Capturing Watermarks using Reflectance Transform Imaging with 3D Modeling and Fast Fourier Transform Processing

Abstract

An important aspect in paper conservation is identification of the source of a paper used for a work of art. Identifying three-dimensional characteristics such as laid lines, chain lines, and watermarks made in the manufacturing process of papers can aid in this process. Reflectance Transform Imaging (RTI) has become a point of interest, as it is particularly useful when the primary support is lined with secondary or even tertiary supports of canvas, boards, or other papers with different textures that would obstruct the use of transmitted light or X-ray imaging. Working with the surface normal and depth map generated from a 3D model based on the RTI data, we use frequency separation methods and Fast Fourier Transforms to isolate specific three-dimensional features from the images.

Kurt Heumiller
Soyeon Choi

Jens Stenger
Chelsea Alene Graham

YALE CENTER FOR BRITISH ART

Yale *Institute for the Preservation of Cultural Heritage*

Background

Yale Center for British Art is conducting a study of a group of large-scale preparatory watercolors by Samuel Scott. Part of this study relates to the primary support, or paper that the watercolors were executed on. Watermarks, laid lines, and chain lines can aid in identifying the source of the paper.

Fig 1. The Thames With Montagu House and Westminster Bridge. Samuel Scott, ca. 1702–1772. Yale Center for British Art, Paul Mellon Fund, in honor of John Baskett. B2009.5.1

Transmitted light photography [fig 2.] or x-ray is traditionally used to document these impressions. This provides a clear visualization of the watermark, the chain lines and the laid lines.

Fig 2. Transmitted light photography of A Paper Mill at Rickmansworth. Attributed to Robert Udney, 1740–1808; Formerly attributed to Samuel Scott, ca. 1702–1772. Yale Center for British Art, Paul Mellon Collection

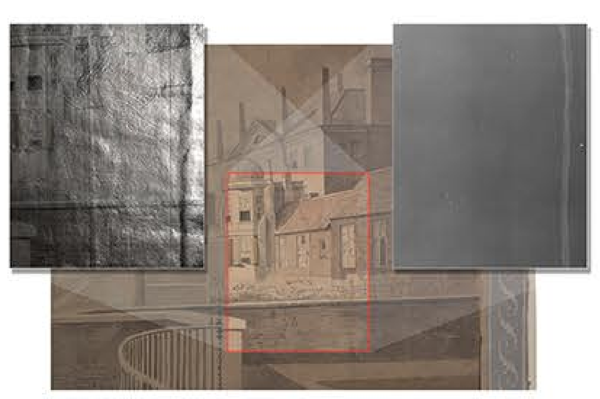

Fig 3. Detail of fig 1, showing RTI with specular enhancment on left and x-ray on right. (X-ray contrast enhanced, yet still reveals no impression)

The primary supports of these watercolors are lined with one or two layers of textured canvas and other types of laid papers. These additional layers made x-ray [fig 3.] and transmitted light ineffective.

Reflectance Transform Imaging (RTI) is typically used as an alternative to raking light photography, allowing the viewers to adjust the angle of the lighting to highlight specific textures. Imaging was performed using an RTI dome [fig. 4].

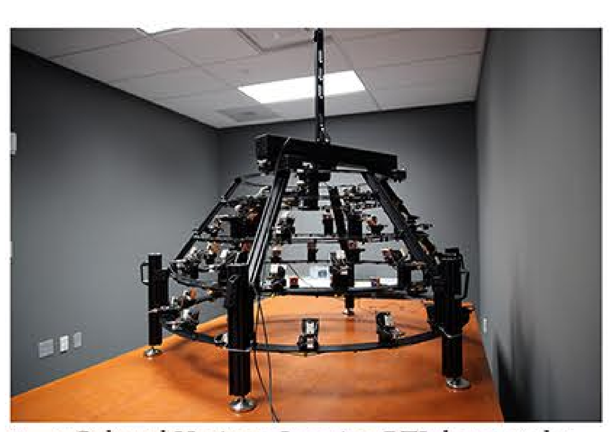

Fig 4. Cultural Heritage Imaging RTI dome at the Yale Institute for the Preservation of Cultural Heritage

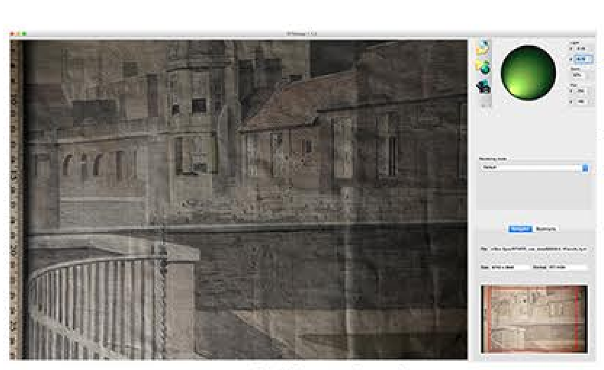

Fig 5. RTI viewer provided by Cultural Heritage Imaging http://www.culturalhertiageimaging.org

RTI is useful, but requires specialized software [fig. 5] that can impeed collaboration. Also much of the information osberved of the impressions is from the movement of the light. A single angle of light must be chosen for print publications and requires a compromise that highlights features perpendicular to the angle of light while understating parallel features.

Surface Normals

The RTI viewer allows the user to see and export the surface normal map [fig. 7]. The surface normal map is a visualization of the normal vectors [fig. 6] of the surface across the image. The angle of the X axis of the vector is displayed in the Red channel of the image, the Y angle in the Green, and the orientation of the Z axis in the blue.

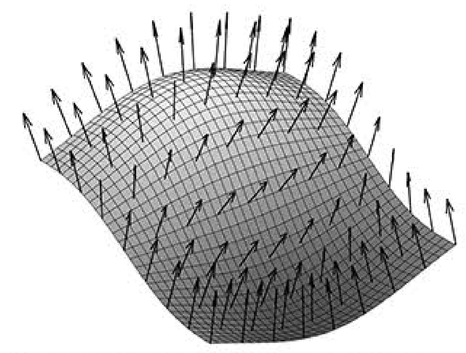

Fig 6. Illustration of normal vectors
Source: Nicolás Guarín-Zapata, Wikipedia

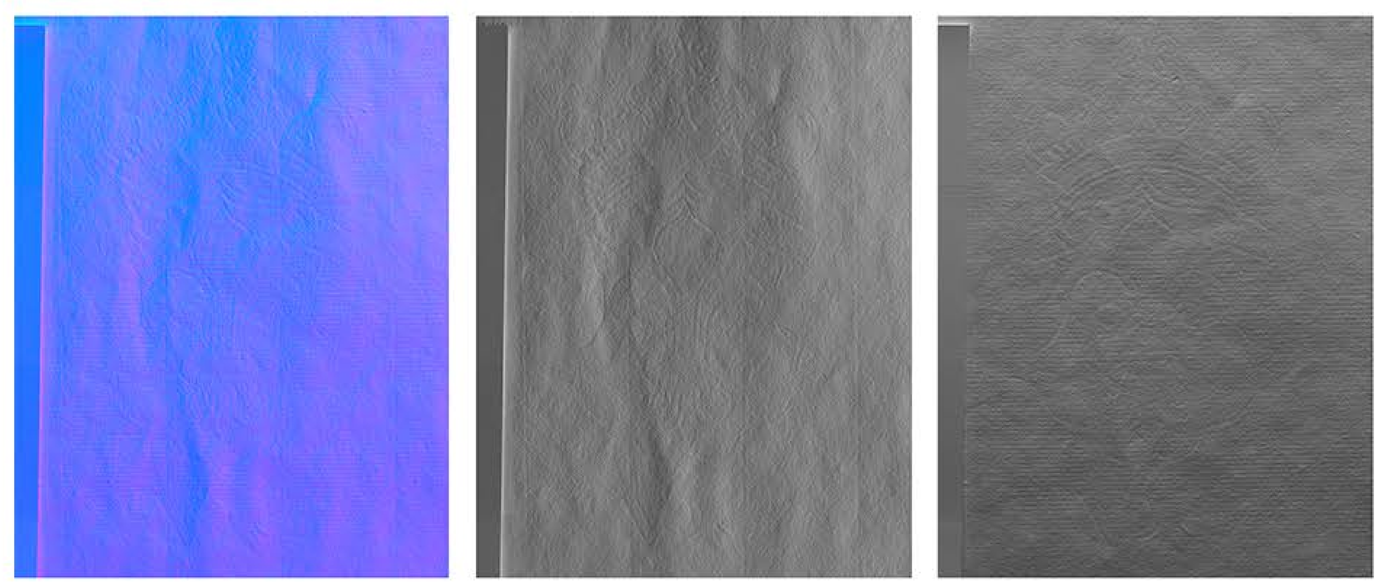

Fig 7. RGB surface normal image of watermark [left], red channel of image [center], and green channel [right]

Human perception of luminance is dominated by the green channel. So looking at the RGB normal map we perceive the textures along the Y axis as more dominant than the red X channel. Additionally, the blue channel is typically pure white, indicating a positive direction of the vector, but unnecessary to our interpretation.

Using a Photoshop script, we can overlay the red and green channels into a greyscale image to give them equal weight and remove the blank blue channel [fig. 8]. This provides an image that shows the surface impressions in the X and Y axes equally.

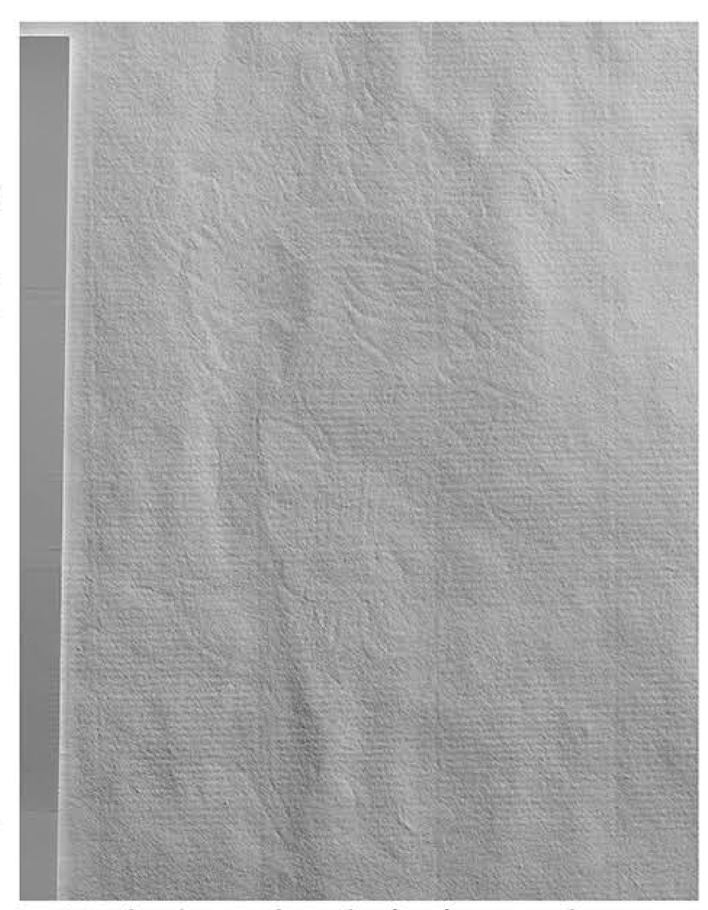

Fig 8. Red and green channels of surface normal map overlayed (Contrast enhanced for visability)

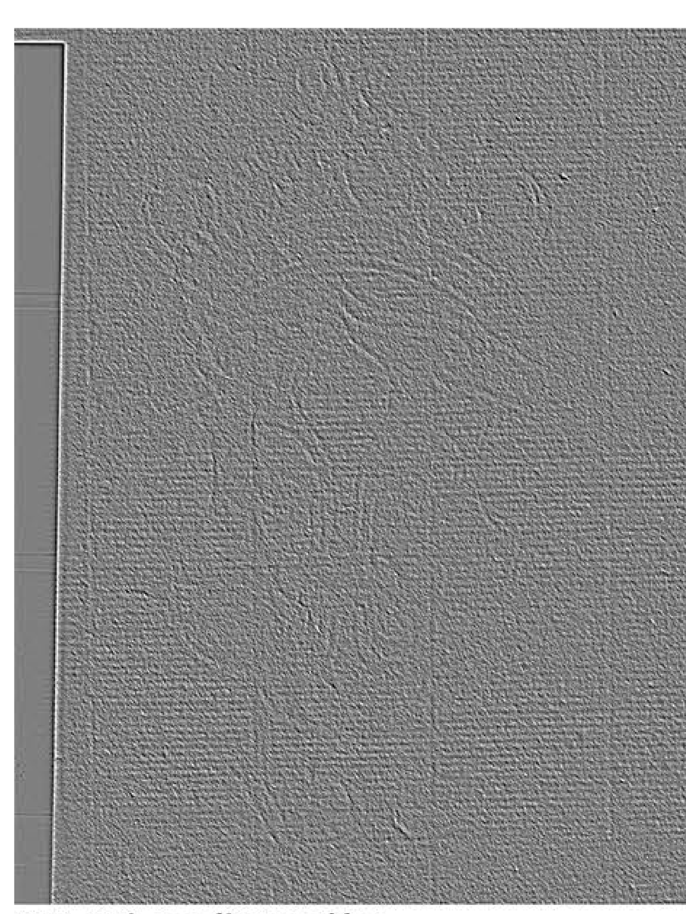

Fig 9. High-pass filtering of fig 8

In this particular case of objects though, surface distortions in the paper still causes distraction. As a solution to it, we add a high pass filter to isolate rapid changes in the surface to highlight the desired impressions and ignore gradual changes from warping [fig. 9].

3D Model

An alternative approach is to us a 3D model. Using a program written by computer science researchers at Yale, an approximate 3D model was made from the RTI dataset [fig. 10].

Fig 10. Various views of a 3D model of a watermark, including one with surface color removed [top right] as well as a side view [bottom]

Fig 11. Depiction of depth map, with higher points being assigned lighter colors and lower points being assigned darker values

With this 3D model, we can create a depth-map of the image that displays the areas farthest from the observer in dark and those closest in white [fig. 11].

This model suffers from the same issues with existing distortions in the paper as the Surface Normal Map, but again, desired impressions can be isolated by applying a High Pass filter [fig. 12]. In addition to high pass filtering, the contrast is increased and the tone is inverted to make an image more comparable to a transmitted light photograph.

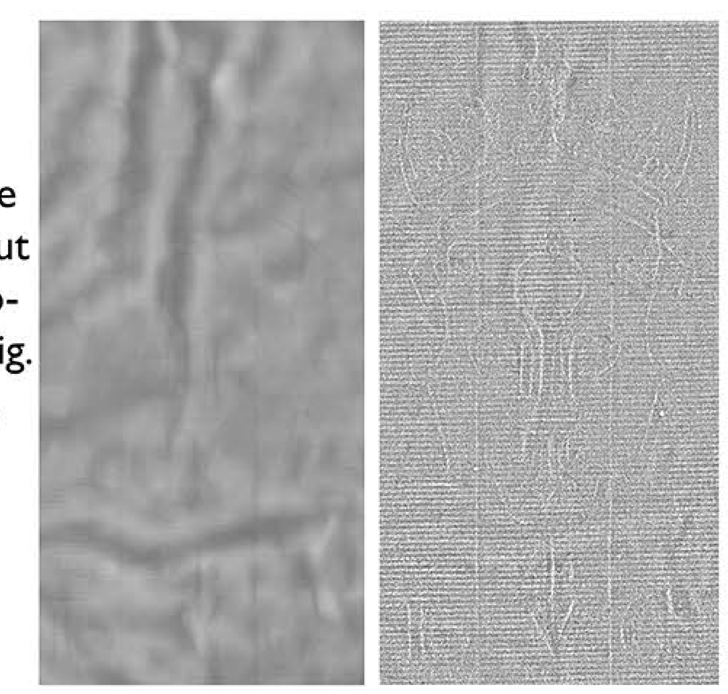

Fig 12. Depth map view of watermark [left] and processed with high pass filtering, contrast enhancement, and inverted tones (to mimic transmitted light) [right]

Removing Laid Lines

In these papers, the laid lines are made in a very rapid regular pattern. Using a program like Image J, it is possible to convert one of these images into a frequency domain image using a Fast Fourier Transform [fig. 13a].

Fig 13a. Fast Fourier Transform of fig. 12 processed image

Fig 13b. Zoomed in view of center of FFT image

Fig 13c. Masking repeated pattern highlights out

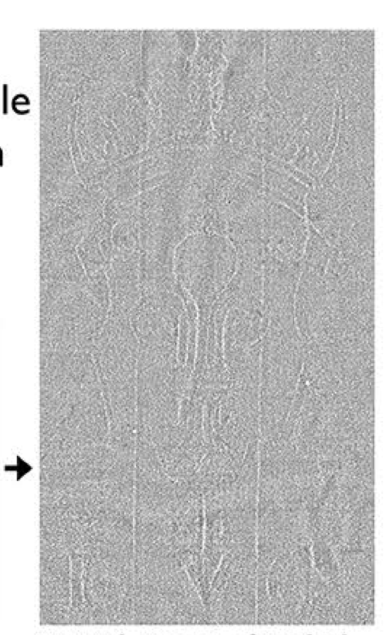

Fig 13d. Inverse of masked FFT Image with laid lines removed

The repeated pattern will show up as a hot spot in the frequency domain [fig. 13b]. Removing these points from the frequency domain image [fig.13c] and reversing the Fourier Transform will render an image with the pattern of the laid lines removed [fig. 13d].