New applications of photogrammetry and reflectance transformation imaging to an Easter Island statue

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New methods of visualisation offer the potential for a more detailed record of archaeological objects and the ability to create virtual 3D models that can be made widely available online. Here, two different techniques are applied to the impressive Easter Island statue on display in the Wellcome Gallery at the British Museum. Of particular importance are the details revealed of the petroglyphs that decorate its surface.

Keywords: Easter Island, British Museum, Hoa Hakananai'a, photogrammetry, reflectance transformation imaging, birdman ceremony

Introduction

Hoa Hakananai'a, a fine Easter Island statue now prominently displayed in the British Museum, is well known to the public. How it reached London in 1869 has been described by Jo Anne Van Tilburg (1992, 2006), along with details of its shape and its unusual petroglyphs. Although the site from which it was taken is known (Routledge 1920), this has not been archaeologically examined in modern times.

The petroglyphs on the back of Hoa Hakananai'a were added after the statue was carved. These were largely concealed from public view until the statue was moved into the British Museum's new Great Court in 2000, and then to its present site in the Wellcome Gallery. They had attracted further recent attention, but details remained difficult to decipher (Horley & Lee 2008; Davletshin 2012). A virtual model of the statue, using a 3D laser scan conducted by Z+F UK, had been described, but remains unpublished in detail (Van Tilburg 2007; Van Tilburg & Pakarati 2012). It seemed clear that a new digital survey of the statue, which could be made freely available, would be of value to specialists and to an interested public, not least on Rapa Nui (Easter Island). Such a survey might reveal details hitherto obscure or unremarked that could throw light on both the statue and the wider field of Easter Island rock art and ritual.

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Methodology

We conducted the survey after public opening hours in February 2012, focusing particularly on the surface detail of the petroglyphs (Pitts 2012; Miles *et al.* 2013). We considered several methodologies, including laser scanning, photogrammetry and reflectance transformation imaging (RTI). A number of issues affected the choice. The first was access. With only two evening sessions, we needed a capturing system that would allow enough detail to be recorded in a short time. Another was lighting: different techniques require differing amounts of light, so we needed to control illumination. The statue stands around 2.5m high on top of a 1.3m-high plinth, so its size was also a consideration. The available triangulation laser was heavy, required direct power and would be hard to reposition when scanning the top of the statue; furthermore, we did not wish to duplicate the 2006 laser survey noted above. We decided that a full working photogrammetry model, and a set of RTI images, would together meet the needs of our projected analysis.

Photogrammetry modelling begins with a series of photographs taken from varying angles. Common features are matched within overlapping photographs, relevant depths are extracted and a virtual 3D model is created. We used this for Hoa Hakananai'a because of the ease of capture, encouraged by work completed by Heinz (2002), Ioannidis and Tsakiri (2003), Chandler and Fryer (2005) and Jazayeri *et al.* (2010), who all deal with artefacts of comparable size, detail and type. The method offers a quick capturing process that could be done within a few hours.

This work took one of our allotted two nights at the British Museum. In total, we captured 500 images using both a Nikon D3X DSLR (*Nikon* n.d. a) and a Nikon D7000 DSLR (*Nikon* n.d. b). Although not all of the photographs were used in the virtual model, it was essential to take as many as possible since it was unlikely we would be able to return in the foreseeable future. We were thus able to create a full photographic record of the statue, from which we could select images for immediate use.

Reflectance transformation imaging

Reflectance transformation imaging (RTI) offers a two-and-a-half dimensional representation of surface detail. The method has been used in a number of cultural heritage investigations. Earl *et al.* (2010b) give an overview of the technique; Mudge *et al.* (2006), Duffy (2010) and Earl *et al.* (2010a) give specific rock art related examples; and Dellepiane *et al.* (2006) compare objects of similar size to Hoa Hakananai'a.

The process is simple, requiring a fixed camera and object, a flash or light that can be moved for each image, and a small, fixed shiny ball to record the light's direction as it changes (*Archaeological Computing Research Group* n.d.; *Cultural Heritage Imaging* n.d. a). The method of capturing and processing is straightforward, but it is important to note that to create the two-and-a-half dimensional representation, the software has to calculate the location of the light source in every image. To do this, it needs photographs that have been taken from the same position and at the same pixel resolution. Movement is a common feature during data collection, and there are methods to resolve the resulting problems (Miles 2013a), but ideally it is better to capture the images without moving the camera, the

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object or the shiny ball. Once the separate light paths are established, the viewing software can combine the images and represent the extra 'half dimension' of the two-dimensional photographs with a virtual light movement that shows shadows and highlights.

We could have recorded the whole of Hoa Hakananai'a's front and back in two separate RTI files, but we decided to split the back area into key sections. There were two reasons for this. To collect the RTI dataset, the light source needs to be at a distance of around three times the diagonal measurement between the object's corners—the larger the object in view, the further away the light must be. To capture the entire statue within one dataset would have been impossible, as other museum displays would have interfered with the placing of the light source.

The other issue was image resolution. A single dataset offered a resolution of 24 megapixels (mpx), determined by the camera. It was felt that important small details would not be clear enough if the whole of the back was contained within a single image set. Splitting the back into zones would allow finer analysis, with each one represented at 24mpx.

Thus we captured five separate RTIs, one of part of the front and four of the back. For this we used a Nikon D3X camera (*Nikon* n.d. a), and light from a Nikon SB-910 speedlight (*Nikon* n.d. c). Wireless triggers avoided camera movement; we used a length of string to position the flash, ensuring an even distribution of light at a constant distance. The number of images captured for each dataset ranged from 57 to 87. Each dataset was processed individually to create a working RTI, with camera distortion and colour corrected, and then checked by eye to see if any movement had occurred.

To process and view the RTI datasets, we used open source software produced by Cultural Heritage Imaging (n.d. b). This offers a straightforward step-by-step method. After opening, the images are processed to find the shiny ball and their subsequent highlights from the different lights used. A light position file is then created from the dataset: the software is able to determine the origin of the light in each image, and calculate the reflectance of each pixel. From this the images are merged into a single file that allows a virtual light to be moved, adding an extra half dimension to a two-dimensional dataset. Lighting can be placed in any position required, and the software offers a number of different rendering modes that enable detailed study of the statue.

Photogrammetry

Agisoft PhotoScan software allowed us to create a working photogrammetry model of the statue through a series of stages (*Agisoft PhotoScan* n.d). Photos were imported and masks drawn around the object, to focus the algorithmic process on specific parts of the images. This masking was important, as a lot of irrelevant data were captured around the statue, which would increase the time taken to produce a working model as the software tried to analyse and stitch everything in the background (Figure 1). Once the masks had been drawn, the software identified overlapping features and created a series of points in association with photographs from which a meshed model could be produced (Figure 2). The completed model, fully textured, was exported as an OBJ file and opened in MeshLab for analysis (*MeshLab* n.d).

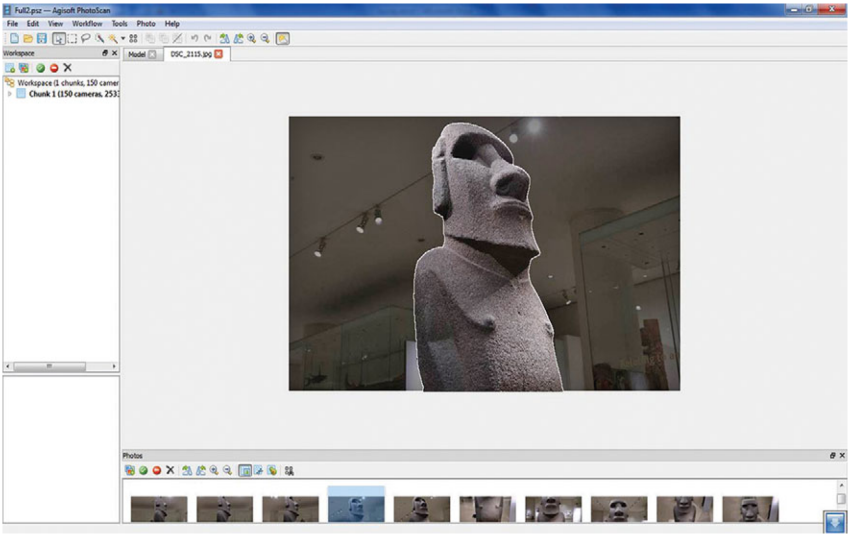

Figure 1. An example of the masking process in Agisoft PhotoScan, removing background data captured within the photogrammetry shots.

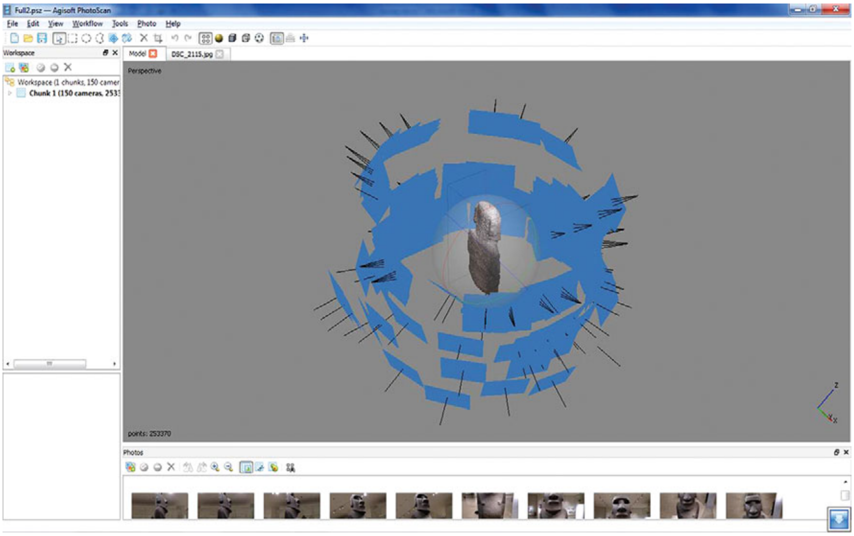

Figure 2. Fully stitched point cloud identifying photogrammetry camera locations within Agisoft PhotoScan.

Discussion

It is important to note the difficulties that we encountered. Firstly, capturing the images was complicated by the statue's size. Scaffolding was needed to create an even coverage of photographs for the photogrammetry model (Figure 3). For each angle, the scaffolding (kindly provided by the British Museum) had to be moved, taking up valuable time. We also used the scaffolding in the RTI capturing process, to raise the camera in line with the back of the head (Figure 4) in order to create a flat horizontal alignment. The problem here

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Figure 3. Photogrammetry capture, using scaffolding to access sufficient angles to produce a workable model.

was that the scaffolding offered limited positions for placing a camera tripod, and we had to move it as far back as possible. This in turn led to another RTI problem, namely camera focus. With the camera on the scaffolding, it had to be focused in position with one member having to climb up and down between datasets, occasionally causing the camera to move slightly, leading to a series of out-of-focus shots. This again added to the time taken, as the images could be viewed only once each dataset was captured.

Problems also occurred during data processing. All of the images were suitable, so it was hard to decide which to use and which to omit for the photogrammetry model. We tried over 400 images in our first attempt, which took over 300 hours to process using a 32GB RAM computer with Intel I7 processor. The results were very poor: there were too many photographs to align. The software tried to align certain images that did not match, and the ambient light affected the surface detail within the photographs, preventing the software from correctly seeing overlapping features. In a second attempt we used 150 images, carefully selected to show a range of wide and close-up views. The processing time was a lot shorter, and the results were far more accurate and pleasing. There were still errors in the statue's eyes, due to the shadowing caused by the ambient light; these errors could be resolved if needed through post-processing or further masking around the eyes. Compared to the RTI datasets, which had no errors in processing, this technique took far more time to produce reliable results: drawing masks around each image is slow, and the processing time is dependent on the computer's CPU and RAM capabilities.

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Results

Previous studies of the statue and its petroglyphs employed conventional observation, aided by photos and drawings (Van Tilburg 1992, 2006; Horley & Lee 2008; Davletshin 2012). Despite many difficulties with our survey of Hoa Hakananai'a, it offers a significant advance on available imaging. The new images allow for the manipulation of a virtual light on a three dimensional model in photogrammetry and in two and a half dimensions within the RTI. We have used both methods together to analyse the statue's surface detail by comparing results seen within the RTI datasets to the three dimensional model. This allows for a unique examination, revealing subtle differences that cannot be seen with the naked eye—in overview in the photogrammetry data (Figure 5), and in specific detail in the RTI images (Figure 6). As the data are based directly and purely on images, the original dataset and the photogrammetry model can be reanalysed when key features are found, allowing for the identification of differences in depths of possible engravings within the three dimensional model. Likewise the photogrammetry record can be enhanced in certain areas as desired, by adding high-detailed existing photographs or ones that can be taken in the future including the rendered RTI images.

Figure 4. RTI capture, with the camera fixed on scaffolding just out of shot to left; light is delivered by moveable remote flash, set at a constant distance from the statue determined by a length of string.

Combined, these methods have given new insights into Hoa Hakananai'a as it was originally carved, and the way the petroglyphs were engraved. These insights are significant, not least because the hard grey flow lava (unusual for an Easter Island statue, which would more typically be shaped from softer, badly weathering tuff) has preserved the worked surfaces extremely well. There is not space here to describe our full analysis, which will be published in detail elsewhere (Pitts *et al.* in press). However, with the proviso that the arguments to support this analysis cannot be presented here, it seems worth outlining our key conclusions.

First, we believe Hoa Hakananai'a was made from the start with a tapering base, as suggested by details of surface topography and condition at the lower extremity of the visible statue (the tip is hidden within the plinth). In the absence of any evidence to the contrary, it must then be assumed that it had stood only where it was found in 1868, supported in a hole in the ground. Most Easter Island statues were carved with flat bases,

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Figure 5. Snapshots from photogrammetry model of Hoa Hakananai'a.

Figure 6. Examples of an analysed RTI dataset of Hoa Hakananai'a (lower back), rendered in natural colours and with specular enhancement; textures, colours, and light direction and intensity can be varied.

and were balanced on stone platforms or *ahu* (Van Tilburg 2006: 10). In the past it has been assumed that Hoa Hakananai'a had been moved from such a platform, when its presumed original flat base would have been trimmed (Routledge 1920: 436; Van Tilburg 2006: 44).

Hoa Hakananai'a's head has a noticeably smooth, flat top, a feature elsewhere ascribed to the need to support a stone 'hat' or *pukau* (Van Tilburg 2006: 30). If this statue was carved for only one site, the implication would be that it was designed to have such a 'hat' at that site. Katherine Routledge (1920: 436 & pl. X.2) recorded a circular, flat stone nearby, of unknown thickness, of "hard basalt". She considered it had been re-used in a wall built after

Figure 7. The photogrammetric model shows a komari *symbol whose curved top runs onto the flat of the head (left); a second symbol (right) was partly removed by later carving of a paddle head, and the lower parts of both may have been truncated.*

the statue was raised, but had been made as a base on which Hoa Hakananai'a originally stood. Another possible explanation is that this was Hoa Hakananai'a's *pukau*. As the statue now stands (in a plinth fitted soon after its acquisition by the British Museum), seen from the front the top slopes a little to the left. Rotating images so that this top becomes horizontal gives the statue as a whole a more balanced appearance.

The nature of petroglyphs on the back at the top of the head had proved elusive (for example, compare quite different renditions by Van Tilburg (2006: image 60) and Horley & Lee (2008: fig. 4)). In our digital images these resolve clearly into two large *komari* (classic Rapa Nui symbols for female genitalia), preceding the other petroglyphs and partly removed by them (Figure 7). We interpret the remaining petroglyphs as a single, contemporary composition that narrates the island's unique birdman ceremony as recorded in the nineteenth and early twentieth centuries (Van Tilburg 2006: 20–22).

This new way of seeing derives from details of the digital imaging, in particular of the right birdman's beak (Figure 5, right). That has traditionally been shown as coming to a point and touching the beak of the opposite birdman (e.g. Van Tilburg 2006: image 60). However, shallow damage which probably occurred during and after transport from Easter Island has been confused with original petroglyph carving; the beak was shorter, with a rounded tip. This shape can be seen in a photograph taken in 1868, in paint that was still preserved on the stone (Roussel 1926: 497). Horley & Lee (2012) have suggested that such rounded beaks are indicative of female gender. Hoa Hakananai'a has further female symbols on its right ear (*komari*) and male on its left (ceremonial paddles; Van Tilburg 2006: 38),

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supporting the idea that the two main figures are female and male respectively. Thus they can be read as the parents of the newly hatched fledgling which rises between them.

Another objective of the investigation of Hoa Hakananai'a was to create an open resource where users can view and analyse the petroglyphs. The statue is a highlight of the British Museum's collection, typically attracting sufficient visitors to compromise study under normal opening hours. The museum was extremely helpful in granting us access when the public were not admitted, but such an arrangement is not practical for most people, and could be offered to few.

By contrast, the complete virtual model of the statue and the RTI images, available online where users could manipulate the datasets, would make study of Hoa Hakananai'a and its petroglyphs, casually or in exhaustive detail, easy and convenient. We have placed a low resolution photogrammetric model of Hoa Hakananai'a in a virtual 3D viewer (Pagi & Miles 2013, in GrabCAD). Here the petroglyphs can be seen in detail, sections can be drawn and measurements taken. In collaboration with this virtual 3D viewer, Pagi (2012) has created a WordPress plugin to allow RTIs to be seen online. At the time of writing, that has not been made publicly available, but illustrative images have been captured from the RTI viewer and placed on a blog (Miles 2013b), where users can study surface detail. Both of these methods encourage further analysis by those who may not have the resources to study the statue in person, creating a system that allows for future collaboration on not only this important statue but also other Easter Island statues and petroglyphs.

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Method