to/ Availability of

- Skills required
- Time
- Product
- Accuracy
- Ease of using data

Analysis of the dataset retrieved from laser scanning and polynomial texture mapping focussed on comparison between the pre-treatment sample, the mould, the cast produced from the mould and the post-conservation artefact. These comparisons took three forms: visual examination of the laser scan and PTM datasets, and metric comparison of the laser scan data.

The pre-conservation state of the head piece is considered to be the original in this study and gives the baseline against which all findings are compared. An area containing tool marks was chosen for close examination (Figure 1 and 2).

Fig 1: Head piece 2255 before conservation

Fig 2: Area for close examination

6 CONSERVATION OF THE HEAD PIECE

After an initial clean using a soft brush under running tap water, the head piece was immersed in 20%PEG 400 for six weeks followed by two weeks in 20% PEG4000. The timber was frozen in a domestic chest freezer for three days and then vacuum freeze dried for four days (Figure 4). No dimensional change measurements were carried out.

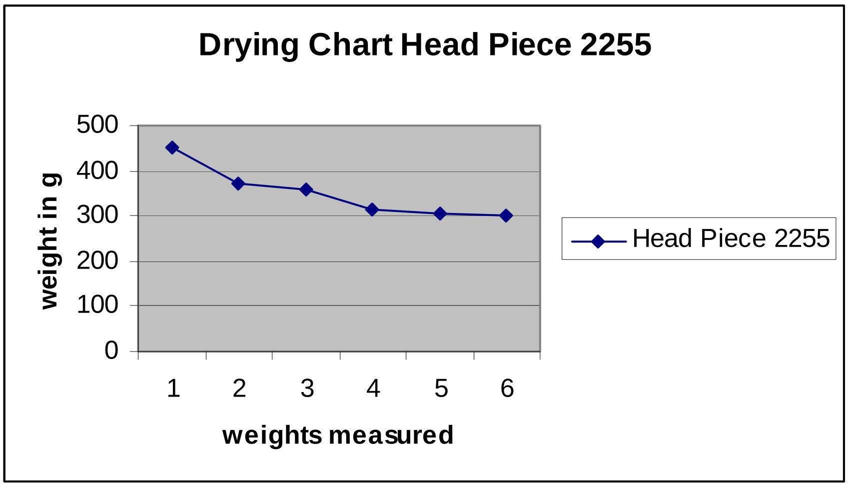

Fig 4: Drying curve for head piece 2255

7 TRADITIONAL RECORDING TECHNIQUES

7.1 Sketch

The easiest and fastest way to capture the general shape of an object is by sketch (Figure 5). This is commonly done on site when the first record of a timber is created, normally on a wood record sheet. Annotating the sketch gives the added benefit of marking damage, tool marks or dimensions.

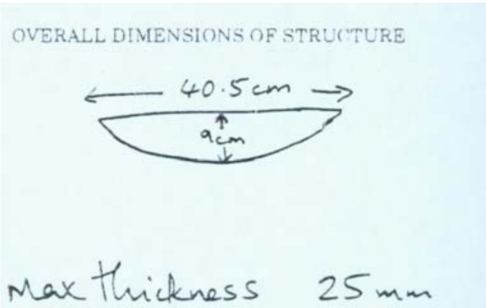

Fig 5: Sketch of head piece 2255

7.2 Hand drawing

A more detailed and accurate record is obtained when creating a hand drawing at scale 1:1 (Figure 6). This is commonly done before any conservation treatment is attempted to keep a record of the pre-conservation dimensions. A hand drawing also allows putting emphasis on details that are difficult to illustrate with a photograph.

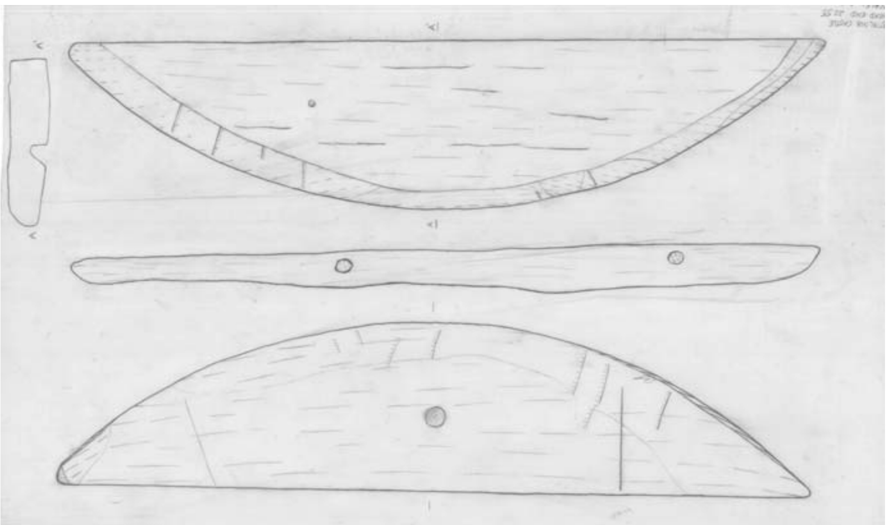

Fig 6: Hand drawing of head piece 2255

7.3 Illustration

A more accurate depiction of a timber can be achieved with an illustration at scale 1:1 (Figure 7). Drawing of timbers before conservation is a common method to record dimensions and the position of natural features (eg. grain), working marks (eg. tool marks, constructional features) and areas of damage (eg. abrasion, wood borer damage).

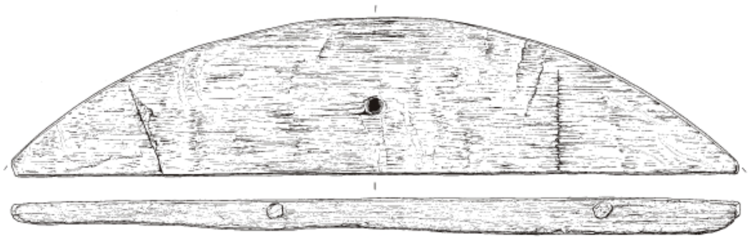

Fig 7: Illustration of head piece 2255 (drawn by Chris Evans)

7.4 Photography

A quick record of a timber can also be obtained by a photograph (Figure 8). Digital photography is now widely available and commonly used. Fine surface details are difficult to capture on wet, dark timbers and good lighting and some experience and patience are necessary.

Fig 8: Head piece 2255 after conservation

7.5 X-Radiography

This visualisation technique is not commonly used for organic materials, although it is becoming more recognised (O'Connor and Brooks 2007). When Earwood notes that some constructional details such as dowels can only be observed if wooden vessels are being dismantled (1993, 175), no consideration was given to non-destructive investigative techniques such as x-radiography.

In this study x-radiography was used to examine of the wooden dowels inside the head piece (Figure 9).

Fig 9: X-radiograph of dowels within the head piece 2255

7.6 Silicone rubber mould and plaster cast

The use of silicone rubber moulds to record tool marks is adequately discussed by Sands (1997). This well established technique accurately captures surface features and allows for close examination without needing the object or for reproduction in form of casts. The silicone rubber mould captures shape, size and direction of surface features in a reversed "negative" way. A "positive" can be obtained by casting a replica using plaster of Paris or resins (Figure 10). Surface details on the mould or on the cast can be viewed without any aid or examined closely under the microscope or Scanning Electron Microscope without having to handle the original artefact. Often photography is used in combination with this technique, which is ideally suited for a comparison of tool marks on different artefacts.

Fig 10: Silicone mould and plaster of Paris cast

8 INNOVATIVE RECORDING TECHNIQUES

The head piece was recorded by staff at the Archaeological Computing Research Group at the University of Southampton. Two techniques were employed. First, a non-contact laser scanning digitiser was used to produce a dense surface mesh. Second, the Polynomial Texture Mapping technique was used to produce an interactive rendering of the surface, and also to define surface variations. Surface data was captured for the original head piece, for a mould of the head piece, a cast produced from this mould, and the post-conservation timber. The study identified benefits and problems associated with both surface capture methods.

Analysis of the wood was focussed on comparisons between the pre-treatment sample, the mould, the cast produced from the mould, and the post-conservation artefact. These comparisons took three forms: visual examination of the laser scan and PTM datasets, and metric comparison of the laser scan data.

8.1 Laser scanning

A variety of non-contact digitising approaches now exist that are suitable for cultural heritage applications including structured light, time of flight and triangulation scanning. Laser scanning or non-contact digitising is becoming an increasingly common tool for conservation recording and analysis. Blais *et al*'s (2008) study of the *Mona Lisa* demonstrated the extraordinary detail possible and the value for fine grained analysis. The value of such techniques for cultural heritage visualisation was recognised almost as soon as the technology was developed. Implementations include the work of the Stanford

Digital Michelangelo project (Levoy *et al* 2000), scanning and unwrapping of cuneiform (Anderson and Levoy 2002) and mosaics (Maino 2009).

The non-contact digitiser employed for this study was a Konica Minolta vi910 triangulation laser scanner (Figure 11). All captures in this study used the telephoto lens with a focal length of 25mm. The measurement range was set at a constant 0.6m, which provides the maximum possible density of points for this instrument. Each capture produced a maximum of 307,000 individual points with a quoted accuracy in the x of ±0.22mm, y of ±0.16mm and z of ±0.10mm. The instrument also captures low resolution colour data which was not used. All instrument settings were set to the highest possible capture quality for this study.

Fig 11: Laser scanning of the post-conservation timber

Laser scan data was captured for each of the four comparators. Sufficient scan data was captured to produce a complete model of each object. However, in order to enable fine comparison a small area was chosen for detailed analysis. This small area has prominent scored marks and wood grain, and measures approximately 40mm by 55mm (see Fig 2).

Four separate software packages were used in the capture and processing of the laser scan data. These were RapidForm, Polygon Editing Tool, MeshLab, and 3ds Max. Each of these provides specific advantages in terms of data capture, manipulation and comparison. Interoperability between the software was achieved via Binary STL and OBJ file formats. Polygon Editing Tool was used to capture the scan data and for initial registration. Hole filling or mesh smoothing was not performed at any stage of the capture and analysis process. 3ds Max was used to invert the mould scan data to provide a comparable surface to the timber and the cast. The mould data was inverted according to its object-level Z axis, defined from the original scan data.

In order to facilitate both visual and metric comparison the scanned data were registered i.e. they were orientated within the same spatial reference system. MeshLab was used to complete first stage precise registration of scan datasets. An eight-point configuration was used (Figure 12), with the points evenly spread across the scan datasets.

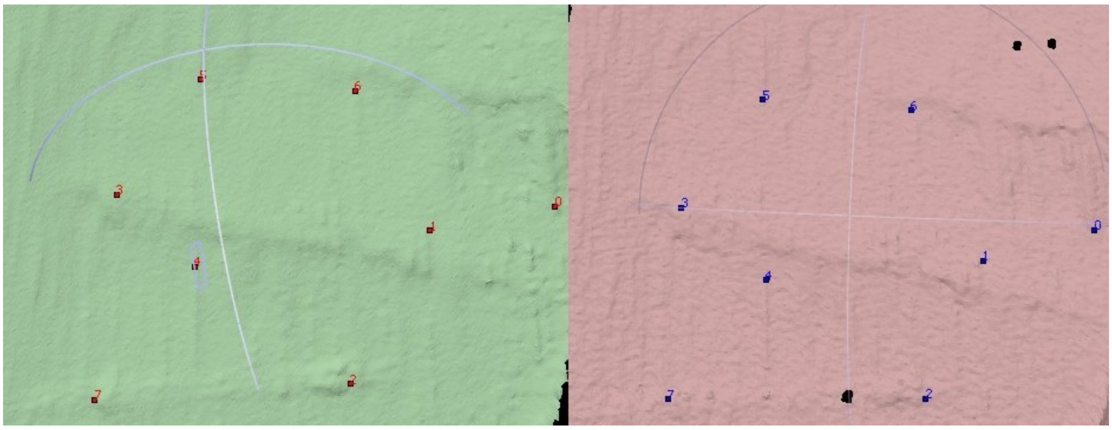

Fig 12: Location of registration points on plaster cast (left) and pre-treatment timber scan (right)

Registration points were chosen on flat areas and on ridges in order to minimise the impact of the transformation of the underlying surfaces on the registration process. Further fine registration was carried out in Polygon Editing Tool. Experimentation has previously suggested that this offers the best final fit. In the last stage data were moved to RapidForm for comparison of the scanned datasets. All data were registered directly to the pre-treatment scan dataset. This defines the co-ordinate space for all subsequent analyses.

Registration of the scan data was not unproblematic. Despite experimentation with a wide range of configurations the modification to the artefact during conservation made registration of the pre- and post-conservation data very difficult. The only way to guarantee correct spatial registration of scan data pre- and post-conservation is to provide fixed registration points attached to the object. This armature of registration points enables precise matching and hence comparison of surface deviations relative to these known points. However, in this study it was impossible to use a fixed armature since the armature would itself have influenced any modification of the object due to conservation treatment. Metric comparison of the data must be viewed bearing in mind the problems with registration. In fact, our initial assessment suggests that the registration process provides a good indication of the extent to which small scale surface modifications occur in the timber as a consequence of the conservation processes.

Registration statistics were captured for each scan and are listed in Table 2 below.

8.2 Polynomial Texture Mapping

Polynomial Texture Mapping was invented by Hewlett Packard Labs in 2000 (Malzbender *et al* 2000)[1]. This technique employs a fixed position digital SLR camera and records multiple frames with varying light source directions and has seen application in a range of archaeological and other contexts (Earl *et al* 2010a; Earl *et al* 2010b). The technique is analogous to the raking light photography commonly employed in the recording of archaeological artefacts (Figure 13). However, its automated implementation has a number of benefits. First, it employs many more light directions and therefore provides a good coverage of the likely best shadow and light configurations for viewing subtle surface details. The best location of light for identification of surface detail can be defined automatically in software, in addition to by trial and error approaches. Second, the Polynomial Texture Map (PTM) format enables interactive movement of the light source, including artificial reduction of the grazing angle to enhance very low relief details. Thirdly, the digital record can be subjected to a range of image processing algorithms in order to enhance surface details. Fourthly, variations in surface form can be extracted and then used to provide metric comparisons. Finally, the PTM file can be used to provide relighting of the object, using multiple light sources, in order to produce idealised photographs for publication.

Fig 13: PTM of plaster cast illustrating the impact of differently angled lighting (left and centre) and specular enhancement (right)

PTM files are generated using one of two techniques. Firstly, an automated lighting rig can produce a standardised configuration of incident lighting directions. Secondly, a spherical

[1] Further details are available from: http://www.hpl.hp.com/research/ptm/

target can be incorporated into the scene with varying lighting created by manual movement of the incident light source (Barbosa *et al* 2007). Both techniques were trialled on the Stirling Castle barrel stave. However, the PTMs used in the analysis below were all captured using the fixed rig developed by the University of Southampton as this offers increased precision in terms of light orientation and enables more rapid capture of high numbers of samples. The rig consists of a fixed camera mount and a robotic arm. In the Stirling Castle captures this arm was mounted with seven low power LED light sources. Bespoke software moves the robotic arm to the correct orientation, turns on the appropriate LED and fires the camera. A total of 56 sample light directions were captured for each of the Stirling Castle analyses. Experimental results have shown that above 60 samples very little improvement in data quality is seen (Dellepiane *et al* 2006).

Images were captured using a Nikon D300 digital SLR camera. This generates images with a resolution of 4288x2848 pixels (12.2 mega pixels). As colour calibration was not required high quality JPEG images were captured rather than RAW files. The images were then fitted to generate a PTM using the HP PTM Fitter software and then viewed via the HP PTM Viewer. Both of these are freely available for non-commercial use (Malzbender and Gelb nd).

9 RESULTS

An evaluation of each technique employed is given below (Table 2–9) and a summary is provided in Table 10 and Figure 14.

9.1 Evaluation of traditional recording techniques

Sketch

Table 2: Evaluation of the sketch

Access to/ Availability of	A sketch is a very quick and easy way of capturing the general shape of an artefact. Annotating a sketch gives the added benefit of dimensions or other important features.
Skills required	Good observational skills are an advantage, as is a basic understanding of wood and wood working and recording.
Time	It took 5min to create this annotated sketch.
Product	The information is captured as a sketch, which can stand alone, or is commonly incorporated in a wood recording sheet (WRS).
Accuracy	Not very accurate
Ease of using data	In the raw form the sketch can be viewed without any aids. To use the drawing for publications, etc. it has to be scanned to make it available in digital format.
Overall rating	The sketch outlines of the general shape of the head piece. The annotation gives the dimension and is a valuable addition in this case. This is a very quick and easy way of creating a record. As no special equipment or skills are needed to create or use it, this method is commonly applied. A detailed study of the head piece using the sketch alone is not possible. As the only record for an archaeological artefact the sketch is probably not sufficient.

Hand drawing

Table 3: Evaluation of the hand drawing

Access to/ Availability of	The head piece was hand drawn on perma-trace (scale 1:1) in pencil, when still wet. This is easy to carry out, as no specialised equipment is needed and this can be done when the piece is still wet, creating a record of the artefact as found. Perma-trace and pencils are ideal when drawing wet timbers.
Skills required	A general understanding of the object, its manufacture and good observational skills are required, as an interpretation and selection of features will undoubtedly be made by the person creating the drawing.
Time	It took 45min to create this drawing.
Product	The information is captured in a hand drawing, on paper or perma-trace.
Accuracy	Accurate
Ease of using data	In the raw form the drawing can be viewed without any aids. To use the drawing for publications, etc it has to be scanned to make it available in digital format.
Overall rating	This is a quick and easy way of creating a record. As no special equipment or skills are needed to create or use it, this method can be applied widely. Drawing conventions may be taken into account.

Illustration

Table 4: Evaluation of the illustration

Access to/ Availability of	An illustration is normally carried out by a professional illustrator using specialist drawing equipment.
Skills required	Either training in illustrating archaeological artefacts or sufficient experience is of advantage when creating an illustration of adequate quality. Some knowledge of the object is also necessary.
Time	It took about 6 days to create this illustration.
Product	The information is captured in an illustration.
Accuracy	Accurate
Ease of using data	In the raw form the illustration can be viewed without any aids. To use the drawing for publications, etc. it has to be scanned to make it available in digital format.
Overall rating	The illustration gives a high quality artistic representation the head piece, putting focus on features that are more difficult to capture using photography.

Photography

Table 5: Evaluation of photography

Access to/ Availability of	Photography is a common technique to create a quick and accurate image of an item. Digital cameras are widely used and everyday equipment on site or in the laboratory.
Skills required	A general understanding of the object, its manufacture and good observational skills are required. An understanding of photography and lighting is desirable. Wet surfaces show tool marks and surface details best, but are paradoxically more difficult to capture due to the reflective qualities of the water.
Time	A good quality image can be obtained in 3min. Together with time for setting up, detailed shots and downloading, 5–10min are probably more realistic.
Product	For this project digital photography was used and the files are obtained in jpeg and tiff format.
Accuracy	Very accurate
Ease of using data	The photograph can be viewed on a computer with appropriate software or on the camera itself. The digital format makes it easy for images to be incorporated into publications. A print out from the digital file is possible.
Overall rating	This is a quick and common method to obtain an image of an artefact. The photo gives a very good visual representation of the head piece. A sense of dimension can be obtained from the scale. The pre-conservation photos are more difficult to create, as the uniform dark and wet surface of the wood reflects light and obscures surface details. A strong angled light source would have helped to overcome this problem. Surface details such as grain or tool marks are more easily seen in the post-conservation photo. For a detailed study close ups are valuable. A photo should be the minimum record of an artefact and forms part of the archive. As only basic equipment is needed, it is a widely used technique.

X-Radiography

Table 6: Evaluation of X-radiography

Access to/ Availability of	X-radiography equipment for use in an archaeological context is not available in every institution, but access is possible via working relationships or on a contract basis. The use of x-radiography for archaeological wood is not common practice, it has been used for certain purposes in the past though (Fougerousse and Gueneau 1971). For this project it has been used to visualise constructional features inside the head piece.
Skills required	Training to use x-radiography equipment is essential. Experience in x-raying organic artefacts is an advantage, but not necessary.
Time	To create an x-radiograph took 25min. This includes the time for processing of the x-ray film. The x-ray film has to be dried for another 30minutes.
Product	The image is captured on an x-ray film, sometimes referred to as the x-ray plate.
Accuracy	Accurate
Ease of using data	The image can be viewed, ideally with the aid of a light box in a darkened room. For publications the x-ray plate has to be scanned or photographed to be available digitally.
Overall rating	This is an ideal technique to create an image of an artefact that allows the visualisation of internal features, such as construction or damage. In this case it was used to visualise the two dowels that can only be seen on one face of the head piece. The x-radiograph shows the recess and the length and angle of the dowels.

Silicone mould and plaster cast

Table 7: Evaluation of moulding and casting

Access to/ Availability of	The use of silicone rubber moulds to record tool marks is adequately discussed by Sands (1997, 14ff). This well established technique accurately captures surface features and allows for close examination without needing the object or for reproduction in form of casts. For this project a silicone rubber mould with plaster case and a plaster cast have been made.
Skills required	Experience in the making of silicone rubber moulds is desirable. Manual skills are advantageous.
Time	Including curing time for the silicone rubber mould and the plaster of Paris cast it can take up to 1.5 days until the end product can be fully used.
Product	The silicone rubber mould captured shape, size and surface features in a reversed ("negative") way. A "positive" can be obtained by casting a replica in the mould using plaster of Paris or resins.
Accuracy	Very accurate
Ease of using data	Surface details on the mould or on the cast can be viewed without any aid or examined closely under the microscope or Scanning Electron Microscope without having to handle the original artefact. Often photography is used in combination with this technique, which is ideally suited for a comparison of tool marks on different artefacts.
Overall rating	This technique requires slightly more effort in terms of time and equipment. If a detailed study of surface features is intended it does however provide many advantages compared to other techniques.

9.2 Evaluation of innovative recording techniques

Laser Scanning

Table 8: Evaluation of laser scanning

Access to/ Availability of	Laser scanning equipment is expensive. Entry level devices for small objects are available for several thousand pounds. Scanners capable of large object capture at high resolution are extremely expensive. Scanning is increasingly common in specialist archaeological contexts including laboratories and in the field. Commercial software for processing scan data is expensive. However, the excellent MeshLab software is available freely under an open source license.
Skills required	Capturing data via a laser scanner requires training but is not complex. However, processing of scan data requires considerable technical knowledge.
Time	Capture is very quick. The laser scanner used in this case study captures and stores more than 300,000 individual points in a matter of seconds. Processing of scan data is minimal if no registration is required, ie if a single scan captures the required surface information. Where multiple scans have to be matched error is introduced and increased time taken. Subsequent processing of scan data to produce metric comparisons, export 3d models and so on can be very time consuming and although modern software simplifies the procedures a high degree of knowledge is required to ensure high data quality.
Product	The laser scanner produces a file containing X,Y,Z point locations with optional colour information per point. It may also capture a low resolution photograph of the area scanned. The point data can be viewed and measured in its raw format. More usually the point cloud is converted into a triangulated mesh of faces. This process normally includes cleaning of the data to remove overlapping faces and filling of holes. The data can also be used to produce non-photorealistic renderings of a similar style to hand drawn illustrations.

Accuracy	The laser scanner provides a quoted accuracy and precision. Sub-mm measurements are commonplace for artefact scans. Evaluation of the resolution of data captured and the subsequent processing of it is simplified by modern software.
Ease of using data	Hardware improvements in recent years mean that the size of data gathered via a laser scanner no longer presents problems for viewing. Faster network speeds mean that transfer of laser scan data is no longer problematic. In addition many of the laser scanner file formats have freely available utilities for viewing and measuring their point cloud outputs.
Overall rating	Scanning produces a very accurate model of surface morphology in a short time. Although a degree of training is required the value and flexibility of the output data are considerable. These data are increasingly easy to share and manipulate. The equipment is however expensive, even given the availability of new desktop alternatives.

PTM

Table 9: Evaluation of polynomial texture mapping

Access to/ Availability of	Bulk capture of PTMs is enhanced via a specialist rig where available. This requires specialist equipment and development time. However, the alternative highlight method requires only a digital camera, tripod, flash and a shiny reference ball. The software for fitting is freely available (Highlight HP fitter is free for non-commercial use; RTI fitter is available under an open source license)
Skills required	Training is required to enable high quality capture. However, the technique is not complex.
Time	Initial setup of a portable capture rig can take 30 minutes. However, the highlight system takes only a few minutes to setup. Capture of each PTM takes between 1 and 5 minutes. Processing takes up to 5 minutes per PTM, depending on resolution, but can be batch processed.
Product	The PTM process produces a single PTM file per capture.

Accuracy	PTM accuracy is dependent upon quality of lens, resolution of camera, focal length and focussing distance. In this respect it is identical to digital photography. The PTM fitter produces a good representation of surface detail which in relative terms is comparable or better than laser scan datasets. In absolute terms derivation of 3d data from PTM remains experimental. Combination with photogrammetric approaches has been demonstrated to offer the best combined approach (Mudge pers comm).
Ease of using data	The PTM is in the HP .ptm format and is viewable via a viewer. This software can be downloaded from the HP website and is free for non-commercial use. An open source viewer is under development.
Overall rating	Once learned the PTM technique is a simple, cheap alternative to conventional raking light photography. It increases the time taken to photograph the object but capture times can be drastically reduced by building a capture rig. PTMs can be disseminated very easily, including via online viewers embedded on web pages. The viewer itself is simple to use.

Table 10: Evaluation summary of the techniques employed

	Accuracy	Availability	Time	Costs
Sketch	not very accurate	readily available	minimal	minimal
Hand Drawing	accurate	readily available	medium	minimal
Illustration	accurate	available	medium	minimal
Photography	accurate	readily available	medium	minimal
X-radiography	accurate	specialist equipment required	medium	medium
Silicone mould and cast	very accurate	specialist equipment required	medium	medium
Laser scanning	very accurate	specialist equipment required	high	high
PTM	very accurate	possible with readily available equipment	medium	medium

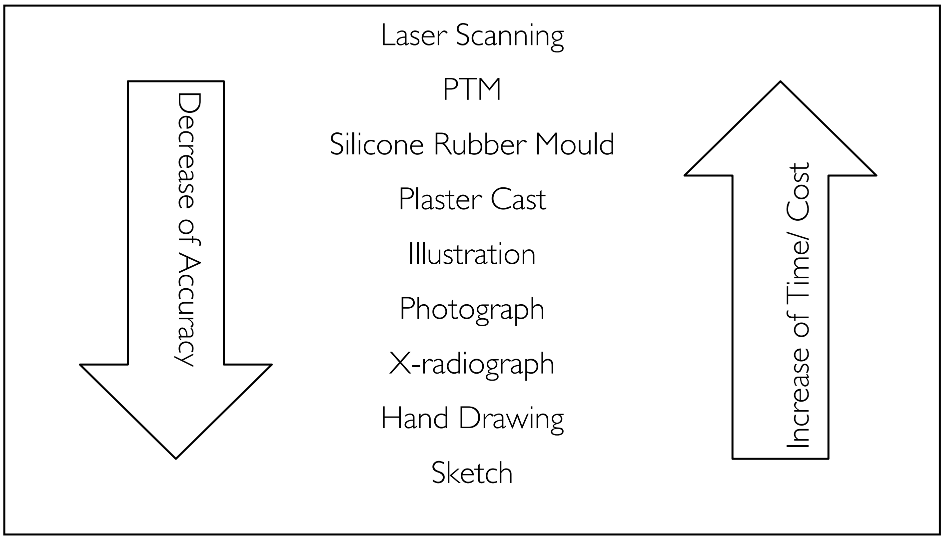

Fig 14: Rating of the techniques employed

9.3 Results – Effect of conservation treatment on fine surface details

9.3.1 Visual analysis of laser scans and PTMs

Visual analysis of the scans indicated that the more the process moves away from the original (which we consider to be the pre-conservation wood), the less accurate the maintenance of fine surface details between processes becomes. So wet wood and silicone mould are fairly similar with a little loss of detail at the edges, the silicone mould and the plaster cast are again fairly similar, with the greatest difference seen between the pre and post treatment wood. But the loss of fine surface details from pre-conservation wood to plaster cast is a little bigger than the other two, as this is an accumulation of the surface detail loss experienced during the other two stages (Figure 15).

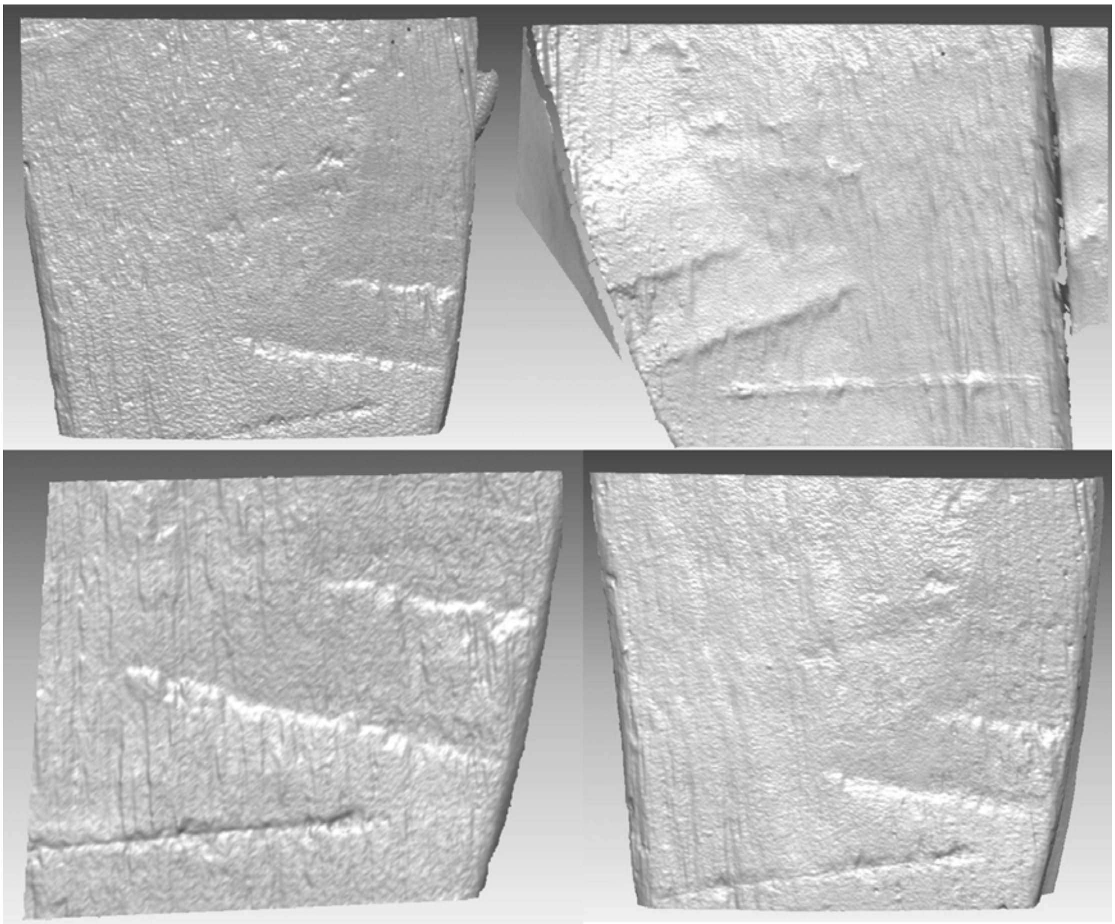

Fig 15: Visual comparison of the scans confirms a progressive softening of the sharpened edges present in the pre-treatment timber (clockwise from top left: pre-treatment timber, silicone mould, post-treatment timber, plaster cast)

Polynomial Texture Mapping datasets were gathered for each of the four comparators. The same small area chosen for the laser scanning formed the focus for the subsequent PTM visual analyses. In order to provide comparable datasets the HP PTM Viewer software was used to derive a PPM format Normal Map. A normal map is an RGB colour representation of surface morphology. The red channel indicates left versus right orientations, the green channel indicates up versus down orientations, and the blue channel indicates relative vertical distance. The normal map thus provides a metric for the angle and direction of each pixel within the PTM and hence of the surface recorded (Figure 16). Visual analysis of these data, coupled with interactive analysis of the PTM files confirmed the visual appraisal of the laser scan data. Visualisation of the data via the PTM viewer was found to be a more intuitive method for studying the surface morphology.

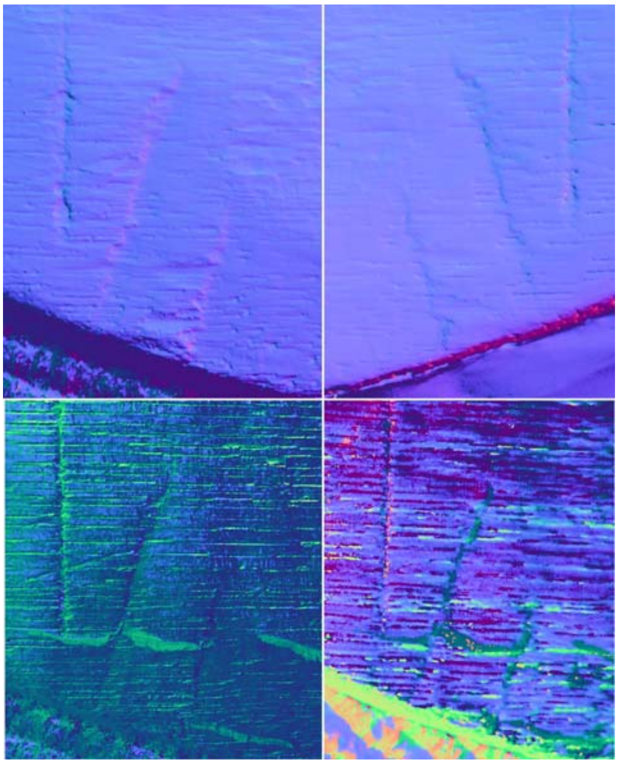

Fig 16: Normals derived from PTMs of (clockwise from top left) pre-treatment timber, mould, post-treatment timber and plaster cast

9.3.2 Metric analysis of laser scan data

Having spatially referenced the scan data it was possible to undertake two metric comparisons, both using the analytical tools of RapidForm. The first, Shell-Shell deviation, produces a raster representation of the deviation between two registered scan datasets. In the analyses conducted an absolute colour range was used and the whole shell was tested in order to achieve the best possible data. The Z axis used in the calculation of the deviation is derived from the overall registration space, derived from the pre-treatment scan. Cross-section analysis cuts a vertical plane through the scan data and extracts a curve representing the surface form. As noted above however both of these techniques are wholly dependent on the accuracy of the registration, and hence on the variation in the surface morphology.

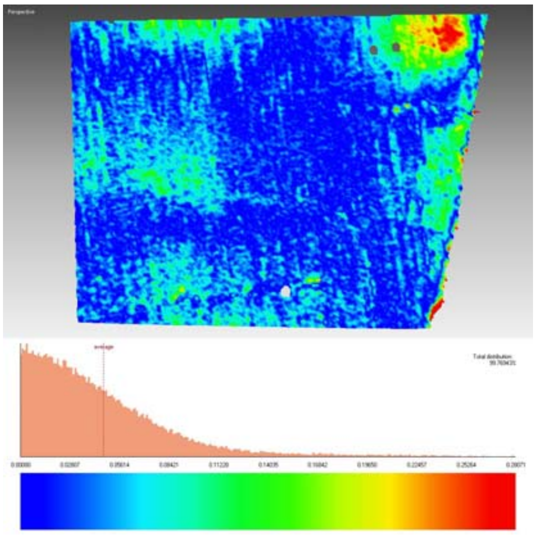

Fig 17: Metric comparison between pre-treatment timber and mould

Comparison of the scan data has identified some interesting interim conclusions. The difference between the pre-treatment timber and the mould suggests that the latter generally provides a good representation of the deeper scratches, although there is some slight indication of a flattening of the edges of these areas and the central scratch has lost some definition (Figure 17). The longitudinal wood grain is more poorly represented by the mould. The error in the top right is unexplained. It may be that this corresponds to a poorer registration of the scans in this area, relative to the central portion. The comparison between the mould and the cast shows a very good level of reproduction of wood grain, but some loss of material on the edges of the scratches. This is less pronounced than between the pre-treatment timber and the mould. A direct comparison between the pre-treatment timber and the cast highlighted the cumulative impact of these stages. Loss of data is clear in the longitudinal wood grain, and on the periphery of the scratches. It also demonstrates the cumulative impact on the central portion of the scratches, where in each of the three scratches loss of detail has clearly occurred. Metric comparison between the pre- and post-treatment timber offered a suggestion of continued surface modification in the areas of the scratches (Figure 18). However, the comparison should be considered in the light of the poor scan registration which is also a consequence of this transformation.

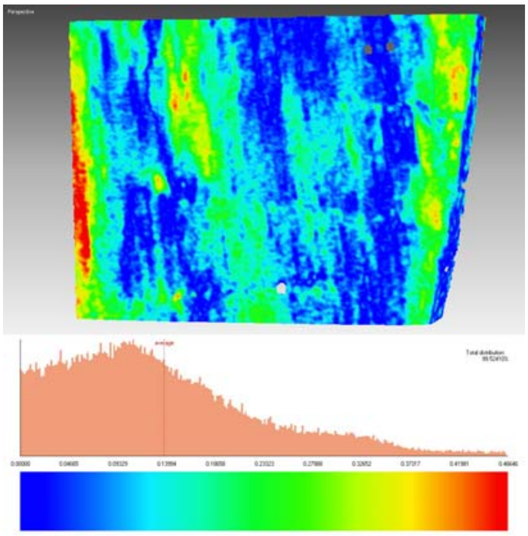

Fig 18: Metric comparison between pre-treatment timber and post-treatment timber

The cross-sections through the laser scan datasets support this appraisal (Figure 19 and 20. The mould demonstrates that edge details are lost and that in some areas it is possible voids were present during the casting process. The cast cross-section illustrates the multiplication of this effect. The post-treatment scan shows a considerable change which confirms the surface appraisal. However, we do not feel able to confirm a quantitative value for the lost volume of wood. Although the cross-sections illustrate a fair match between the datasets the lack of a fixed comparison means that the data will always be dependent on the degree of fit between the pre- and post-treatment scans, and hence is self-referential. The volume lost is also close to the tolerances of the laser scanner used.

Fig 19: Illustration of where cross section analysis (Fig 20) through timber was carried out

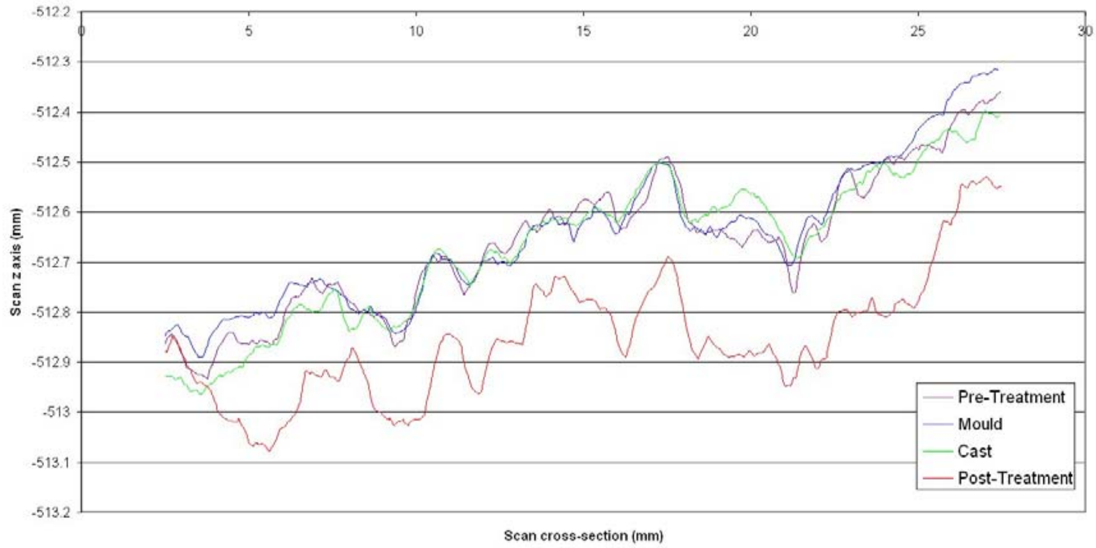

Fig 20: Cross section through the timber illustrates how the post-treatment timber differs from the mould, cast and pre-treatment timber. Note however that although the profile is roughly similar the low quality of match between the pre- and post-conservation scan datasets prohibits direct use of the quantitative values eg difference in volume

Taken together the laser scan datasets support the statistics obtained during the registration of the scans, ie that since the surface morphology remains well preserved in the cast and mould the fit to the pre-treatment data is robust, if not perfect. The post-treatment timber experienced considerably more surface modification and therefore matches significantly worse to the pre-treatment timber. It may therefore be concluded that the statistics from the registration themselves provide the best overall measure of variation between the surfaces with local variation more difficult to quantify.

Whilst the registration of scan datasets is problematic where surfaces are changed the accuracy of recording each surface is extremely high. Visual comparisons between these datasets are therefore easy to undertake. The polynomial texture maps produced are also very easy to analyse visually, supported by the option for additional image processing. Metric comparison of the extracted surface normals is also possible but suffers from the same limitations as the scan dataset. Namely, that registration is dependent upon the similarity of the scan datasets and hence is directly impacted by the modifications to the surfaces seen in this study.

10 DISCUSSION

All traditional recording techniques require some understanding of wood conversion and technology. The graphical techniques will most likely result in a selection or interpretation as the drawing is created. Drawing conventions are a way of bringing conformity into the wide field of personal styles (Clarke *et al* 1993). Close collaboration between archaeologists, wood technologists, conservators and the illustrator are essential. Imaging techniques such as photography, X-radiography, laser scanning and PTM do not make a selection and it depends on the knowledge and the skills of the operator to record important surface details. Laser scanning and PTM also offer the added benefit of an analytical element that allows for measurements or distortion analysis to be undertaken. Moulding is a technique that captures all surface details regardless of their nature and the skills of the operator (provided that mould and cast are produced correctly and to a high standard).

Photography, sketching and hand drawing are the techniques most commonly carried out during field work and at later stages. No special equipment is needed and with some practice good results can be achieved in relatively short time. Archaeological illustration, X-radiography and moulding require slightly more time. These techniques are carried out by personnel trained or qualified in these areas and more specialist equipment is needed.

Laser scanning and PTM are not routinely carried out and their application is often triggered by a research question. However, the low price of capture equipment, relatively simple implementation, and the free availability of the necessary software required for polynomial texture mapping mean that it could rapidly become a regularly employed technique.

Laser scanning and PTM are useful techniques to evaluate the effect of conservation treatment on fine surface details, such as tool marks. The analysis showed that there is some change between the pre-conservation and post-conservation timber. It is however difficult to quantify this change. First, it would appear that the volume lost is close to the tolerance of the laser. Second, comparison of laser scan datasets requires an accurate registration of the scans. As the processes studied themselves distort the surface there is a direct, inverse relationship between the quality of match between the scans and the accuracy of the measured difference between them.

Visual analysis of the scans indicated that the more the process of capturing surface details moves away from the original (which we consider to be the pre-conservation wood), the less accurate the maintenance of fine surface details between processes becomes. So wet wood and silicone mould are fairly similar with a little loss of detail at the edges, the silicone mould and the plaster cast are again fairly similar, with the greatest difference seen between the pre- and post-treatment wood. The loss of fine surface details from pre-conservation wood to plaster cast is a little bigger than the other two, as this is an accumulation of the surface detail loss experienced during the other two stages.

11 CONCLUSION

The pilot study has demonstrated that various recording techniques are available, which can be utilised depending on the nature of an object or the overall project. Each method has its own benefits and shortcomings and an informed decision has to be taken when choosing one recording technique over another. Often a combination of two or more techniques will prove useful.

In order to evaluate the effect of conservation treatment on fine surface details and to establish the accuracy when using moulding and casting techniques, the innovative techniques are more suitable than the traditional ones, as they allow the user to carry out analysis.

The findings support our expectations and reiterate that recording should be carried out on the wet timber. Some surface changes take place during conservation. And even though a detailed study of fine surface details is not impossible after conservation, better results will probably be achieved when examining the wet timber before conservation.

12 FUTURE WORK

An ongoing study by the authors is employing the same techniques to wooden artefacts as part of a reburial study. Although problems of scan registration will continue to be an issue we propose to employ a range of different fitting algorithms and to use these as the primary means of mesh comparison. Given a high sample rate in terms of registration points we believe that more accurate metric comparisons will be possible. As with the head piece it has not been possible to use fixed registration points attached to an armature both on grounds of minimising damage to the samples and also because such an armature would impact the deformation of the artefacts and hence impact on the results. In a future study we propose capturing data on a sample to which fixed points can be applied.

Our available facilities for capturing PTM data have significantly improved since the experimental work described here. Earl was awarded an AHRC grant under the Digital Equipment and Database Enhancement For Impact (DEDEFI) scheme in March 2010 and this will enable far higher resolution PTM data capture, in addition to a range of other benefits[2]. The project will provide free access to capture rig designs and necessary software. Ongoing work in computer science offers significant potential for applications of PTM and related techniques to wood and other artefacts. In particular the metric study will be enhanced by derivation of accurate true three-dimensional data from the PTM (Drew *et al* 2009). An attempt was made during this study to perform a metric comparison of the normals derived from the PTM files. However, slight variation in the orientation of each of the PTM captures meant that the normals were not directly comparable. In the next stage of this work we will use other techniques for precise matching of the various PTM captures, and for post-processing of the normal maps to remove errors introduced by changes in orientation.

[2] Further details are available from: http://www.southampton.ac.uk/archaeology/acrg/acrg_research_DEDEFI.html

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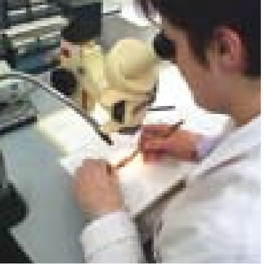
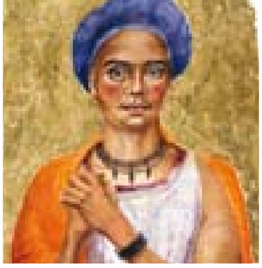



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