Understanding RTI

Reflectance Transformation Imaging, or RTI for short, refers to “a computational photography technique”[1] used to capture information about objects and materials in the three-dimensional world. Invented in 2001 by Tom Malzbender, of Hewlett-Packard (HP) Labs, [2] RTI is an application that enhances the surface and shape perception of objects through digital photographs. RTI can generally be described as a three-step process: capturing images, processing a texture map, and visualizing the RTI model.[3] By capturing a sequence of photographs—approximately 30-60 in total—of a fixed object under constant conditions but varying light positions an RTI model can be built. However, in order to achieve optimal results, the object must never move, the camera angle and position must be unchanged throughout the process and the light source must illuminate the object from as many directions as possible. RTI requires this luminance or lighting technique in order to recognize the surface normal[4] and synthesize this data into its virtual representation: “When an object is illuminated from different directions, the reflection patterns of each segment of the surface are captured in the corresponding pixel of each photograph and subsequently, through a set of mathematical calculations made by RTI software […] the normals are identified.”[5] Thus, information captured

[1] Jacqueline F. DiBiasie Sammons, “Application of Reflectance Transformation Imaging (RTI) to the Study of Ancient Graffiti from Herculaneum, Italy,” *Journal of Archaeological Science*: Reports 17 (February 2018): 184.

[2] Originally known as Polynomial Texture Mapping (PTM)

[3] Silvia N. Manrique Tamayo, Juan Valcarcel Andres, and Julia Osca Pons, "Applications of reflectance transformation imaging for documentation and surface analysis in conservation," *International Journal of Conservation Science*, 4 (2013), 539.

[4] *Reflectance Transformation Imaging: Glossary of Photographic and Technical Terms for RTI.* Cultural Heritage Imaging, 2014, 9. The mathematical term for the directional vector that is perpendicular to the surface of an object at a specific point. Reflectance Transformation Image (RTI) software calculates the surface normal at each point of an object, using information derived from the lighting angles at each pixel in each of a series of images. Normal information, in the form of surface shape, is included along with color information for each pixel in the resulting RTI image. This enables viewer software to show the surface shape of the subject in great detail.

[5] Manrique Tamayo, Andres and Pons, "Applications of reflectance transformation imaging,” 537.

in the normal—via varied lighting—allows the RTI Builder to discern the topography of the object and replicate it digitally. How this information is conveyed depends on the method used by the researcher: the dome method or the Highlight method.[6]

I selected the Highlight method for this project which allowed easier capture and required less equipment. Highlight RTI operates in a similar fashion to the aforementioned process except it requires the use of glossy black spheres. Equipment for this method includes, "a digital SLR camera, a tripod, a light source and a glossy black sphere, whose dimension is relative to the size of the object under examination."[7] Once the images are captured stored and uploaded to the RTI Builder software [8] the data processing begins. Users select the image set for the model, identify the black spheres in a single image and recognize the highlight on those spheres, in order for the software to execute sphere and highlight detection. Once detected the RTI Builder will "calculate the exact position of the light source by identifying the position and angle of the specular highlight reflected on each of the black spheres"[9] and apply it to all files in the image set. Lastly, users must choose to crop and fit their model. Using the PTM or the Hemispherical Harmonics (HSH) fitter the RTI Builder will complete the fitting and produce in polynomial texture map[10] or reflectance transformation imaging format (*.ptm or *.rti).[11]

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[6] Eleni Kotoula and Maria Kyranoudi, "Study of ancient greek and roman coins using reflectance transformation imaging," E-conservation magazine 25 (2013), 76.
[7] Kotoula and Kyranoudi, "Study of ancient greek and roman coins," 76.
[8] Developed in 2006 by the University of Minho and the Cultural Heritage Institute. http://culturalheritageimaging.org/What_We_Offer/Downloads/RTI_Hlt_Capture_Guide_v2_0.pdf
[9] Manrique Tamayo, Andres and Pons, "Applications of reflectance transformation imaging," 540.
[10] *Reflectance Transformation Imaging: Glossary of Photographic and Technical Terms for RTI.* Cultural Heritage Imaging, 2014, 8. "The first type of RTI imaging, invented by Tom Malzbender at HP Labs in 2001."
[11] Kotoula and Kyranoudi, "Study of ancient greek and roman coins,"77.

The RTI model produced by RTI Builder, in essence, becomes an interactive image where viewers can manipulate light conditions and rendering filters in order to examine the object closer.[12] This interactivity permits viewers to analyze and amplify surface details of the object as if it were under continuous raking lights.[13] Because RTI models contain data at a pixel level the RTI Viewer can retrieve the 3D data and display it in a 2D space as if it occupied a

Figure 1: RTI Viewer with cursor positioned in light controller at Northeastern horizon. RTI screenshot capture. May 4, 2020.

space in the 3D world.[14] By moving the mouse cursor around the light controller (a large circular area towards the right of the model in RTI Viewer) users can see the object at 'high noon' when positioned in the center and at the 'horizon' when positioned towards the outer edge of the object. This explains why some angles reflect brightly while others are much darker.[15]

[12] DiBiasie Sammons, "Application of Reflectance Transformation Imaging (RTI)," 186.
[13] Manrique Tamayo, Andres and Pons, "Applications of reflectance transformation imaging," 537.
[14] Mark Mudge, Jean-Pierre Voutaz, Carla Schroer, and Marlin Lum, "Reflection Transformation Imaging and Virtual Representations of Coins from the Hospice of the Grand St. Bernard," The 6th International Symposium on Virtual Reality, 2005, 30.
[15] Mudge, et al., "Reflection Transformation Imaging and Virtual Representations," 30.

RTI and millennium coins

The study of coins, particularly the process of displaying and documenting them, has been a complicated and arduous process for many. Indeed, their principal metallic and reflective characteristics, not to mention their size, has made it difficult to replicate the experience of hands-on examination when studying the aesthetic features of coins.[16] With RTI, the 2D (sometimes referred to as 2.5 dimensions) image displays just as much, if not more, information than can be seen under physical examination—due in part to its ability to capture surfaces without loss of data.[17] Therefore, when analyzing coins visually and materially, RTI enables a more thorough and accessible examination.

To create my RTI models I spent four months testing the capture process with various research assistants. My supervisor and I experimented with the intensity of the light, the exposure and focus settings of the camera as well as the type of coins under observation. The camera (Canon 5D Mark II with a 50 mm macro lens, f-stop of 3.5 and 400 ISO) was mounted on a copy stand without the accompanying lights, and a portable light with barn doors attached (Feliix brand, 5K light, set at full intensity on the colour white) was used to illuminate the coins. The reflective black spheres (black bracelet beads purchased at Michael's Craft Store) were 14mm in size and stabilized by a hole in the middle. The light was manipulated by my research assistant before each photographic capture and the distance (25 inches in length) was confirmed by string to ensure consistency between shots. Each image was then captured remotely by triggering the camera attached to my computer (using Canon's EOS Utility Program). Every coin was photographed an average of 30-40 times with the light positioned at various points in order

[16] Mudge, et al., "Reflection Transformation Imaging and Virtual Representations," 30-1.
[17] Mudge, et al., "Reflection Transformation Imaging and Virtual Representations," 37-8.

to create a “virtual light dome” or ‘umbrella coverage’.[18] Photographs were captured along four axes in the following directions: north/south, east/west, northwest/southeast/ and southwest/northeast. Setup of the equipment required five to ten minutes and the shooting took approximately fifteen to twenty minutes per coin. The equipment setup is key to producing optimal models but is also discernible in the final RTI image. In the end what the RTI Builder captures is the coin and its situation in relation to the light, the room and me. This is perhaps most noticeable in the failed and blurry models created during the trial stage.

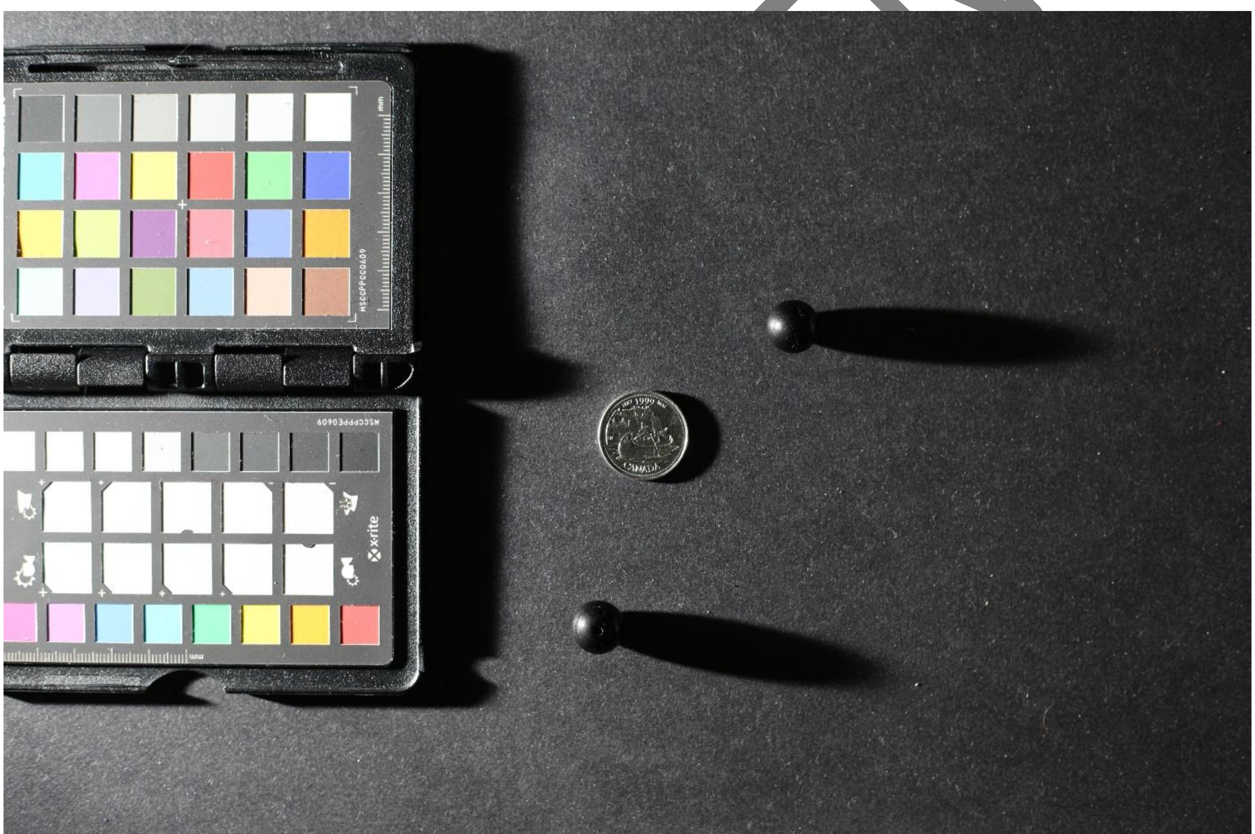

Figure 2: An unedited image of the RTI coin capture process. *The Voyageurs,* May 1999. Coin capture. February 21, 2020.

[18] DiBiasie Sammons, “Application of Reflectance Transformation Imaging (RTI),” 187.