

DIGITAL TECHNIQUES FOR DOCUMENTING AND PRESERVING CULTURAL HERITAGE

Edited by **ANNA BENTKOWSKA-KAFEL**
and **LINDSAY MacDONALD**



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COLLECTION DEVELOPMENT, CULTURAL HERITAGE, AND DIGITAL HUMANITIES

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REFLECTANCE TRANSFORMATION IMAGING

LINDSAY MACDONALD

COSCH Case Studies that have employed this technology: Roman coins, Germolles (H-RTI)

Definition

Reflectance Transformation Imaging (RTI) is a family of methods for modelling the distribution of light reflected from an object surface as functions of space, angle, spectrum, and time. One instance is the Polynomial Texture Mapping (PTM) technique, which enables the visualization of relief surfaces under a variable lighting direction.

Description

Malzbender et al. (2001) introduced PTM as a novel image-based relighting technique, which takes a set of digital images of an object, all captured from a fixed camera position, each lit by a point source at a different but known coordinate position. Malzbender designed and built the original apparatus at HP Labs, Palo Alto, California, from an acrylic hemisphere of diameter 18 inches (45 cm) with twenty-four flash lights. He demonstrated the power of the PTM technique for the visual representation of objects with surface relief, such as fossils and inscribed clay tablets.

The PTM algorithm fits a biquadratic function (two-dimensional parabola with six parameters) to the set of intensities at each pixel location. The interactive viewer software then uses the cursor position, representing the geometric coordinates of a virtual light source, to generate the intensity of each pixel as if it had been illuminated from that direction. A separate set of six coefficients is fitted to the image data for each pixel and stored as a spatial map, which has the same spatial resolution as each of the original n images, but has a low resolution in the angular space of the incident illumination, because the n directions of the

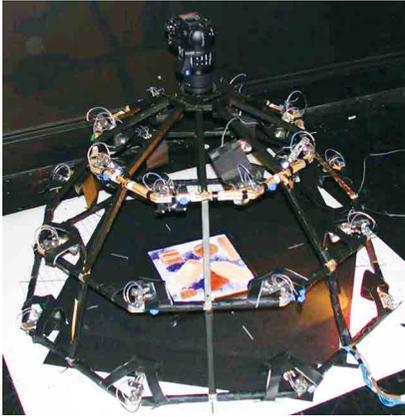


Figure 20.1.
Left: experimental apparatus for PTM at the National Gallery (London) with twenty-four tungsten spotlights mounted on a rigid framework. Below: surface relief of a painted test panel, lit from the top right. © Joseph Padfield, National Gallery, London.



image set are approximated by only six coefficients at each pixel. An improved set of basis functions, known as hemispherical harmonics (HSH), was introduced by Gautron et al. (2004), which gives a better estimation of intensity as a function of angle, at the expense of additional parameters. The interactive control of lighting direction in the viewer software facilitates perception of the surface structure compared to static photographs, thereby enhancing the legibility of surface relief and inscriptions. The visual effect is of a virtual torch moving over a static 3D object surface, although there is no inherent 3D geometry.

Key to the broader adoption of RTI has been the development of Highlight-RTI, in which a glossy sphere is placed in the scene so that the direction of the incident illumination can later be inferred from the coordinates of the highlight in each image. The H-RTI method was introduced by Mudge et al. (2006) for on-site imaging of rock art. The feature is that the illumination source, such as a flash or spotlight, can be moved freely to any position above the surface for each image,

with no predetermined constraints and also no specific recording of its position. H-RTI obviates the need for a dome system, and enables the photography to be done *in situ*. Such a technique is essential for field work where the objects are so large or impossible to move that there is no alternative but to do the imaging on site, such as monuments, caves, and excavations. A good review of applications in archaeology is given by Earl et al. (2010), and a guide to good practice may be found in Duffy (2013).

All methods of PTM and RTI capture rely on knowledge of the light positions used to illuminate the object. For a dome system this is determined by the physical placement of the lights. Alternatively a template might be used to determine the exact positions of one or more movable lights in predetermined locations. An equivalent would be to employ a robot arm to position a lamp successively at pre-programmed locations. Equipment with fixed lighting positions has many advantages, including speed of acquisition, accuracy, and repeatability. But it also has limitations, in particular the maximum object size, cost, portability, and difficulty of adapting to the site topography.

PTM and RTI have found favour with the cultural heritage community because they provide a convenient and attractive way to visualize artefacts and simulate the three-dimensional effect. The interactive control of lighting direction in the viewer software facilitates perception of the surface structure compared to static 2D photographs, thereby enhancing the legibility of relief and inscriptions. The set of images affords a richer representation of the object surface than a single image and could therefore be considered as a new data type for the documentation of collections of cultural heritage objects.

Significant Applications

Example 1: Painting Texture, The National Gallery, London

PTM was applied in 2004 at the National Gallery in London to investigate the surface structure of paintings by Frans Hals, Jules-Louis Dupré, and Georges Seurat. Twenty-four tungsten lamps were mounted onto an open framework in three tiers of eight lamps each (fig. 20.1, left). The camera was mounted at the top of the framework, pointing down at the painting on the floor. The lamps were turned on and off manually for each image in the sequence to be captured. With the variable “virtual light” in the PTM viewer more features were visible than could be seen by raking light from one direction alone, enabling the study of surface features in the painting such as impasto (fig. 20.1, right) and also the effects of ageing, such as craquelure and distortion of the support. Comparing PTM renderings made before and after physical handling of the painting facilitated examination of alterations in its texture and shape (Padfield et al. 2005).

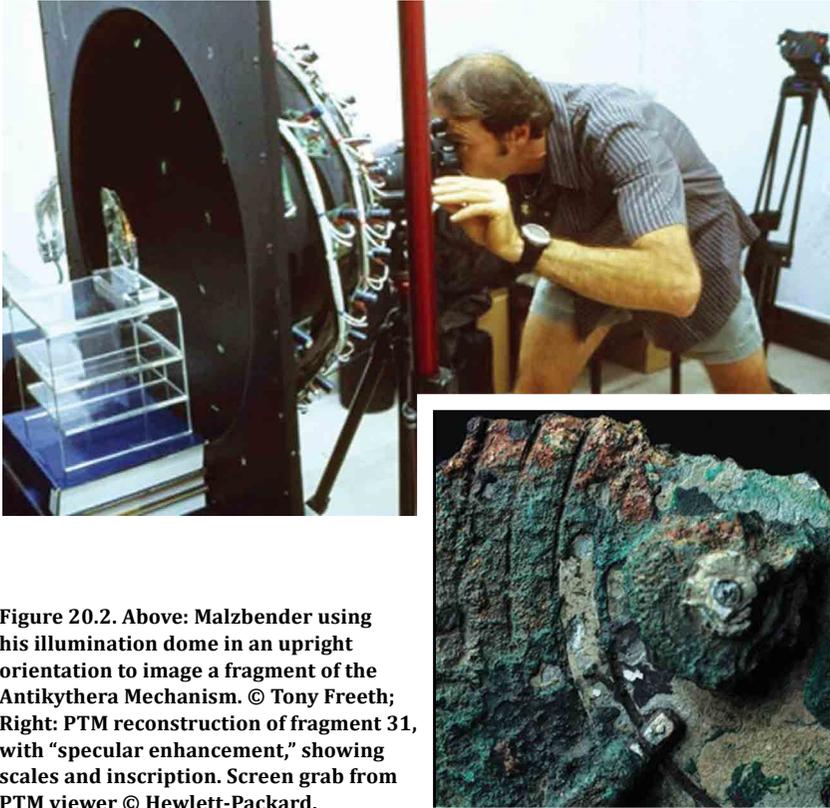


Figure 20.2. Above: Malzbender using his illumination dome in an upright orientation to image a fragment of the Antikythera Mechanism. © Tony Freeth; Right: PTM reconstruction of fragment 31, with “specular enhancement,” showing scales and inscription. Screen grab from PTM viewer © Hewlett-Packard.

Example 2: Inscriptions on Antikythera Mechanism, National Archaeological Museum, Athens

In a famous investigation in 2005, PTM was used to acquire image sets of the fragments of the Antikythera Mechanism at the laboratories of the National Archaeological Museum in Athens. Named after its place of discovery in 1901 in a Roman shipwreck, the Antikythera Mechanism was constructed ca. 200 BC but is technically more complex than any known device for at least a millennium afterwards and indications are that Archimedes was involved in its design. Because the fragile fragments could not be taken out of the museum, the PTM dome was taken there and used in a vertical orientation in front of the camera on a tripod (fig. 20.2, left). Samples were carefully positioned on holders to enable the imaging to be done without any physical contact. The resulting eight-two image sets have been used for analysis of the inscriptions (fig. 20.2, right), enabling a better understanding of the structure and function of the mechanism (Freeth et al. 2006).

Example 3: Prehistoric Rock Art at Roughting Linn, Northumberland

Sarah Duffy in 2009 used RTI in a daytime survey of rock art at Roughting Linn, which is considered the largest decorated rock in northern England, originated in the Neolithic and Early Bronze Age. The H-RTI capture method was used with a Canon 22mpx EOS-1Ds Mark III camera and wireless remote-controlled flash, Manfrotto tripod, two black snooker balls, scale ruler, and 18 per cent grey card. One person operated the camera by remote control, while the other held the flash to illuminate the rock surface. A piece of string was mounted on a thin piece of PVC pipe so that the person positioning the light source was able to hold both the flash and the end of the string. Logistical challenges included daytime lighting, windy conditions, and the relatively remote location of the site. To lessen the effects of the daylight, filters were fitted to the camera lens. Additionally, weights were added to the tripod to offset the wind and to stabilize the camera during photography. There was no access to mains electricity, so all the equipment was self-powered and kept properly charged. Multiple PTMs were generated from the data sets gathered through the fieldwork, and were incorporated into the English Heritage site documentation. The PTMs provide additional interpretive insights, with the potential to answer questions about relative chronology, tooling techniques and instruments, and the stylistic programme.

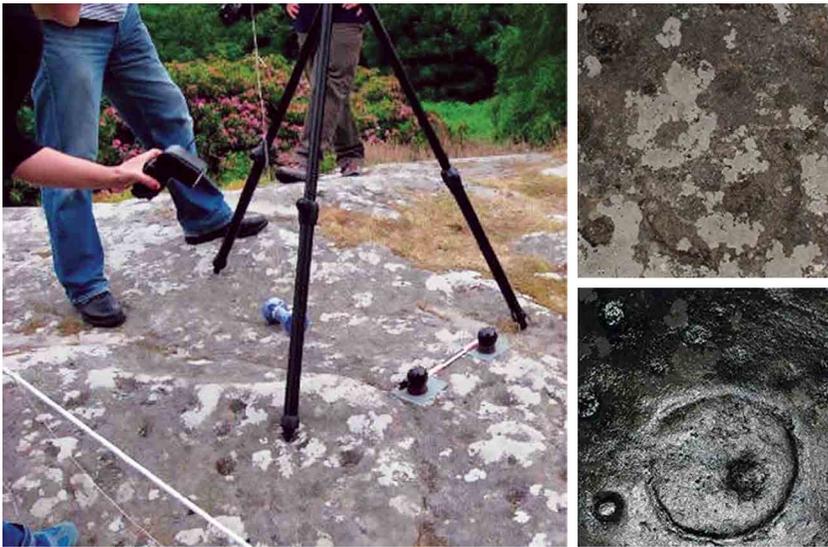


Figure 20.3. Left: on-site photographic recording in process at Roughting Linn.

Top right: traditional static photograph of carving.

Bottom right: screenshot of PTM viewed with specular enhancement. © Sarah M Duffy.

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* Essential texts