A new imaging technique is relatively easy and cheap to operate, yet has enormous possibilities in archaeology. Thomas Goskar and Graeme Earl explain

Polynomial texture mapping for archaeologists

Above: Wessex Archaeology's prototype illumination dome for the automated capture of polynomial texture maps (PTMs)

Right: A basic mapping example of a Henry V gold noble found by Time Team at Codnor Castle in 2007. L–R from top: Photograph under office lighting, PTM illuminated by two virtual lights, specular highlights, 3D surface normals (normals facing in similar directions are similarly coloured)

When we study objects, it is easy to take for granted the factors that reveal subtle details such as colour, texture, undulations or inscriptions. Look at a worn coin in daylight or office lighting, and it may be hard to read the legend or discern the portrait. Hold the coin under a strong directional light, and these details may be clearer. How light is structured determines what we see.

A new technology called polynomial texture mapping (PTM) can help archaeologists see fine surface details. Imagine being able to change how a photo of an artefact is lit, adding a second, very low angled light or circling light around the object. This is what PTM allows us to do, and much more, using directional light sources and conventional digital photography. It can help inform conservators, read engraved writing, confirm coin inscriptions, enhance rock art and even learn about colour and pigmentation.

What it is

Polynomial texture mapping was developed at Hewlett Packard Labs in 2000. It is part of a family of technologies known as reflectance transformation imaging (RTI). PTM was designed to provide more realistic "texture maps" for use with computer-generated 3D pictures. These maps are photographic elements, such as a section of brick wall, that can be repeated indefinitely to cover a 3D surface. To the careful eye such textures rarely look right. This is often down to the light – the photograph for the texture was superimposed in the computer onto an object with completely different lighting.

By capturing a series of photographs, each lit from a different direction, and combining them into a special type of single image (a polynomial texture map, or PTM again), you are one step nearer a higher level of realism in 3D imagery. The virtual object which has a PTM applied to it will look realistic, wherever your light source. Hollywood blockbusters often use these techniques to match live action with computer generated scenery.

It was quickly realised that this approach could benefit the heritage sector, and that complex computer graphic tools were not needed to take advantage of it. In 2001 it was shown that PTM could reveal the pictures and cuneiform on a 2000BC neo-Sumerian tablet better than standard photos. It has since been applied to artefacts from small coins to large architectural fragments. In addition to capturing the appearance of an object under varying lighting conditions, the technique enables the surface geometry to be recorded and measured. These data are presented in the form of "surface normal maps" – a record of the direction in which each pixel faces encoded in the red, green and blue of an image of the object.

How it's done

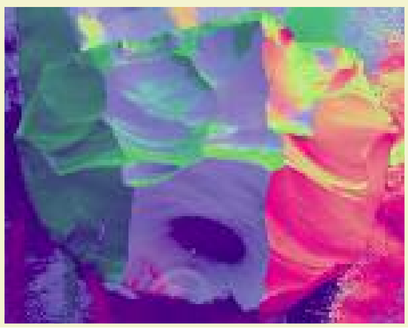
A PTM can be very easy to create. In its simplest form, you take a sequence of photographs of an object from above, in a dark room. The camera is fixed, but in each photograph you light the object from a different direction. Either a mechanical rig can be constructed that switches lights on and off in turn, or a light source such as a camera flash can be moved from position to position. If you move the light, you need a shiny red or black ball in view so that the reflection (specular highlight) may be seen in each photo, and the light's direction calculated. Keeping the light a fixed distance from the centre of the object ensures an even intensity. Working around the subject from very low angles to almost overhead (minding out for the camera) there will be photos for every light position, forming a "dome" of lights. Simple results can be taken with just 24 photos (and evenly spaced lighting angles) but the more the better. Software available from HP Labs (free for non-commercial applications) can be used to generate the PTM from the photos and to view it.

The University of Southampton has constructed a robotic rig for capturing PTM data. This enables rapid capture of PTMs with a varying configuration of lights, using bespoke software written by staff in the School of Electronics and Computer Science. Similarly, Wessex Archaeology has constructed an illumination dome for rapid capture of PTM data. It consists of an acrylic hemisphere with 48 evenly spaced ultra-bright LEDs (which produce very little heat). These are connected to a programmable controller which is in turn connected to a camera to synchronise the lights with the camera shutter.

Staff and students in the Archaeological Computing Research Group at Southampton have applied the PTM technique to a growing range of archaeological material. Currently they are working on the use of the technique to monitor conservation of waterlogged wood and ceramics from various sites in the UK, corroded metal recovered through underwater archaeology, rock art in Scotland and Libya, wall plaster from Çatalhöyük in Turkey, and writing tablets and wall paintings from Herculaneum in Italy. The technique has also been used on a daily basis as part of the AHRC Portus Project, which is focussed on the excavation and survey of the port of imperial Rome. Here PTM has been used to record wood, brick stamps, bone, inscriptions and even excavated contexts and architectural fragments. Other groups are using the technique on a growing range of materials, including cuneiform collections, coins, handaxes, rock art and even the 100BC Antikythera astronomical mechanism. The US-based Cultural Heritage Imaging has led the application of these techniques.

Flint Core

This experimental core made by Phil Harding was the subject of Goskar's first attempt at capturing a PTM. With a camera positioned above the core on a tripod, a red ball from a local toyshop was placed next to it to be in the camera's frame. Using a battery-powered floodlight, a series of photos was taken: eight lit horizontally with the light sources about 45 degrees from each other; eight lit at approximately 30 degrees from the surface; and eight lit at about 60 degrees. A piece of string ensured that the light was roughly the same distance from the centre of the frame for each shot. The photos were digitally processed and converted into a PTM on a laptop shortly afterwards. Despite this rather crude-sounding method, and the relatively few photos, the result is very useful (below right). The faces, edges between them, conchoidal fracture rings and scratches are all clearly visible, and can be interactively visualised in different ways to enhance different features. Successfully conveying the details of a flint artefact through a drawing is a notoriously difficult and laborious task, while standard photos can convey only a general impression. PTM has great potential for lithics specialists and enthusiasts, as image capture can be relatively simple, and easily distributed via the internet



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What it offers

Capture of a PTM can be beneficial for an object in many ways, especially for offering improved access for remote study. Fragile objects can be repeatedly examined thoroughly through the visualisation techniques available with the PTM software, including 3D expression, minimising the need to handle the original. PTM files can be made available via the web, allowing detailed study of objects globally. If the photographs are of a high resolution and well taken, a PTM can even produce more detailed surface data than models produced by most 3D laser scanners – and can be considerably quicker and cheaper.

As well as benefits for remote access, PTM has great potential for enhancing

Above: Graeme Earl capturing a PTM of a painted Amazon head recovered in conservation work at Herculaneum in 2006

detail in objects even when they can be handled or seen in a museum display. By extrapolating lighting positions, extremely low angles of grazing light can be used to accentuate subtle details in relief. The newest implementation of the technology even allows PTMs to be produced interactively, using a high speed video camera. An object such as a handaxe can be held in the field of view and the lighting varied whilst the object is moved. Initial trials of this technique suggest that it provides very effective imaging of archaeological artefacts.

The PTM approach could be employed to enhance museum displays or in galleries. An online exhibition hosted by Tate in partnership with the National Gallery has demonstrated the value of the technique for visualising surface detail in paintings.

The ability to virtually relight an object is very compelling, and need not be restricted to photographs of real objects. PTMs can also be made from existing 3D data (as collected by laser scanners and lidar) by building a virtual illumination dome in software. This enables intuitive, easy to share representations of surface detail. As viewer software is enhanced it will become possible to extract precise information from the visualisations, such as measures of surface curvature or position. The software can even be used to provide interactive views that have nothing to do with surface texture. For example, a series of photographs of an object can be taken with different focal lengths, and the resultant PTM will allow these to be varied within the one image.

Polynomial texture mapping is already a proven tool amongst the small but growing group of archaeologists and heritage professionals experimenting with the technology. We hope that more people will adopt these techniques and apply them widely, from the lab to the field. Students from the University of Southampton have been using PTM outside to record rock art at Torbhlaren, Argyll and Ben Lawers, Perth and Kinross. The PTMs provide a record that allows subtle surface details to be assessed, including at different times of the day and year. PTM (alongside x-ray tomography) helped to increase the number of readable characters on the Antikythera mechanism from 800 to over 2,000. Metalwork conservators are interested in using PTM to record objects before and after conservation (as well as informing it), and the technology has also been trialled by Southampton and the Portable Antiquities Scheme as a means for documenting artefacts. The archaeological potential is huge.

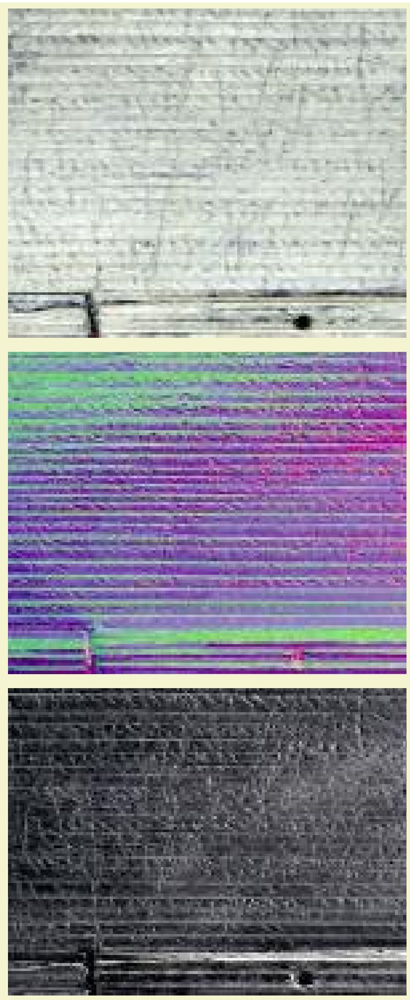
What makes this an even more compelling technology is that it is accessible. To begin experimenting with it, only existing photographic equipment and some free software is needed. Everyone can try it. We look forward to seeing what happens and welcome ideas for new implementations and developments.

Guides and examples can be found on the websites of Cultural Heritage Imaging (c-h-i.org), Archaeological Computing Research Group, with interactive PTMs (www.southampton.ac.uk/archaeology/acrg/acrg_research_PTM.html), Hewlett Packard, with access to software (hpl.hp.com/research/ptm) and Wessex Archaeology (wessexarch.co.uk/computing/ptm). Thomas Goskar is web manager at Wessex Archaeology. Graeme Earl is lecturer at the Archaeological Computing Research Group, University of Southampton and is codirector of the Portus Project, an excavation and survey of the imperial port of Rome

Vindolanda tablets

The Archaeological Computing Research Group (ACRG) at the University of Southampton has been working in partnership with the Oxford Centre for the Study of Ancient Documents (CSAD) in the recording and analysis of the inscribed Roman tablets from Vindolanda. The Southampton PTM rig was used to record some 200 of these tablets held at the British Museum. Many of them have poorly-preserved scratched detail in the wood that has previously been impossible to read. The initial PTM results suggest that new legible text fragments will be revealed.

The Southampton and Oxford teams hope to update the technology soon to enable interactive analysis of the tablets in real time, and also increasingly high-resolution data acquisition – both of the Vindolanda pieces and of other vitally important ancient documentary artefacts such as cuneiform tablets. The images show a detail of a Vindolanda tablet photographed under flat lighting (top), the surface normals extracted from PTM (centre) and an angled PTM view (bottom)



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