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Documenting Archaeological Textiles with Reflectance Transformation Imaging (RTI)

Introduction

As interest in textile studies grows, we should re-examine current methods of documenting textile information. Documentation of the physical attributes of archaeological textiles is time-consuming. The detailed recording of such features as dimensions, raw materials, construction technique, condition, textile and yarn structures is often limited by the time and budgetary constraints of a project. Additionally, these analyses require significant object handling, which is undesirable from a conservation perspective. Bruselius Scharff and others propose detailed photo documentation as a way to quickly save information for later analysis and to decrease handling (Scharff 2007). Ræder Knudsen (2007) also suggests digital photography and enhancement in Adobe Photoshop as a desirable method of textile documentation (Ræder Knudsen 2007, 105). As technological capabilities increase, new ways of gathering and saving information and decreasing handling have become more readily available.

I examine the feasibility and effectiveness of Reflectance Transformation Imaging (RTI) as a way of documenting archaeological textiles preserved by imprint, mineralisation or carbonisation. RTI is a computational imaging technique that allows a researcher to relight an object from any direction and to mathematically enhance an object's surface and colour to reveal texture imperceptible during empirical examination (Earl *et al*. 2010, 1; Cultural Heritage Imaging 2014b). As such, it is an excellent way to document textured surfaces. The ability to manipulate the light source and enhance surface attributes in RTI expedites identification of important features of archaeological textiles from documentation. This is especially important for unstable material, such as carbonised textile remains, because access to the original material is often limited. I propose that RTI is a better way to document features of archaeological textiles and well worth the time, data, cost, and potential risk.

What is Reflectance Transformation Imaging?

Reflectance Transformation Imaging is a computational photographic imaging technique invented in 2000 by Tom Malzbender and Dan Gelb at Hewlett Packard (HP) Labs (Malzbender *et al*. 2000; Malzbender *et al*. 2001). It was originally called Polynomial Texture Mapping (PTM), and this original fitting algorithm creates .ptm files. In 2008, a second fitter that uses a slightly different algorithm and creates .rti files was developed under James Davis at the University of California, Santa Cruz (Schroer 2012; Wang *et al*. 2009). The technology uses multiple digital images, each with a different illumination direction (Fig. 1), that are compiled into an interactive file, buildable and viewable via free open-source software available online. The interactive file viewed with the software can provide a complex view of an object far more comprehensive and detailed than any of the individual digital screenshots shown as examples in this paper. Much of the benefit of RTI described in this publication cannot be shown in print. Please contact

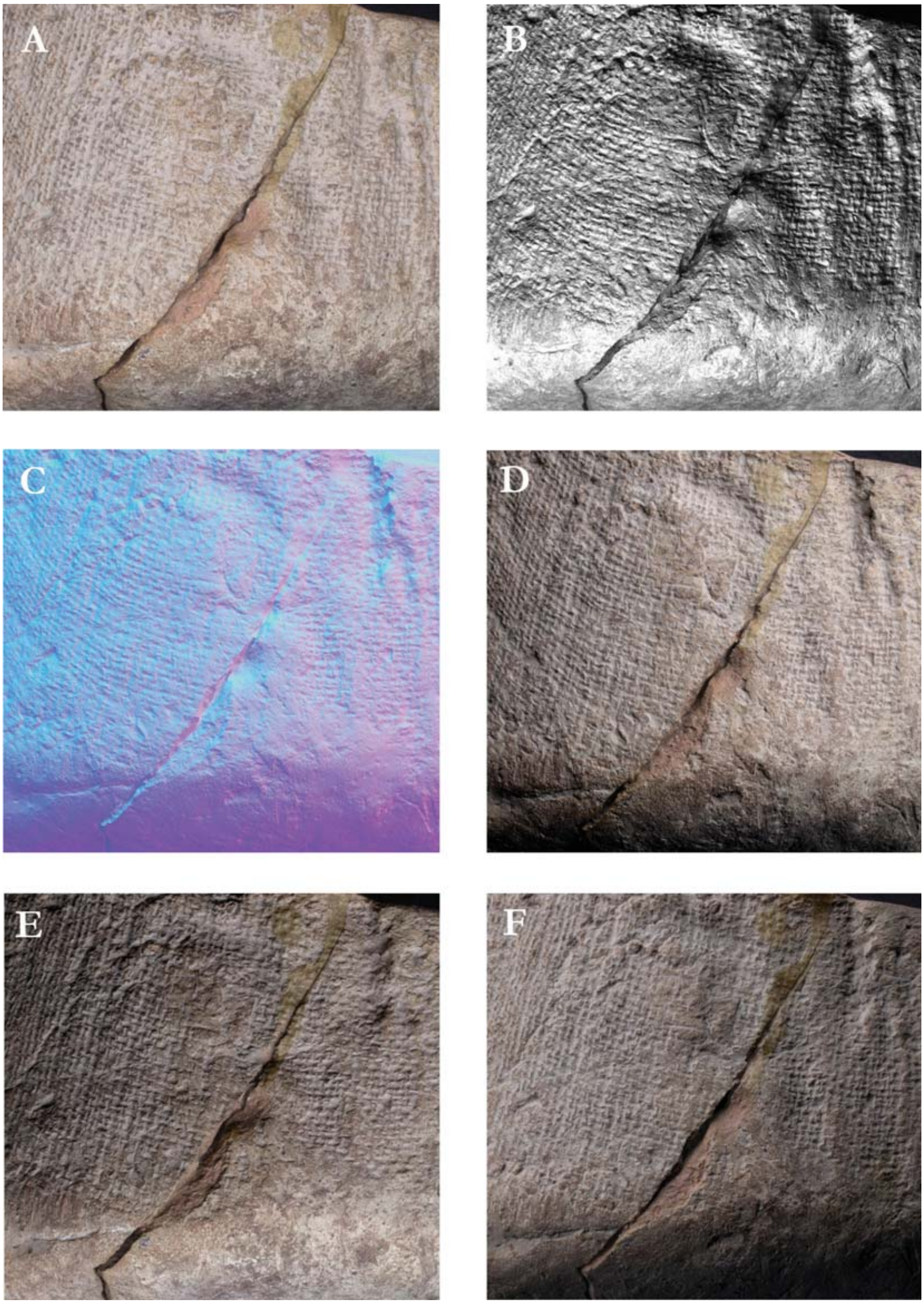


Fig. 1: Screenshots illustrating the range of individual images produced by RTI of a textile impression on ceramic (© University College London (UCL) Institute of Archaeology Collections). These and other digital images are compiled in an interactive file and viewed with RTI software. A) flat light; B) specular enhancement; C) normals visualisation; and D), E) and F) three images with different directional raking light.

the author if you wish to view the interactive .rti files discussed below.

To build an RTI, the program must know or determine the direction of illumination in the source images (Payne 2012, 18; Malesevic *et al*. 2014, 3). Thus, RTI source images can be collected in two ways. They can be taken in an arc or dome, where the lights are mounted mechanically and the locations of the lights are programmed into the compilation software (Fig. 2a), or source images can be collected with a moveable light, if a specular sphere is captured in each image (Fig. 2b) (Payne 2012, 18). A highlight from the light source is created on the sphere in each image, and the compilation software can determine the light position from this highlight on the sphere (Mudge *et al*. 2007, 4-5; Earl *et al*. 2010, 150).

Inherent in the RTI, saved per pixel, is red-green-blue (RGB) colour information and the mathematical description of 'normal' values. Normals are vectors that are perpendicular to the object's surface at any given point (Payne 2012, 18; Cultural Heritage Imaging 2014c); they enable the computation of reflection in the RTI and allow the image to be artificially relit from different directions (Payne 2012, 18).

Once the RTI has been created, the viewer can alter light qualities using specular enhancement to better examine the feature of interest. Specular enhancement yields an artificially shiny surface that provides increased tonal contrast (Earl *et al*. 2010, 3) and gives surface information where it might otherwise be lost due to specular reflection (Mudge *et al*. 2005, 7).

Considerations before using Reflection Transformation Imaging for documentation

Before starting documentation, users should consider several important technical aspects: image quality and size, image processing protocols, digital archival processes, image back-up, and longevity of the .rti file format.

For RTI to be effective, source images must be shot at the highest image quality and saved as RAW or non-compressed files. These files are extensive, and a large memory card is needed for a full set of images (usually between 40 and 70 images), which can be combined to form an RTI file. After image processing, the source images are saved as digital negatives (.dng) with embedded raw files to provide transparency. These file types hold metadata detailing the capture of the images, essentially embedding image provenance in the file so future researchers can have confidence in the representation. The files are then re-saved in a separate folder as .jpeg images. The .jpeg images are used by the compilation program to create the .rti file, which is usually about 100 MB worth of data. Often the collective data from the RTI of an object (the .dng files, .jpeg files, and the finished .rti file) can be as big as one GB of data.

There are many ethical implications in image processing, especially considering the vast capabilities of Adobe Photoshop. When images are used as documentation, an object's appearance should not be altered in any way that might confuse the viewer's understanding of the object or misrepresent the object's appearance.

Institutions usually establish a specific image workflow and standard for digital documentation. Before beginning documentation, the researcher should consider how RTI files will fit into an institution's organisational system. Often digital photographs are saved as compressed files (.jpeg) or as both compressed and non-compressed versions in different locations.

A backup plan for the data should be established. With the rapid development of digital technology, digital documents are at risk of becoming obsolete if attention is not paid to periodically saving files in new formats to new storage media (Mudge *et al.* 2010, 21). As RTI is not as widespread as digital photography is at present, the researcher should consider saving some, or all, of the digital source photographs of the image in addition to the RTI. Should .rti become obsolete, or should the RTI viewing software cease to work with new computer operating systems, it is important to have backup in other formats that are, at present, more mainstream.

Additionally, the goals of the documentation should be considered prior to beginning imaging, as the setup and applicability of RTI may vary depending on the goals of the researcher. One advantage of RTI as documentation is the ability to revisit and analyse the specifics of textile features later. If the specific goals are undetermined when original documentation takes place, the knowledge that the object is of importance and will be studied or displayed in the future might be enough to justify the use of RTI.

Reflectance Transformation Imaging specifics: camera, setup and software used

I used the following RTI setup to document several examples of archaeological textiles. I based my setup on information from the two primary published RTI guides: *RTI: Guide to Highlight Image Capture,* published by Cultural Heritage Imaging (CHI), and *Multi-light Imaging for Heritage Applications*, published by English Heritage. These works are both user-friendly and they complement each other well, especially when used with CHI's *Reflectance Transformation Imaging: Glossary of Photographic and Technical Terms for RTI*.

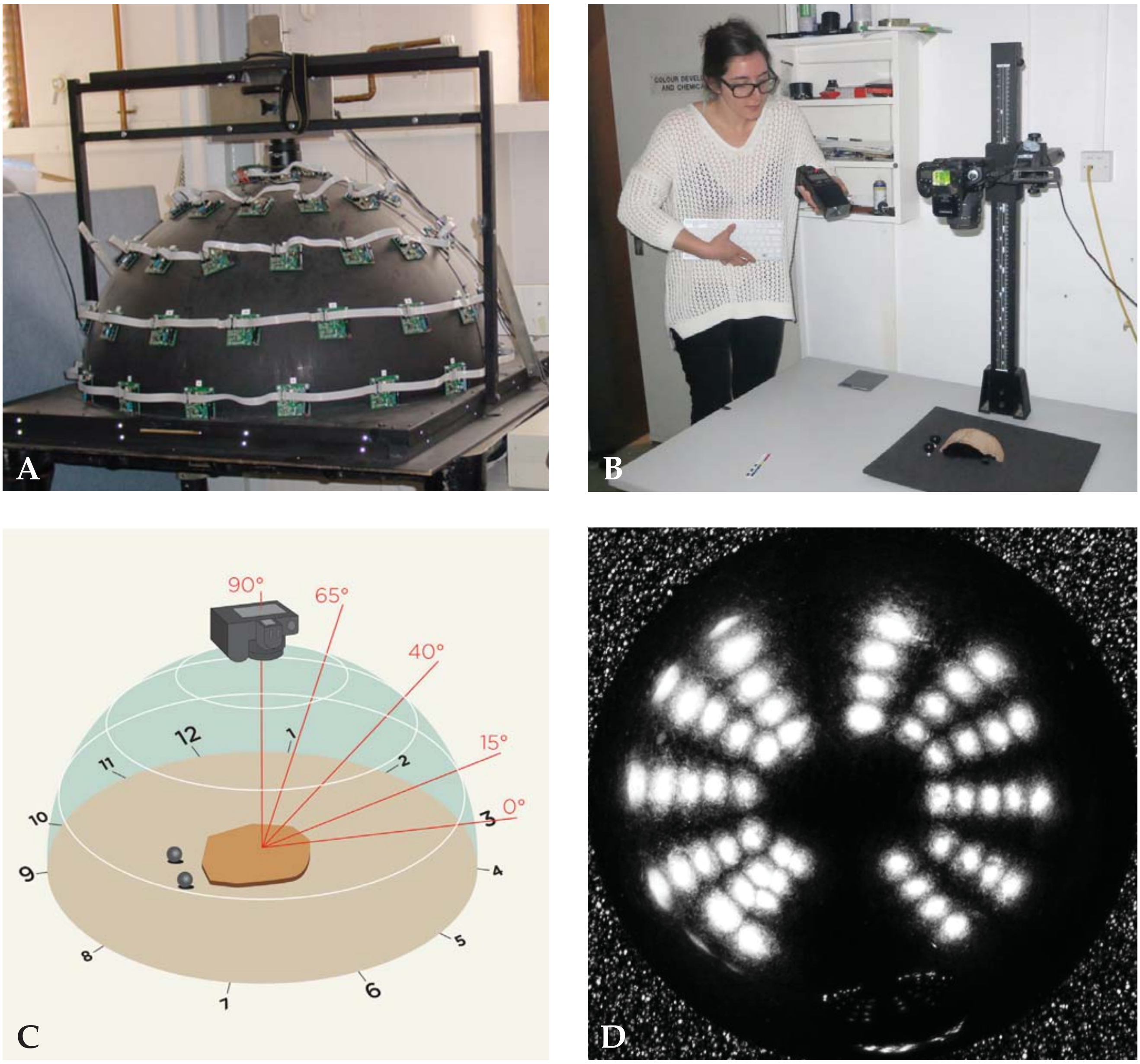


Fig. 2: A) RTI dome; B) RTI highlight capture set-up; C) virtual lighting dome centred around virtual clock: 12 images (approximately one at each hour) are taken around each white line (drawing: Charlotte Gudmundsson); D) blended image created by RTI Builder to determine light positions during highlight RTI.

Reflectance Transformation Imaging kit for documentation of archaeological textiles

Digital camera

Most digital single-lens reflex (SLR) cameras are acceptable for RTI.[1] For RTI, capturing accurate surface information is the priority, so the lens choice is also important. I used a Canon EOS 60D with a 50 mm macro lens and was pleased with the results. I found electrical tape useful to secure the lens focus; I noticed that after about 30 images the lens tended to drop focus as a result of the mechanical action of the shutter during photography. The mirror lock-up feature of the camera (where applicable) can also help to prevent the lens from dropping focus.

Computer

Any computer that can support the appropriate camera capture software will do. I used a Macbook Air.

Camera capture software
Camera capture software should be chosen based on the make of the camera. I used Canon Camera Capture.

Universal Serial Bus (USB) cable
A USB cable is used to connect the camera to the computer. In some cases, depending on the setup and size of the object, a USB extension cable is useful. Rubber bands and twist ties are useful as cable holders and are easy to procure. I used rubber bands secured with twist ties to attach the extra cable to the copy stand to avoid any shadow on the object during photography.

Two flat surfaces
The object should be placed on one surface and the computer on another. The two surfaces should be separated to avoid any vibration surrounding use of the computer. I used two tables.

Copy stand[2] or tripod
The camera should be securely suspended above the object. I used a copy stand. CHI suggests weighing down the feet of a tripod for extra stability.

Flash
The flash is the moveable light source. I used a Nikon Speedlight SB-24 and was satisfied with the results.

Two triggers
One trigger should be attached to the camera, and one to the flash. I used two Yongnuo Digital YN-622C E-TTL Wireless Flash Trigger Transceivers.

Level
This is used to ensure the camera is level before photography.

Specular Balls[3]
CHI suggests red or black specular balls. I used two ball bearings procured at a nearby bike shop.

String
The string is used to measure the distance of the light source from the object. It should be about four times the length of the object.

Chargers and batteries
Make sure all necessary chargers and batteries are easily accessible.

Scale
A scale should be included in at least one image for size, white balance and colour correction.

Wireless Bluetooth keyboard
I used a wireless Bluetooth keyboard as a substitute for a second person. Usually one person moves the light while another captures the image from the computer. With the Bluetooth-capable keyboard, I was able to capture the image while holding the light.

RTI Builder
Free software is available from HP and CHI. I used CHI's RTI Builder Version 2.0.2 for Mac, which is available on the CHI website: http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html

RTI Viewer
Free software is available from HP and CHI: I used CHI's RTI Viewer Version 1.1 for Mac, which is available on the CHI website: http://culturalheritageimaging.org/What_We_Offer/Downloads/View/index.html

Results and discussion
To illustrate the value of RTI for documentation of archaeological textiles, I have documented three examples: one imprint (Fig. 3), one mineralised (Fig. 4) and one carbonised (Fig. 5).

RTI is the most revealing and exciting when used on archaeological textile impressions. Specular enhancement clearly increases the legibility of dimensions (Figs. 3f, 3g, 3h), weave type (Figs. 3c and 3d), edge structure (Figs. 3c and 3d), irregularities (Fig. 3h) and condition (Figs. 3c, 3d, 3g, 3h). Perhaps most notably, specular enhancement allows the viewer to notice depth (Figs. 3c, 3d, 3g, and 3h) that is not obvious in raking light images. In Fig. 3, the weave is far more three-dimensional in the enhanced views, a feature that facilitates understanding of the original mat, not just the impression of it.

RTI is effective for documenting mineralised textiles, though the information that can be gained from the example in Fig. 4 by any technique is limited. The most information was gained by viewing the object with different sources of raking light. The 'z' spin direction of a few threads is visible under certain raking light conditions (Fig. 4f). Perhaps the weave type was more legible under specular enhancement, though that is debatable (Figs. 4c, 4d, 4g, and 4h). Information about dimensions and condition can also be obtained from the RTI image in Fig. 4.

RTI is effective in documenting features of carbonised textiles, but it may not provide more information than any single raking light photograph. However, the use of RTI can be justified because the ability to interact with the light source and move the direction of illumination offers a more coherent analysis experience than examining a few raking light images. The viewer can

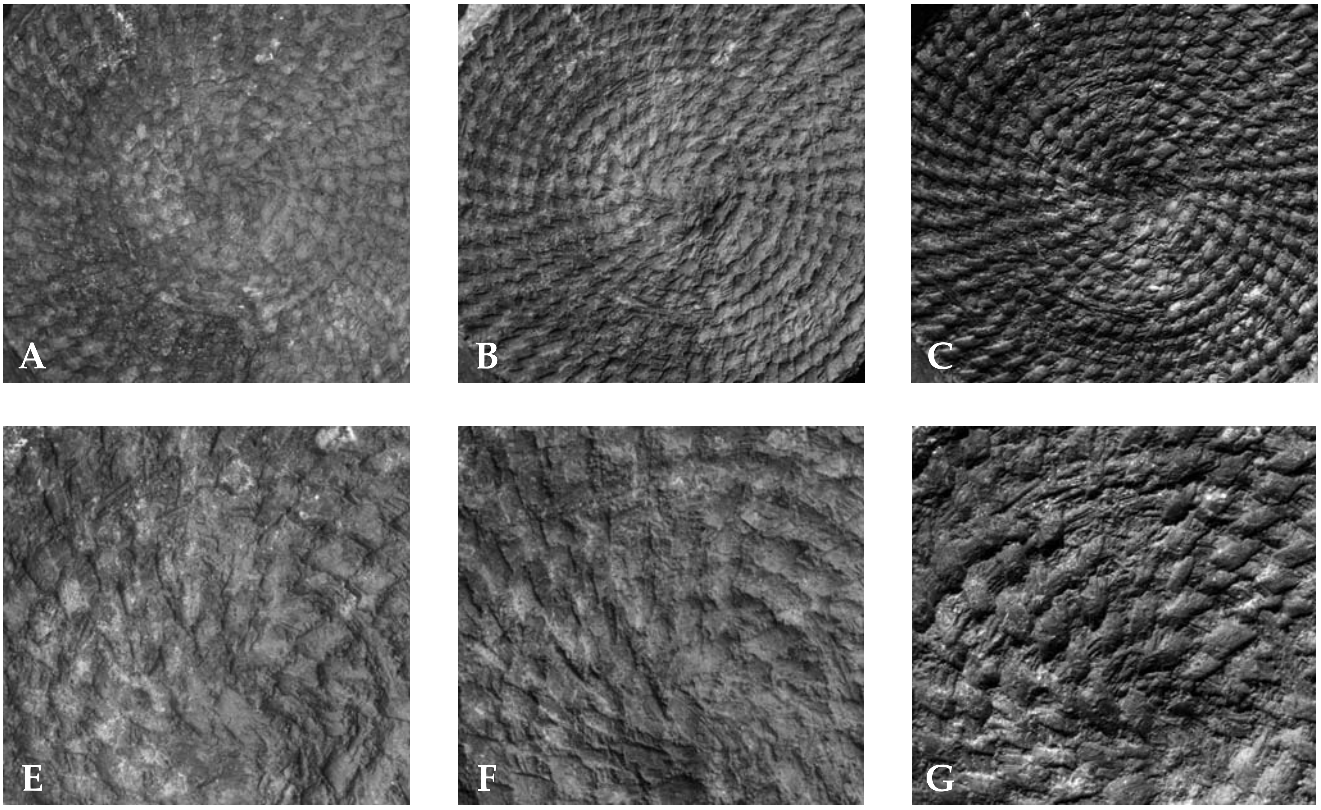


Fig. 3: Screenshots of RTI images of a textile imprint on a ceramic from Pakistan (© UCL Institute of Archaeology Collections). A) and E) flat light; B) and F) raking light; C), D), G) and H) two variations of specular enhancement.

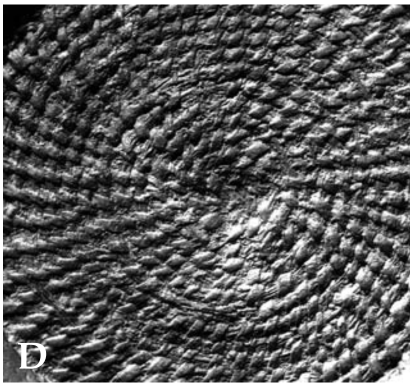
obtain information from Fig. 5 regarding dimensions, weave type, thread count and condition.

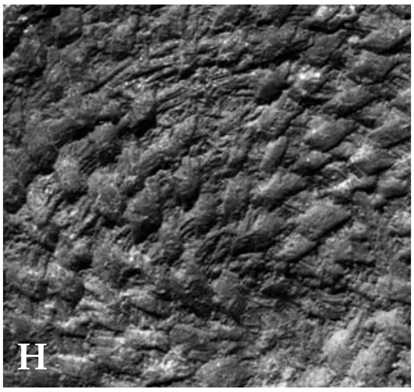
Though digital photographs gather and save much information about an object, RTI is superior because it allows contrast manipulation. By showing the surface behaviour under different illumination, RTI preserves previously inaccessible details (Malesevic *et al*. 2014, 3). RTI saves everything a digital photograph preserves, and in the context of archaeological textile remains, RTI provides more information than any one photograph can. It should be noted that high-resolution documentation photography is inherent in the RTI workflow.

The facility of use of the RTI viewer allows both informed and uninformed viewers to interact with final RTI files and to benefit from the information saved. Thus, RTI files are as accessible as photographs (with the minor stipulation that the viewer must download the free RTI viewer first). Furthermore, RTI source images can be captured without handling. The object suffers minimal contact during RTI; it is typically moved once to place the object on the surface, and once to return it to its packaging.

The cost of RTI is quite low, especially in institutions equipped for digital photography. CHI sells an RTI starter kit for 350 USD, which includes a range of sizes of specular balls and various hardware useful for constructing an RTI setup. Alternatively, the necessary tools can easily be compiled for little or no cost, with the exception of the computer, camera, lens, flash and camera capture software (all of which should be accessible in any lab equipped for digital photography and none of which are included in CHI's kit).

On the other hand, there are a few disadvantages to RTI. Processing images into RTI files may require minimal training. However, with the current knowledge of digital photography standard in archaeology and conservation, and improved software, this roadblock is easily overcome (Payne 2012, 18).





RTI retains some of the limitations of digital photography. For example, documenting curved surfaces is difficult, as seen in Fig. 4. Also, RTI provides only one fixed view of the object, though PTM object movies (POM) have been created (Mudge *et al*. 2006, 5) and will likely be relatively easy to create in the foreseeable future.
RTI is more time-consuming than digital photography, at least initially. By the third session though, I was able to take and process an image set in 40 min.
Long-term storage of RTI files is still problematic, and something that should be carefully considered before adapting institutional policies to include RTI as commonplace documentation.
Finally, researchers should consider the potential risks of any new documentation technique.

Risk assessment for Reflectance Transformation Imaging
A new application of any technique requires risk assessment. The main risks posed by RTI are those of electromagnetic radiation (light) and object handling (Payne 2012, 23-25). The heat output from flash bulbs is negligible, thus addressing any concern about temperature and relative humidity (RH) changes as a result of RTI with the setup described above. Additionally, there is no ultraviolet (UV) radiation emission in the setup.
I calculated the lux values associated with RTI and determined that they can reach 60,000,000 lux for periods of about one millisecond during RTI. Each shot is about 600 lx/sec. When multiplied by 50 shots (an average RTI session) and converted to lx/hr, the light levels are equivalent to 8.3 lux for one hour or 50 lux for about 12 minutes. Based on the Canadian Conservation Institute's (CCI) assessment of damage to highly sensitive and sensitive textiles, I calculate that at about 50 lx with no UV, an object must be exposed for 700 years or more for any damage to be observed (Michalski 2014). Thus, the light levels associated with RTI are well within the published appropriate exposure levels for unstable organic material.
As with any form of examination and documentation, object handling is a big threat. In cases where access to the material in conditions conducive to investigation is limited, documentation images of the object, or a digital artefact, can be studied instead (Galliker 2010, 48-49). With RTI files, the viewer can almost reproduce the experience of handling the object under ideal light conditions to discern texture.

Conclusion
Previously published work on RTI has examined applications of the technique to a range of archaeological and museum materials. The work presented above successfully applies the analytical capabilities of RTI to archaeological textile remains preserved through imprint, mineralisation and carbonisation. These capabilities, particularly when combined with the decrease in handling made possible by interactive RTI files, suggest that RTI can be very useful for investigation of textiles. RTI may be specifically illuminating for textile imprints, a material class that until now has been documented with photography. The detailed images produced could be beneficial for analysis and conservation, and could be used in a representative capacity in exhibitions and online. Considering the time, data, cost and potential risk, RTI is a promising and reasonable way to document archaeological textiles.

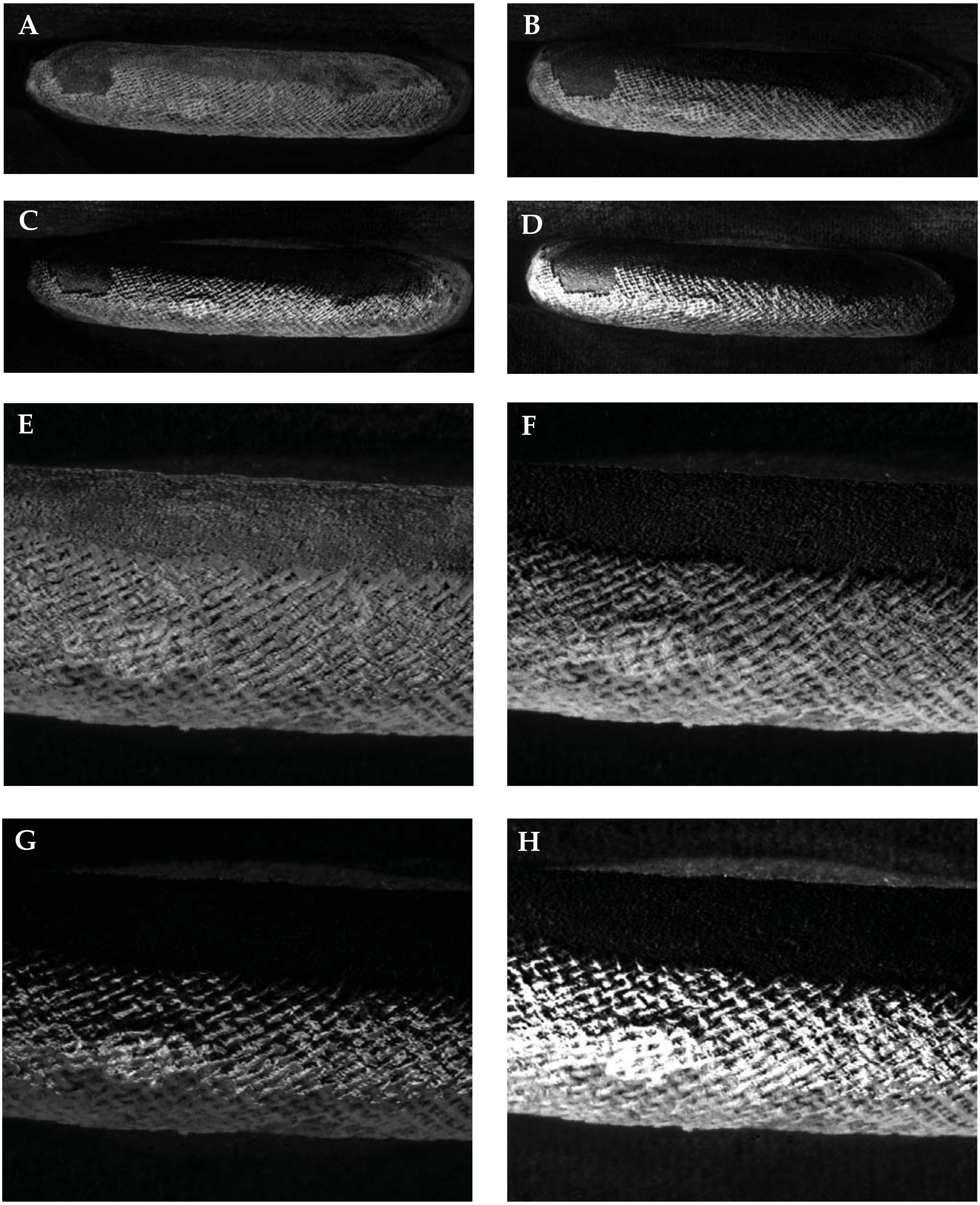


Fig. 4: Screenshots of RTI images of a mineralised textile on a bronze bracelet from Thailand (© UCL Institute of Archaeology Collections). A) and E) flat light; B) and F) raking light; C), D), G) and H) two variations of specular enhancement.

Notes

1. To learn more, I suggest consulting Kathryn Piquette's blog entry "Choosing a Camera for Highlight RTI" at http://kathrynpiquette.blogspot.com/.
2. A copy stand is a device used in photography to stabilise the camera to "copy" information. The object is placed on a flat surface and the camera is mounted parallel to the surface above the object. The height of the camera can be adjusted.
3. Specularity refers to the reflective quality of a mirror. The two balls used in RTI capture should allow mirror-like reflection from their surface.

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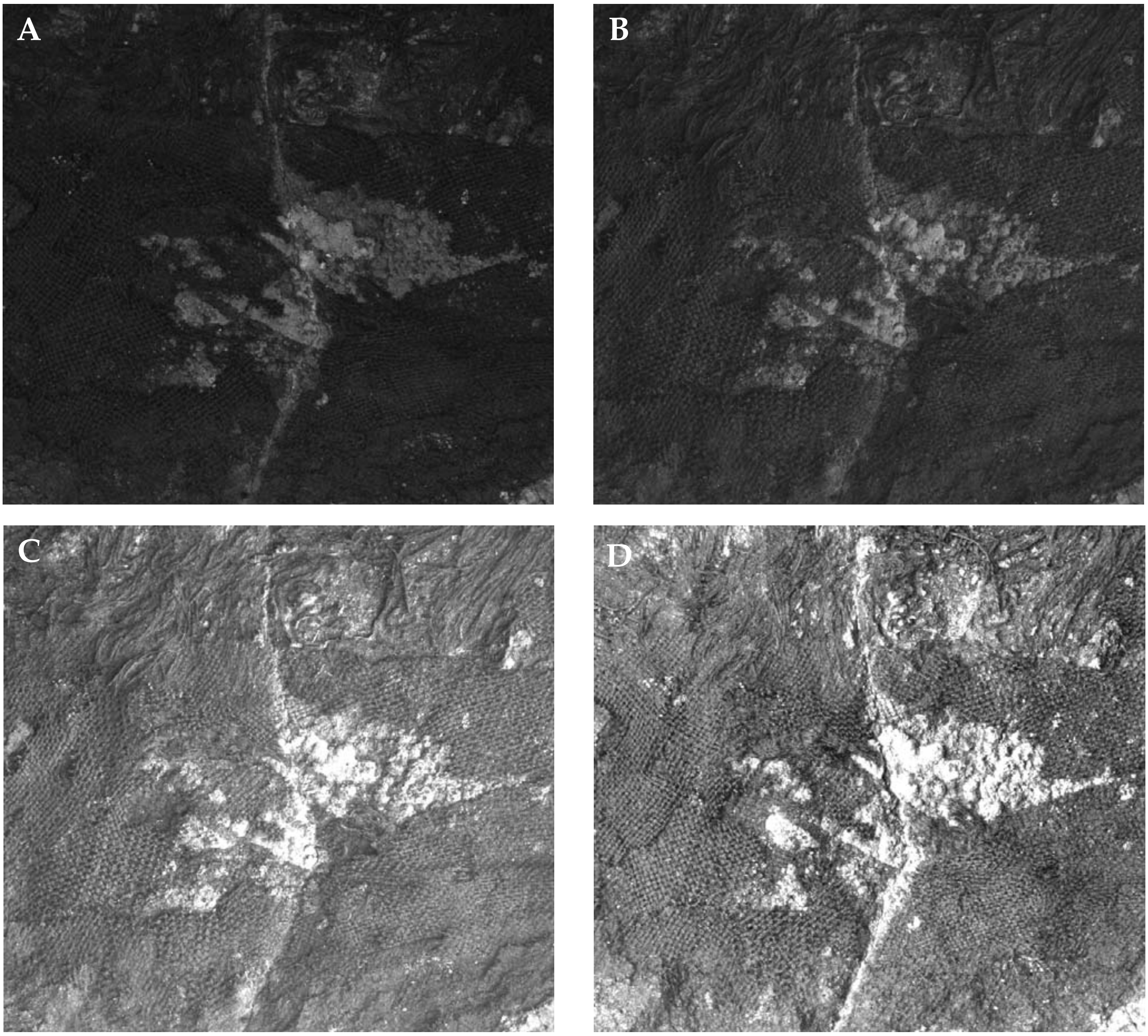

Fig. 5: Screenshots of RTI images of a carbonised textile on a bronze sheet from Ur (© UCL Institute of Archaeology Collections). A) flat light; B) raking light; C) and D) two variations of specular enhancement.

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