POLYNOMIAL TEXTURE MAPPING AND RELATED IMAGING TECHNOLOGIES FOR THE RECORDING, ANALYSIS AND PRESENTATION OF ARCHAEOLOGICAL MATERIALS

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ABSTRACT:

Polynomial Texture Mapping (Malzbender et al., 2000, 2001) uses multiple images to capture the reflectance properties of a given surface. Multiple captures may be combined in order to produce interactive, relit records of the material sampled. Cultural heritage examples of the technology include work on cuneiform tablets, numismatic archives and lithic artefacts. This paper introduces the PTM data capture and processing technologies available for artefact recording, and the perceived archaeological potential of additional methods to supplement the standard PTM datasets. Case studies in the use of PTM include ongoing work on stylus writing tablets, medieval wood, excavated material from the site of Portus (www.portusproject.org) and medieval ceramics. Each of these presents particular challenge for recording, analysis and presentation. The paper also identifies the synergies between PTM, related imaging technologies, photogrammetry and non-contact digitisation through case studies on Libyan rock art and on a Roman polychrome statue. It identifies ongoing challenges and proposed future developments.

INTRODUCTION

Polynomial Texture Mapping (PTM) has since its creation been a technique with clear applications to archaeology and cultural heritage. PTM allows a detailed surface model of an object to be generated from a series of photographs (Malzbender et al., 2000, 2001). A PTM data set is collected by photographing an object from a fixed camera many times using a single light source which is moved by a small iteration between each exposure. The results of this process are then compiled into a single file which can be displayed in a software viewer. The user is able to virtually move the light position as well as extracting other data relating to the reflective properties of the surface.

Reflectance Transformation Imaging (RTI) defines a wide range of approaches to surface characterisation (Mudge et al., 2005). PTM forms only one of a number of these methods for encoding the surface properties of the object recorded (Mudge et al., 2008). Researchers at the Katholieke Universiteit Leuven have developed an alternative approach and viewer (Havemann et al., 2008; Willems et al., 2005). The data produced in the production of RTI data are highly versatile and can be applied in a variety of analyses, either in their completed form or through re-processing of the input photographic datasets (Bartesaghi et al., 2005; Fattal et al., 2007; Mudge et al., 2005; Toler-Franklin et al., 2007).

1. POLYNOMIAL TEXTURE MAPPING AND SURFACE RECORDING

In the last ten years photographic methods for two- and three-dimensional recording have taken considerable steps forward. Photogrammetry and reflection transformation imaging have been used widely in cultural heritage. The following paragraphs will therefore focus on practical issues of implementing a subset of the techniques rather than discussing the methods themselves. Publications identifying and evaluating the methodological aspects from a cultural heritage perspective include Bryan (et al. 2008), Cohen (et al., 2004), Corsini (et al.,

2006), Fryer (et al., 2004), Malzbender (et al. 2001) and Mudge (et al., 2008).

1.1 Polyomial Texture Mapping for artefact recording

A very broad range of archaeological applications of the RTI approach are now available for study. Archaeological data were amongst the first surface forms to be imaged and since then many object and surface type has been trialled (see Earl et al. 2010 for a recent summary). In a small number of cases these trials have gone on to form the basis for extended implementations of the technology. However, the technology continues to remain under-utilised. In this section we will introduce applications of the technique to archaeological data for surface analysis and for provision of a conservation record.

Conservation recording via PTM has taken two forms: first, the capture of surface data for the interactive examination of artefacts pre- and post- conservation and second, quantitative comparisons. In the former case we have employed the technique on surfaces such as waterlogged wood, wall paintings, medieval ceramics and on metal objects such as a bronze ram (Earl et al., 2010). Interactive viewing of surfaces enables very ready identification of damage and also an assessment of the impact of conservation strategies (Figure 1).
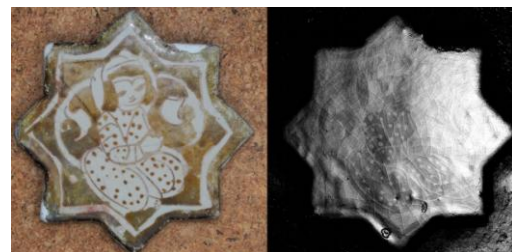

Figure 1: Ceramic (left) showing clear cracking to the surface, identified through specular enhancement (right) of a PTM dataset

Repeated capture enables a clear visual identification of modifications to surface structure and appearance that is easily shared. However, formal analysis of conservation practice may also require quantitative comparison of surface data captures. Two opportunities for this are presented by image based approaches. First, photometric stereo enables the production of three-dimensional datasets which can then be compared using a standard shell deviation approach employed in many reverse-engineering processes. Second, surface normal maps can be compared directly without range data. This approach is seen in the comparison of triangulation scanning and PTM, and between PTM datasets of varying quality described by Dellepiane (et al., 2006).
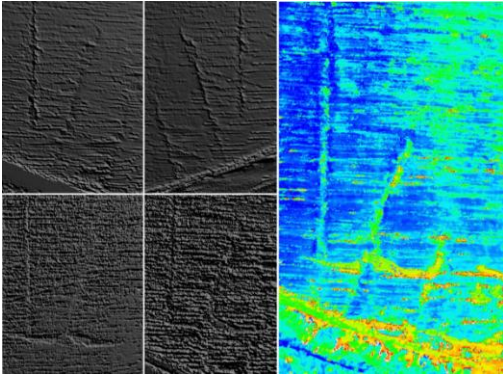

Figure 2: Geometric normal mapping of PTM datasets derived from waterlogged wood at different stages in treatment and analysis (left); initial metric comparison of two normal mapped surfaces (right)

In our ongoing work with English Heritage evaluating the use of triangulation scanning and PTM for recording waterlogged wood we have used the normal map to derive geometric data using a standard computer graphics displacement mapping approach, implemented in 3ds Max 2010. This enables metric comparison (Figure 2). Accurate registration of PTM normal maps is problematic but the comparison methodology was simple to implement.

Applications of PTM have also been successful in the analysis and publication of archaeological surfaces. Our work at the site of Portus (Earl et al., 2008) identified the speed and utility of the technique as a replacement to conventional finds photography for objects such as brick stamps, coins, architectural fragments and inscriptions. The PTM datasets allowed easy sharing of surface data between dispersed project participants, and an interface that enabled relighting of objects for publication at any stage. The value of such data for formal analysis of surface properties has been furthered evidenced in our work with Roman stylus writing tablets (Earl et al 2010; Figure 3).
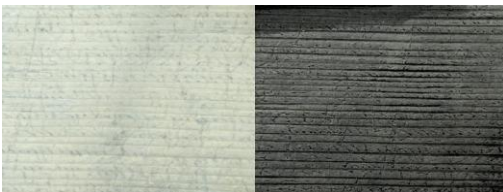

Figure 3: Roman stylus tablet (left) with enhancement of scratched detail in the PTM (right)

1.2 PTM and photogrammetry

In addition to artefact recording we have employed the PTM approach on a range of architectural components and rock art panels. Most recently work on the Oxford University rock art documentation project in Libya, led by Victoria Waldock, used the highlight based RTI technique (Mudge et al., 2006) and photogrammetry alongside conventional rock art recording methods. A PTM file presents a two-dimensional view of a recorded surface, enhanced to provide a visualisation of its three-dimensionality. Although methods for deriving true three-dimensional data from PTM input data are becoming increasingly accurate they are not readily accessible in a cultural heritage context (for one example see Havemann et al., 2008). By comparison photogrammetric techniques producing three-dimensional datasets are widely available to archaeological researchers.

As shown above reflectance transformation techniques enable intuitive enhancement of subtle surface details. In the Libyan study we hoped for similar results for weathered rock art. The main benefit of the PTM image is to recreate different lighting conditions, which is crucial to the location, capture and interpretation of ephemeral rock art. It is vital to visit rock art sites several times in order to appreciate them under given lighting conditions. PTM data were captured of several panels (each varying from c. 1-9m^2) where possible rock art traces might be seen. As the surface of rock was cracked and undulating the results of the PTM approach were highly variable. For example, in Figures 4 and 5 the PTM adds very little to the interpretation of the surface.

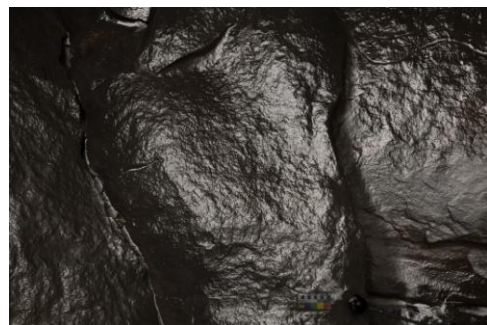Figure 4: PTM of panel viewed under standard lighting

Figure 5: PTM with specular enhancement

Other rock art panels (Figure 6) demonstrated that, even in very bright sunlight, it is possible to capture very high quality images with intricate surface detail (see Mudge et al. 2006 for a detailed explanation of the capture technique). Results across the sample of panels were generally good, even where the morphology of the surface required a very large depth of field. Where possible

PTMs were captured of the panels from multiple angles to ensure the maximum flat area.

Figure 6: 3x2m panel captured under daylight conditions using a studio flash and neutral density filter; inset shows specular enhancement of data

Overall PTM proved a powerful capture tool. It is a straightforward process, it is easy to learn and it is cheap. Depending on setup the average capture time on the field is usually about half an hour. In the desert we experienced that the less equipment and cables you have the better. We found the best field setup was simply a high resolution camera and the light unit. Having a laptop computer for preview and camera control is beneficial indoors, but impractical in sandy and rocky environments.

Photogrammetry has also been used to capture rock art with great success (see for example Bryan et al., 2008; Alshawabkeh et al., 2004; Remondino et al., 2008.). On the Libyan project photogrammetry using ADAM Technology software was employed alongside PTM to provide wider context to the rock art panels. Very often a small rock art fragment deemed to be of most significance is disarticulated from the surrounding, larger panel. The fragment is cropped and viewed out of context. However, the wider panel may itself play a role in the appearance of the detailed area, perhaps through shadowing, and have other spatially significant relationships to it. The ability to place a fragment in the wider context is therefore vital to its interpretation.
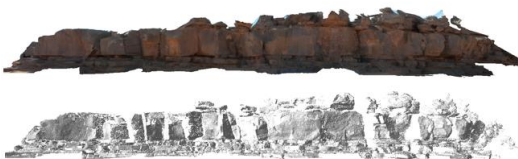

Figure 7: c. 80m rock panel filled with engravings captured using photogrammetry

The two methods complemented each other well. The photogrammetric data provides a rapid capture process for demonstrating to the context of the detailed rock art panels. In addition the availability of photogrammetric software on site enabled the production of dense surface meshes of the detailed panels which could then be matched to the PTM data. PTM provided an excellent interactive tool for exploring rock art panels close up, particularly for very weathered areas. Capturing the two methods in parallel is vital as often the surface properties limit the quality of one or other approach.

Taken together the methods offer more possibilities for subsequent processing. As a visualisation tool PTM datasets are easier to share and the viewers offer more intuitive access to raking light imagery. However, PTM currently lacks the scaling and annotation facilities seen in true three-dimensional viewers. We believe that these should be the focus of future development. In addition the sense of context provided by the photogrammetric data remains disarticulated from interaction with the PTM. An ideal viewer would enable light positions set when viewing photogrammetry to pass simultaneously to a PTM, preferably embedded in context in the same viewer. Below we advance a method for viewing laser scan and photogrammetric data side by side with PTM which offers an interim solution.

2. POLYNOMIAL TEXTURE MAPPING AND COMPUTER GRAPHICS

Reflectance transformation imaging offers useful data to assist in the accurate digital simulation of cultural heritage material. We are currently employing PTM to aid in the construction of physically accurate computer graphic simulations of the disembodied polychrome head of an Amazon statue found at Herculaneum in 2006. This project is focussed on the accurate recording and digital reconstruction and representation of the statue in its hypothesised original context (Beale and Earl in press). As well as being one of the most distinctive visual elements of a statue colour has also proven to be the most transient and subject to alteration (Østergaard, 2008) and therefore capture and reconstruction of surface characteristics are vital .

Several methods have been used in order to accurately record the surface properties of the Amazon head and its original context. Among these have been methods which allow the reproduction of the surface geometry such as laser scanning and also those which allow us to model the subsurface behaviour of light (Happa et al 2009).

2.1 Virtual PTM domes

Of particular interest to this project has been the possibility to use PTM data to provide an indication of the complex reflectance characteristics of archaeological surfaces. Indeed PTM has been the main method for visualisation and comparison of the real and simulated surface properties of the head. Such an approach was first employed in a study of Byzantine art (Mudge et al., 2008; Zányi et al 2007). Recently the advent of customisable computer graphics shaders in renderer software such as Mental Ray has enabled the implementation of experimentally derived surface reflectance data as part of a physically accurate lighting simulation. Whilst PTM data cannot currently be included within a shader the direct comparison of real and simulated surfaces under varying illumination offered by the technique makes for significantly decreased development times.

Computationally expensive computer graphics in archaeology have tended to focus on the replication of the visual appearance of the hypothesised archaeological subject within a physically accurately lit space. The benefits of this kind of approach are well documented (Sundstedt, Chalmers et al., 2004). These are complemented by the incorporation of experimentally derived materials and light. Whilst the former allows a great deal to be said about the hypothetical appearance of an object the latter

allows for variables relating to appearance to be accurately represented and then tested.

If the visual properties of a virtual environment are to allow inductive research to take place (i.e. if the production of simulated imagery is able to meaningfully expand our understanding of the available data and their implications) then it is crucial that the rules governing the behaviour of light and the behaviour of the reflective surfaces within the simulation are physically accurate and that they are fully understood. In the case of the Amazon for example, there would be no sense in attempting to reconstruct pigment and to assess the visual impact of this alteration without first being sure that the underlying simulated marble surface was behaving as it should under given illumination. If we do not have this certainty then subsequent changes to the variables governing the appearance of the statue will cause unpredictable results and any conclusions will lack integrity.

Consequently it is imperative that at the initiation of any process of simulation the results can be validated before hypotheses are tested and variables altered. The method outlined involves the comparison of a simulated virtual environment and a series of PTM data sets. A virtual PTM is generated in a computer graphic environment based upon identical criteria to a corresponding real PTM (Earl et al., 2010). The results should, if the scene is truly physically accurate, be identical. If the two data sets are not identical then it is possible to perform qualitative and quantitative comparisons from any given incident light direction to assess the level of difference, the likely cause, and its impact on the integrity of the virtual scene.

Our workflow begins with assembly of the necessary data to construct a physically accurate scene. This may include high resolution laser or structured light scanning or photogrammetry, capture of the surface bi-directional reflectance distribution function (BRDF; Mueller et al., 2004), sub-surface scattering and colorimetry. These data are incorporated into a single graphic environment such as 3ds Max 2010.

Second, a series of PTMs are captured around the object. This can use either a fixed rig or a highlight based approach. An animated virtual dome is created for each PTM. A script uses the PTM Light Position (LP) file, the distance between the camera and subject, and the relevant photographic EXIF data to automate this process.

Third, the virtual PTMs are located in the correct spatial orientation to the geometric model of the object (Figure 8). Several methods have been devised to achieve this. The most laborious uses a fixed scanning platform with reference markers. The markers enable registration of a fixed PTM rig as part of the scan registration process. An alternative applicable both to fixed rig and highlight methods is to use image based techniques for providing a series of camera locations. Dellepiane (et al., 2006) describes matching a PTM to surface geometry using both image-image and image-geometry correspondences (Franken et al., 2005). As we were restricted to a standard range of software we used the 3ds Max 2010 Camera Match facility to provide a location for each PTM. An alternative where 3ds Max is not available is to define an ideally illuminated snapshot image for each PTM, and then derive a series of correspondence points to the geometry photogrammetrically. Finally this cage of points can be registered to the high resolution geometry.
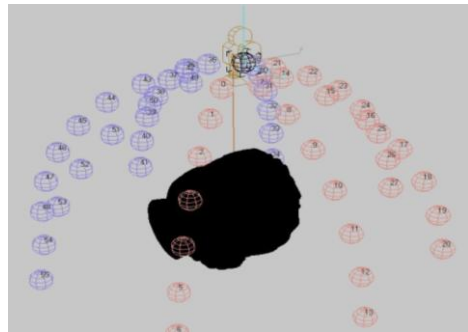

Figure 8: One of the virtual PTM domes set up over the scanned Amazon in 3ds Max 2010

Having spatially orientated the virtual PTM domes the animation is run to produce a separate frame for each light position. These are then assembled into a series of PTMs (Figure 9). The real and virtual PTM are displayed side by side in a modified Java PTM viewer. This enables the lighting direction to be changed simultaneously in both PTM files. Visual and more formal quantitative comparisons may then be conducted between the two datasets.

Figure 9: Comparison of real and virtual PTMs

3. CONCLUSIONS

The combination of Polynomial Texture Mapping and other reflectance transformation techniques with photogrammetry and non-contact digitising provides for a robust suite of capture, monitoring and interpretation tools. Integration of the outputs of these methods remains complex for cultural heritage professionals and further development is required to produce robust workflows. However, the value of these integrated results is clear. Approaches to the simulation of cultural heritage materials benefit from the ability to relight both the simulated material and the captured original, and to derive metric comparisons of properties such as colour, luminance and texture.

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