Reflectance Transformation Imaging (RTI): Capturing Gravestone Detail via Multiple Digital Images

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Gravestone scholars rely heavily on visual images—obtained by photography or rubbings—to create a record in the field which allows subsequent study and analysis, and comparison of stylistic details on monuments physically separated either within the same burial ground or at different sites. Much effort has been devoted to the development of recording methodologies, but the use of oblique light in photography has been the most effective in most cases. Reflectance Transformation Imaging (hereafter RTI) combines many digital photographs shot from exactly the same point but with each the lighting comes from a different angle, taking advantage of the already well-known significance of raking light.[2] The computer processing of multiple images allows the apparent direction of light to be continuously moved, but in addition various forms of processing create different types of representation, which have advantages in some situations, over the standard photograph.

RTI has assisted the discovery of hitherto unseen detail and the collection of high quality images linked to the following aspects of gravestone studies: sculpted detail, particularly where obscured by thin coverings of lichen; lettering where the rock type makes visual recognition problematic; and letter carving detail, including the identification of corrections. Each of these will be illustrated with an example, before discussing the field and computer processing methods.

Sculpted Detail

One particular common form of symbolism on Irish gravestones is that of the I H S within a circular radiance. This design occurs in many forms over a long period, but with some notable regional and chronological variations. It can occur in conjunction with other motifs, including cherubs. As with many gravestone designs, a covering of visually disruptive lichen can impede easy recognition of designs. Even if they can be discerned by feel or with moving light sources (such as with a mirror or reflector in sunny conditions), it can be difficult to obtain a permanent visual record or a publishable image. Here a headstone with a heavy hood moulding makes even single oblique lighting problematic. (Fig. 1a) Lighting from different directions can ameliorate the shadow from the hood moulding for some parts of the design, yet the visual distraction of the lichen remains. (Fig. 1b) One processing output is an image (termed the Normals image; see below for details) which combines data from all the images, and this is created in a purple tone (Fig. 1c) This is distracting, but converting this jpeg image into monochrome, increasing contrast and sometimes increasing sharpness, produces an excellent image where the visual impact of the lichen is minimized (Fig. 1d) Different image processing packages may produce varied results from this process; we have used Corel Paint Shop Pro, but others are also effective. If the lichen is thick and completely fills in the incised or sculpted detail, RTI cannot reveal the buried elements. Where it is largely the lichen's color variation (which also applies to stones with variable geology) that obscures features, the RTI can be an effective solution.

Lettering on Certain Rock Types

Some rock types can challenge those attempting to read inscriptions or identify symbolism, especially where the original appearance was enhanced by paint or gilding. One of the most frequently encountered category of rock which creates this challenge is granite, especially when mottled in appearance or when the relevant element is recessed, making rubbings hard to achieve. On smooth, polished granite surfaces, simple oblique lighting can reveal the lettering because it survives well, though in some cases this illumination is insufficient. Our most resistant memorial was one where the text was carved into a recessed panel in a

Fig. 1. Radiate I H S with cherubs on hood moulded headstone. Collon, County Louth, Ireland.

a) Oblique light as if from the sun;
b) Oblique light from below to minimize effect of the hood moulding;
c) Output from the Normals processing;
d) Normals image after manipulation within a standard photographs package to create a standard monochrome image.

cross base. It was possible to feel the presence and arrangement of the letters, but not the details of their form or what many of the words were. The oblique light (Fig. 2a) merely indicated the presence of much of the text, yet even light from other directions (Fig. 2b) was insufficient to reveal it all. Other processing techniques were therefore applied (see below for an explanation), and again the Normals image allowed far more to be seen (Fig. 2c), and can be processed into a more familiar visual format. (Fig. 2d) Using specular enhancement (see below for an explanation), various elements of the text and the letter forms could be discerned even more clearly (Figs. 2e, 2f), though in this case not easily across the whole panel at once.

Letter Carving, Details and Corrections

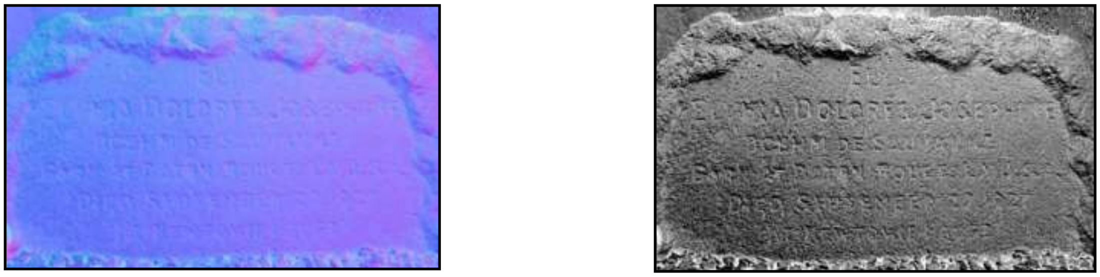
The details of letter forms provide an important way of identifying particular carvers; mistakes and corrections throw light on the skills of carvers, their degree of literacy, and sometimes the complex biographies and changes of use of memorials over time. The examination of letter forms and details, such as lightly incised laying out lines, can be best investigated through the application of specular enhancement. A cross with incised lettering is in reasonable condition and a typical color photograph with oblique lighting reveals most of the detail (Fig. 3a), albeit slightly obscured by lichen. Specular enhancement minimizes the visual distraction of the lichen and improves visibility of the enclosed detail, including the rectangular cut out recess that removes

Fig. 2. Base of granite cross. Termonfeckin, County Louth, Ireland.

a) Oblique light as if from the sun;

b) Oblique light from below to reveal other elements of the inscription;

Fig. 2. Base of granite cross. Termonfeckin,
County Louth, Ireland.



c) Output from the Normals processing;
d) Normals image after manipulation within a standard photographs package to create a standard monochrome image.

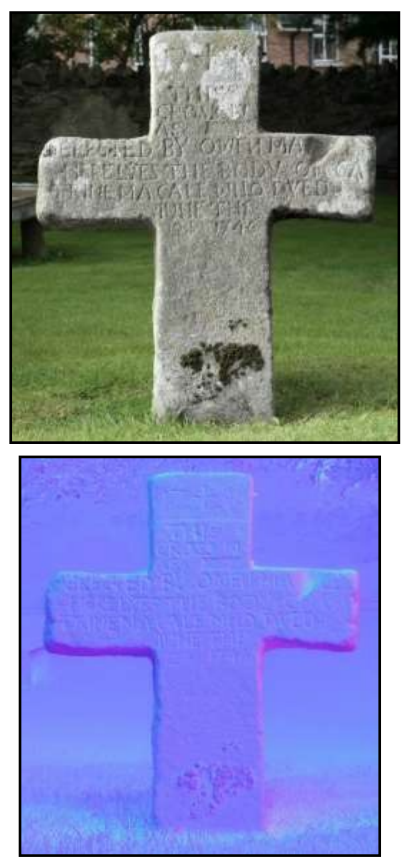
e and f) Outputs from the Specular enhancement processing, with different light directions highlighting different parts of the inscription

an error. (Fig. 3b) All images can be enlarged to examine fine detail, such as this cut out, where slight traces of the original letter cuts are still visible. (Fig. 3c)

Taking Digital Photographs in the Field

These examples indicate the potential of RTI. The other attraction of the method is that it is relatively simple to achieve, if care is taken to create suitable digital images. Fortunately, the process of image capture is straightforward to those well-versed in graveyard photography. There are two main concerns: keeping the camera in *exactly* the same location and orientation for all the images of a particular memorial, and having a standard amount of oblique light falling on the stone from a known direction. Most development across a range of applications of RTI has concentrated on the second of these requirements, but the first is also essential, especially because tripods on turf can move slightly between images. This shift degrades the quality for the processed, combined images. The basic method is outlined here first, followed by some observations on particular issues encountered in the burial ground or with the processing of the images.

Fig. 3. Cross-shaped grave marker with incised inscription.
Magheracloone, County. Monaghan, Ireland.



a) Oblique light as if from the sun;
b) Output from the Normals HSH processing;

c) Output from the Normals PTM processing;
d) Specular enhancement image with light as with a);
e) Specular enhancement image details showing part of text cut out as part of a correction to the text.

The subject size suitable for recording by this method is a maximum of c. 2m across; but it is possible to record even microscopic features. The digital camera must take images in RAW format and manually adjust exposure, aperture and the remote flash to obtain the necessary oblique lighting. The memory card must be able to hold up to 60 images (though we have generally taken only 30 or so) for each memorial. These can then be downloaded onto a laptop for processing and, once checked for quality, deleted from the memory card. The tripod must be robust enough to prevent any movement, and the flash should be powerful enough; this may mean that, as with traditional photography, bright sunlight is not ideal for this method. The guides by Duffy and CHI[3] provide much sensible advice, so it is not worth repeating here. The only items of equipment that an experienced photographer will not already have are the targets necessary for the software to calculate the direction of the light source on each image. These shiny spherical objects must be fixed so that they do not move at all between images, and need to be of a size appropriate to the scale of the subject. We have used billiard balls, baubles (of various sizes) produced for Christmas trees and, at a larger scale, domes used to house security cameras. There are undoubtedly other options. The main consideration is that they must be perfectly spherical (or hemispherical if placed in the correct position so they appear spherical in the camera viewfinder), shiny, and ideally black or red in color; we have also used grey. (Fig. 4) Two are placed within the frame of the image, but not obscuring the features of interest (they can thus be removed from the trimmed final image). Only one is essential for processing, but two means that if, for whatever reason, one is problematic, the other can be used. The spheres reflect the flash which, as it is moved around the object, is in a different position on the sphere. The sphere is identified manually within the processing software; then it automatically detects the reflections and so calculates all the light sources.

Keeping the camera tripod immobile is crucial. It may require weighting down to avoid wind movement. It also must not sink down into the turf as photographs are taken. To ensure maximum clarity of the final processed images, check the magnified images to ensure there is no shake or drift, even if each image is sharp and effective. One or two problematic images can be excluded from the processing in the same way as other sub-standard images, providing sufficient coverage is left to create accurate models of the multiple lighting. If all from one direction have to be removed, take a new set of images. The targets should be kept in place, either on the ground, raised up on stiff rods, or fixed to the monument (e.g. by Blu-tac). Just as the tripod must not move, so these must remain in exactly the same point for all the images. Both the tripod and the targets can create shadows; the latter need to be far enough away from the main subject that oblique light (which therefore casts a long shadow from the target) does not interfere with the part of the image to be used after post-processing trimming.

Fig. 4. Positioning of the spheres from gravestone photography.

a) On the ground; this slab was partly buried so there is shadow on the right, but satisfactory results were obtained even though very oblique flash was not possible from that side.

b) On the surface of the stone. Note the effect of oblique light creating shadow. Careful positioning so as not to mar part of the final cropped image is essential.

Even amounts of light falling on the subject is achieved through using a piece of string attached to the flash with the other end held against the same point on the subject (Fig. 5); the string is then withdrawn and the photograph taken; the string can be extended beyond arm reach by attaching it to a stiff rod (e.g. a bamboo cane) which can be pointed onto the stone. Whilst Duffy suggests that the flash should be at a distance 3 or 4 times the diameter of the image, with larger gravestones standing 1.7m high we have found that distances of 1 and a half times the diameter or even 2m have been sufficient. A greater distance dilutes the impact of the flash; we have not tried carrying out graveyard photography at night because the sites we record are rural ones still in current use and it would be difficult not to cause alarm locally if there were strange flashes coming from a darkened graveyard.

Images should be taken at points along arcs from very oblique to straight on (as long as the flash is not in the image), and from close to the ground to well above the subject. If the whole of a headstone is in the image, light cannot be from directly below; if only an upper part of the monument is being photographed, this may be possible. Other monuments, vegetation and boundary walls may limit the range of angles, but we have found that effective if not perfect results can come from partial coverage. The main challenge is getting enough light to fall over all of a larger subject, as is the case with traditional oblique lighting photography. However, the Normals images seem to be able to cope with this better than the specular enhancement. If the latter is being used to examine particular features in detail, this variation across the whole image may be less problematic. Be systematic in taking the photographs to ensure as even a distribution of angles of the flash as possible; at one stage of the processing look at the distribution of the flashes around the subject. If there are problems such as failed flash, images with shadows or the string in view, just take the image intended and carry on; the problematic images can be removed later during processing.

Fig. 5. Using string to ensure the flash is the same distance from the subject for each exposure.

Processing the Data Sets

The images that form the data set for one particular desired image need to be placed together in a folder. Cultural heritage Imaging (CHI) have provided downloadable software termed RTIBuilder that allows a workflow that processes the images in a number of stages, before they can then be saved for viewing.[4] Duffy has an excellent screen by screen explanation of the processing stages, and should be available as you work through the program.[5] During the various stages of this processing, any problematic images (such as ones with shadows, ones where the flash malfunctioned) can be removed. Some processing is demanding on the computer, so some machines can take a while. Two types of output can be created, and you may wish to undertake processing the same set of digital images to produce both. It is possible to generate polynomial texture mapping (PTM) files or hemispherical harmonics (HSH) files; each has its own advantages (see next section on viewing options for them). The processing produces for each monument various sets of files, each in a separate folder ("assembly," "cropped," "finished," "jpeg"), but the file required for viewing and which can be sent to others to view without any of the rest is that found within the finished folder that ends with "cropped" followed by an identifying number. These final, processed files, c. 100 MB each, are all that is required for the viewing phase. You may wish to rename the files to indicate whether they are derived from PTM or HSH processing from their names.

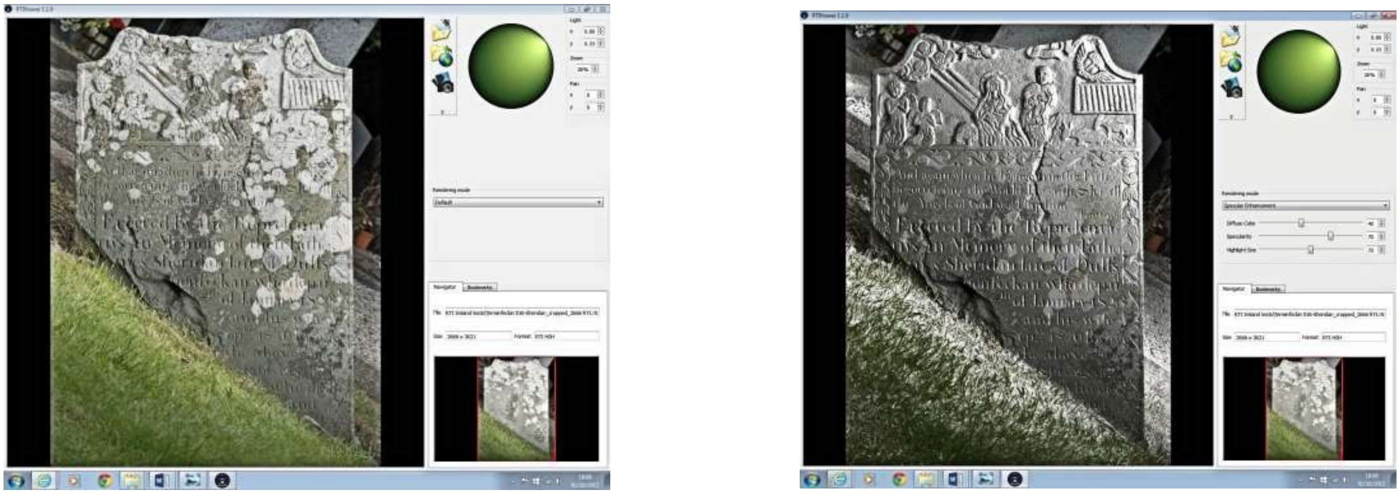
The Types of Image Created by RTI, and Viewing These

A separate software package is required, RTIViewer, to view the images,. This free package does not require RTIBuilder,[6] so those only viewing images merely need the viewer software and do not need to understand the intricacies of the processing. This means that the images can be distributed widely, providing maximum access. Some of the options produce a single image, derived from all the data in the images combined. Others, however, are interactive, and the rollerball in the top right of the screen allows the light direction to be moved around. (Fig. 6) The Zoom allows the image to be viewed in more detail; the mouse then allows the image to be moved around so that different parts can be examined. At any stage the direction of the light source can be altered, and the portion visible in the window can be captured as a snapshot jpeg image by clicking the camera icon. Saved as jpeg images, they should be immediately renamed with a file name that is recognisable to the user.

There are two types of "fitter" at present available which use different methods to create the RTI image options from the data in the original photographs. The first used polynomial texture mapping, which at present produces PTM files. A subsequent process using hemispherical harmonics is also available and this produces what the program RTI files, though we term these HSH for the final viewing file. Both types are actually RTI, and we wish to be able to identify from the file name which processing method has been used, as the two methods do not produce identical results. The more recently developed HSH application has fewer display options at the moment, but others may become available to match those of the PTM process. Further fitters may also be developed.

The files created by HSH processing currently allow only three forms of output. (Figs. 1-3) These are Default (oblique light), Specular enhancement, and Normals visualization. Default provides a typical colored image of the monument where the direction of the light source can be manipulated with the roller ball. (Figs. 1a, 2a, 3a) Specular enhancement, however, significantly departs from normal gravestone photography. Here a monochrome image is created which can have a shiny appearance and can pick up much detail as the light source moves around. (Figs. 2d, e, 3d, e, 6b) In some cases it is possible to capture a greater area with a similar intensity of light by adjusting the Highlight Size slider bar, or degree of contrast with Specularity, and lightness of image with Diffuse Color. We have found the Specular enhancement rendering mode highly effective to create useful images. (Fig. 7 a, b) The third method available with HSH is Normals visualization. This creates a static image which is that represents the 3D surface of the object, with lighting direction adjusted

Fig. 6. The RTIViewer screen with the main icons and the interactive roller ball in the top right.



a) Oblique color;

b) Specular enhancement with light from same direction as the color image.

by the package to maximize the visibility of all features within the one image. It therefore can effectively portray many more elements of a design than an oblique light image. For example, note how with the Collon headstone in the Normals images, all of the radiate halo of the I H S is clear (Figs. 1 c, d), when inevitably part is less visible whatever direction oblique light was applied. (Figs. 1 a, b)

The PTM processing offers additional options to those provided with HSH. However, the same form of output from both methods does not produce identical results, and we have found that the Normals from HSH are far superior for the gravestones we have recorded than those generated within PTM (Figs. 3b, c); in the purple image the latter have bright green highlights which distract even when made monochrome; these are less intrusive in the HSH versions. The specular enhancement of PTM produces a more granular image than HSH, and generally seems less satisfactory for most purposes, but not all. It is worth processing both versions and comparing results. We have found the additional options from the PTM processing produce a range of image types which emphasise various factors, some of which may be useful in some circumstances – we found the Luminance Unsharp Masking and Dynamic Multi Light produce forms of image where the light direction can be adjusted, and Static Multi Light generates a composite image. We have concentrated in this paper on the Normals and Specular enhancement image types which we have found to be most valuable, but the rest are quickly evaluated using the viewer system, and other users may find the alternative modes effective.

Conclusions

RTI can greatly enhance the recording and study of gravestone iconography and lettering. It is possible with only a limited amount of equipment and free software. We have shown how RTI may usefully study sculpted detail, problematic lettering, and lettering details and corrections. It could also be applied to other projects. The quality of the images can form part of a conservation archive, recording the condition of monuments on a particular date, no longer dependent on weather conditions that often affect visibility. The interactive nature of the software makes it effective in public interpretation because it allows the excitement of discovering text and iconography on monuments to be experienced by those unable to access the graveyard. Some of the image processing methods allow better quality images for publication than is otherwise possible, and can make some monuments accessible for analysis, discussion and dissemination. We would be glad to hear of anyone's experiences with the method, because we would like to develop it further.

Fig. 7. Specular enhancement investigating carving detail on a small water-rolled boulder, so the surface is curved. Balrothery, County Dublin, Ireland.

a) Heart and I H S motif; b) Letter cutting.

Notes

1. Harold Mytum directed the graveyard recording project, with essential technical support in the field and with processing initially by Kate Chapman and Alistair Cross, and subsequently developed by J.R. Peterson. Thanks must be given to the various local communities and individuals who facilitated and indeed encouraged our graveyard recording efforts, largely as part of the University of Liverpool, Ireland and Isle of Man Archaeological Field School.

2. For an easily accessible, well-illustrated and readable introduction, see Sara M. Duffy, *Multi-Light Imaging for Heritage Applications*. London: English Heritage, 2013. English Heritage is an organization now split into two, and this publication was issued by that part now called Historic England, and it is from their web site that the publication can be downloaded as a pdf: https://www.historicengland.org.uk/images-books/publications/multi-light-imaging-heritage-applications/. Cultural Heritage Imaging (CHI), the producers of the free downloadable software to process and view the images, at http://culturalheritageimaging.org/What_We_Offer/Downloads/. They have produced a *Glossary*, available as a pdf, and their web site has much useful information and examples of the application of RTI. It is worth checking their website on a regular basis as they frequently update the advice and software.

3. Duffy, 2013 *Multi-Light Imaging*; CHI *Glossary*.

4. Available to download from the CHI web site.

5. Duffy, 2013 *Multi-Light Imaging,* 9-12.

6. Available to download from the CHI web site.

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