Recovery of Lost Writings on Historical Manuscripts with Ultraviolet Illumination

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Abstract

Modern digital imaging techniques have been applied to the recovery of erased and overwritten writings on historical parchment manuscripts. In our work, we have found that images obtained under different illuminations can increase the contrast of erased or faded writings on parchment. This paper focuses on the use of ultraviolet illumination, which causes parchment to fluoresce, emitting visible light towards the blue end of the spectrum. This fluorescence increases the contrast of both faded and erased iron gall inks on parchment. On the thousand-year-old Archimedes Palimpsest, fluorescence imaging, together with post-capture image processing, makes much of the erased Archimedes text visible to the classical mathematics scholars who are trying to read it. In addition, we have found that ultraviolet reflectance imaging has been able to reveal characters on a scraped page of a five-hundred-year-old Hebrew prayer book that showed little evidence of characters under ultraviolet fluorescent imaging. The physical mechanisms for these differences are not well understood, but they can be used to recover writings that otherwise would be lost forever.

Introduction

There are many old manuscripts in libraries and private collections that have been damaged, erased, or have just faded with time. Scholars would very much like to read these writings, which in some cases may be the only remaining copy of an ancient author's work.

A traditional method to read faded writing – one that scholars have used for years – is ultraviolet illumination. A hand-held ultraviolet source is suspended above the manuscript and the erased or faded text is read by eye.

Exactly why ultraviolet illumination helps make the faded or erased text more visible is not clear. For a manuscript that is made of parchment, i.e., the skin of a goat or sheep, the ultraviolet illumination causes the parchment to fluoresce, emitting visible light at the blue end of the spectrum. It appears that this fluorescence increases the contrast of the ink making the writings easier to read.

We have found that if these fluorescent images are recorded with a digital camera, rather than just viewed by eye, still more information can be obtained. There are several reasons for this. The first is that the camera can distinguish more gray levels than can the eye, making it easier to see fainter sections of the ink. The second is that a scientific digital camera can be used to record the parchment and ink responses in regions of the spectrum where the eye cannot see, specifically in the ultraviolet region and in the near infrared. Lastly, it is possible to post-process the digital images to extract more information than can be seen directly from the recorded data.

In this paper, we will describe two manuscripts for which we have used ultraviolet illumination with digital cameras and post-processing to recover erased writings. The first is a thousand-year-old overwritten manuscript whose pages have been erased and overwritten with another text. Ultraviolet fluorescence enhances the erased writings very nicely and subsequent image processing makes them even more visible for the scholars to read.

The second manuscript is a five-hundred-year-old prayer book. Most of the manuscript is in very good condition, but the page that contains important publishing information, such as the name of the scribe, the date it was written, etc., was scraped clean. Ultraviolet fluorescence did not reveal any characters on this page. On the other hand, we found that we were able to record characters in the ultraviolet region of the spectrum. This required using a scientific camera that is sensitive in the ultraviolet and filtering the light to record only the ultraviolet reflectance from the manuscript.

We do not know how well these techniques will work on other manuscripts. In our experience, depending on the nature of the inks and the parchments, some manuscripts do not respond as well as the two described here.

Archimedes Palimpsest

The Archimedes Palimpsest[1-3] is a thousand-year-old manuscript that contains seven works of Archimedes. One of the treatises is the only copy of "Method of Mechanical Theorems" and another is the only copy of "On Floating Bodies" in the original Greek. Eight hundred years ago, the manuscript was disbound, washed to remove the

Archimedes text, and overwritten with the "Euchologion", a Byzantine book of prayers and rituals. The word palimpsest comes from the Greek for "scraped again." Fortunately, the second writings are oriented at right angles to the original text on all but one page, and thus the text is somewhat easier to read than it otherwise would be.

After many years being used as a prayer book, the Archimedes writings were first read in 1906 by the Danish philologist, Johan Ludvig Heiberg. Having only a magnifying glass, he transcribed and published in 1915 what he could see of Archimedes' writings on this manuscript. Today, what the scientific community knows of these two treatises comes only from Heiberg's inspection of the manuscript using one-hundred-year-old technology.

In 1998, at the end of the twentieth century, the Archimedes Palimpsest was sold at auction to a private American collector. Through this collector's generosity, a team of specialists has been established to conserve, image, transcribe and publish a new edition of these works. The Walter's Art Museum, in Baltimore, Maryland, is managing this task and serves as the manuscript's repository during this multi-year effort.

The palimpsest consists of two layers of writing. The bottom layer, the Archimedes' writing, was written in iron gall ink and then later erased. The top layer is the Euchologion text. This text is oriented at 90 degrees to the Archimedes test and it also was written with iron gall ink.

A section of folio 92 verso is shown in Figure 1. The horizontal writing, which is the Archimedes text that the scholars would like to read, is barely visible as faint stains on the parchment. The figure shows the luminance component of an image taken with visible light using a Kodak DCS 760 digital camera.

The vertical writing in Figure 1 is the Euchologion prayer book text. The image should be rotated 90 degrees counterclockwise to properly orient the Euchologion text. The ink from the Euchologion text is still present on the page and is therefore much higher contrast, coarser and sharper than the stains of the Archimedes writings.

The same section of folio 92 verso under ultraviolet illumination is shown in Figure 2. In this image, the contrast of both sets of text is enhanced, though that of the Euchologion text is still greater. Again, the luminance component of the ultraviolet image is shown. Since the camera can detect only visible light, Figure 2 shows the visible response to ultraviolet illumination. In other words, it shows the visible fluorescence that the parchment emits as a result of the ultraviolet illumination. In color, this image would have a very strong blue cast.

The Archimedes text in Figure 2 is now quite visible as horizontal lines of soft-edged characters. The regions of the Archimedes characters that are obscured by the overwritten Euchologion text are not visible in either figure. From an image like Figure 2, however, the scholars can read much of the erased Archimedes text by mentally filling in the gaps where it is obscured through context and by familiarity with the scribe's handwriting.

Remote Sensing

Two years ago, we reported[4] on an image processing method borrowed from the remote sensing field that used several images from different wavelengths to distinguish between the two different inks using their different spectral signatures.

The technique worked well and was able to separate the two writings, however, it was not able to detect Archimedes text in the regions where it is obscured by the overlying Euchologion text.

When we provided images of the separate Archimedes text to the scholars, they preferred to read the Archimedes text from the ultraviolet images, instead. The scholars told us that they could not tell if gaps in the text were due to the now invisible overlying Euchologion text, or because there was no Archimedes text in that gap. As a result, the scholars preferred reading the Archimedes text directly from the ultraviolet images, like the one shown in Figure 2.

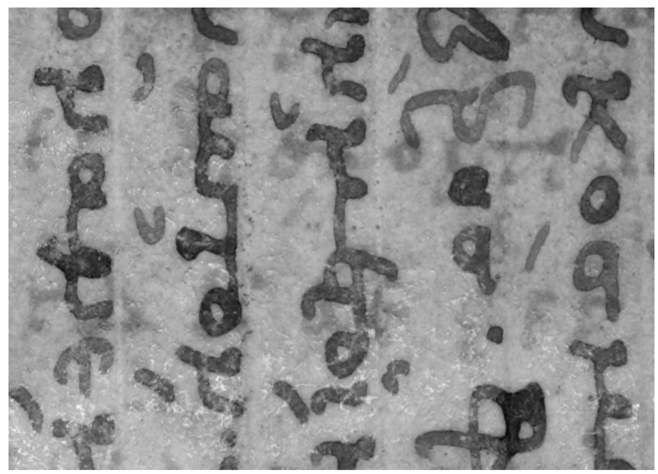

Figure 1. The Archimedes palimpsest in visible light.

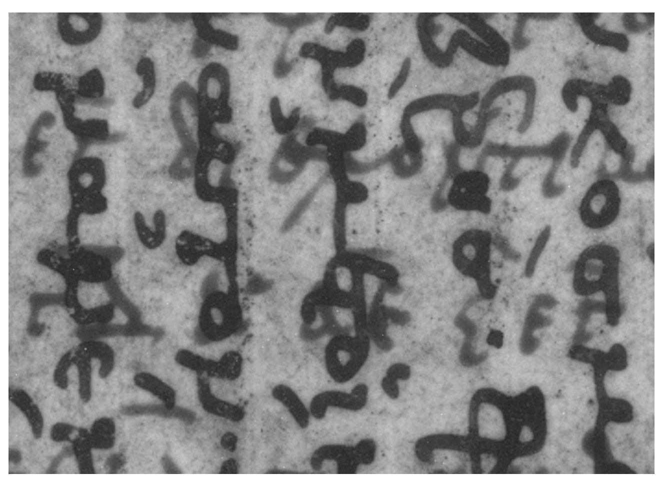

Figure 2. The Archimedes Palimpsest under ultraviolet illumination.

This meant that we needed to re-address the question of how to process the images to make the Archimedes text more legible to the scholars.

Difference Images

By comparing the two images in Figures 1 and 2, it is possible to see significant spectral differences between the two texts. By animating the images to rapidly change between them, the Archimedes text leaps from the page in comparison to the overlying text around it. The question is how to capture this spectral difference and present it in a way that is easily seen by the eye.

The first idea was to compute the difference between the two images. The visible image in Figure 1 shows mainly the Euchologion text and the ultraviolet image in Figure 2 shows both the Archimedes text and the Euchologion text. The difference of two appropriately balanced images would, in theory, contain only the Archimedes text. To balance the images, the digital values of the Euchologion text are matched in both images, as are the parchment levels. In that way, the Euchologion text and the parchment each cancel in the difference image leaving only the Archimedes text.

We tried measuring the levels of the parchment and Euchologion text in the two images and stretching the histograms to make the match. The resulting difference image did contain mainly the Archimedes text. There were a few problems in finding values that would make the Euchologion text cancel uniformly across the page.

We found that the difference image looked very similar to the separation maps that we produced using the remote sensing algorithm in our previous experiments from two years ago. As a result, the difference image had the same problem that the remote sensing image had, you could not distinguish real gaps in the Archimedes text from blank regions where the Euchologion text had been removed. The image shown in Figure 4, although not a difference image, is similar in appearance.

Pseudocolor Images

The solution was to present both the spectral difference and the character information in pseudocolor. The result is an image that contains the same spectral information as the difference image, but with much higher contrast characters and therefore much easier to read.

The pseudocolor image is constructed in a very simple way. The visible image from Figure 1 is put into the red separation of the pseudocolor image and the ultraviolet image from Figure 2 is put into both the green and blue separations of the pseudocolor image. The resultant image is viewed in color.

Because the visible image in the red separation is bright at locations of the Archimedes text while the ultraviolet image placed in the other two separations is dark, the Archimedes text appears red in the pseudocolor image. Conversely, the Euchologion text is dark in all three separations, so it appears as a neutral gray. As a result, the text that the scholars want to read appears in color and the unwanted text is black & white.

To make the spectral difference show up in color in the pseudocolor image, the digital values of the Euchologion text and parchment must be equalized in the visible and ultraviolet images. As mentioned earlier, global adjustments made across an image do not equalize uniformly everywhere over the image.

Balancing of the two images was accomplished with a sliding window 401 pixels square that was moved across the 3032 pixel by 2008 scanline image. At each pixel, the mean and variance of the pixels within the window were measured. A histogram stretching calculation was done to center the mean at 50% and stretch the data 6 standard deviations across the range from black to white. This stretch was then applied to the center pixel only. Then the window was moved one pixel and the calculation repeated.

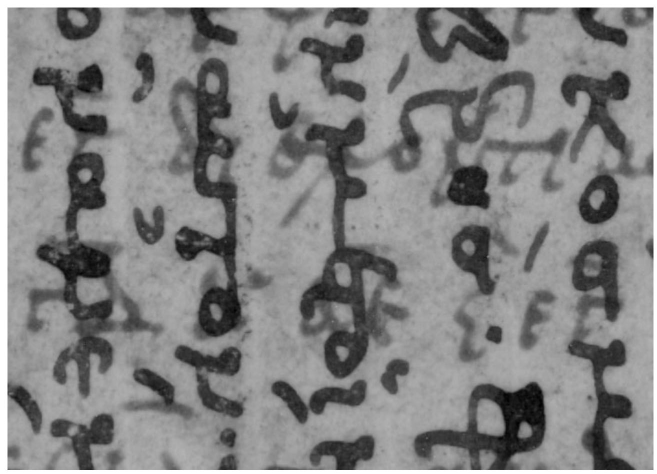

Figure 3. Luminance component of the pseudocolor image.

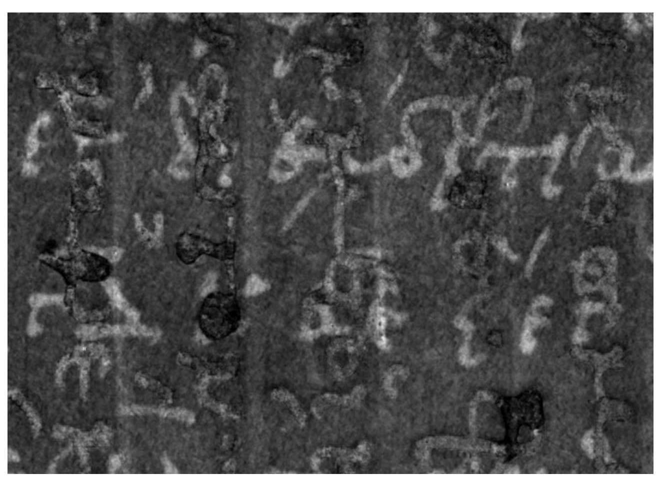

Figure 4. Red-minus-green color component of the pseudocolor.

The pseudocolor image cannot be shown in a black & white, print but the luminance and red-minus-green components are shown in Figures 3 and 4. Note that the luminance conveys the character information and the color component displays the spectral difference information. The pseudocolor image is now the standard image provided to the scholars.

Hebrew Prayer Book

The second manuscript we wish to describe is a 15th Century Hebrew prayer book, written in the Italian style. It is manuscript number 8224 in the Library of the Jewish Theological Seminary of America, located in New York City.

This manuscript is a little over 500 years old and includes 354 parchment leaves bound in book form. Page 327 verso, which has been scraped clean is a colophon, i.e., an inscription containing facts about the book's publication. The scholars at the Jewish Theological Seminary would very much like to read this page to possibly learn more about the history of the book.

Traces of the writing on the colophon are still visible. The top half of the colophon, in visible light, is shown in Figure 5. The writing is laid out in the approximate shape of an hourglass. The top half, shown in this figure, has the shape of an inverted triangle. Hints of characters appear on this page, but nothing legible is visible.

As already mentioned, the standard method to recover erased information is to view the page under ultraviolet illumination. The scholars who viewed this page with ultraviolet illumination reported that no characters were visible.[5]

We tried using the Kodak DCS 760 camera to record an image of the colophon under ultraviolet illumination. Since this camera can only record the visible region of the spectrum, it recorded only the fluorescence of the parchment and any characters that were enhanced by this method.

Figure 6 shows the fluorescence image of the top half of the colophon. Although the scribe lines have been enhanced, no new character information is visible.

An interesting question to ask is, if fluorescence imaging significantly increases the contrast of erased characters on the Archimedes Palimpsest, why would ultraviolet fluorescence not help reveal characters on this erased page?

The answer may be due to the different ways that the characters were erased. As already mentioned, the writing on the Archimedes Palimpsest is believed to have been erased using chemical treatments that dissolved and washed off the ink.[6] This process leaves stains in the parchment that might be what is being enhanced through fluorescence of the parchment.

In the Hebrew prayer book, the colophon was erased by the mechanical process of scraping the ink from the parchment. This may remove the ink and the stains, while leaving nothing to affect the ultraviolet fluorescence of the parchment.

To see if the parchment would respond to other regions of the spectrum, we used a Photometrics SenSys(scientific digital camera that has a Kodak 1602E Blue Plus sensor with enhanced sensitivity in the blue and ultraviolet regions of the spectrum. It also exhibits the usual silicon sensitivity in the infrared.

There are no filters on the surface of this sensor, so wavelength discrimination requires external filters, either held in front of the lens or in an internal filter wheel.

Figure 5. The top half of the colophon viewed in visible light.

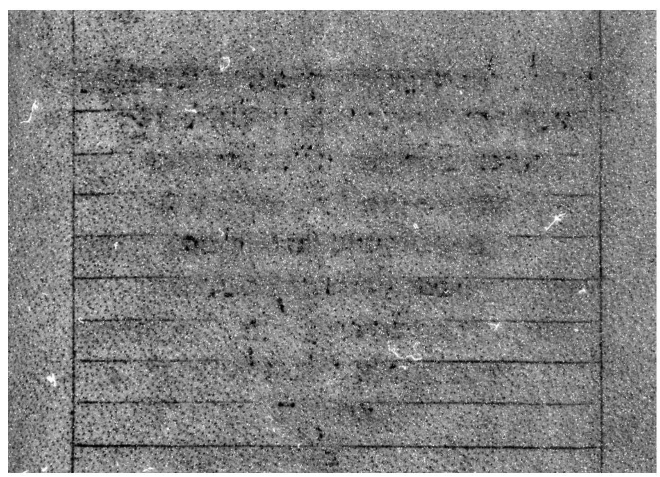

Figure 6. The ultraviolet fluorescence from the colophon.

Using the SenSys camera, we found that the erased writing did respond dramatically to ultraviolet reflectance, though there was no response in the infrared.

The image in Figure 7 shows an image taken under ultraviolet illumination with an astronomical ultraviolet filter in front of the lens.

Because the ultraviolet filter blocks any visible light, the fluorescence of the parchment does not contribute to the image. This image therefore shows only the ultraviolet illumination reflected from the parchment.

Hebrew characters are clearly visible in the image shown in Figure 7. Some of the characters are quite clear while others are not so clear. Unfortunately, the most important information, the scribe's name and the patron's name, are among those characters that are still unclear.

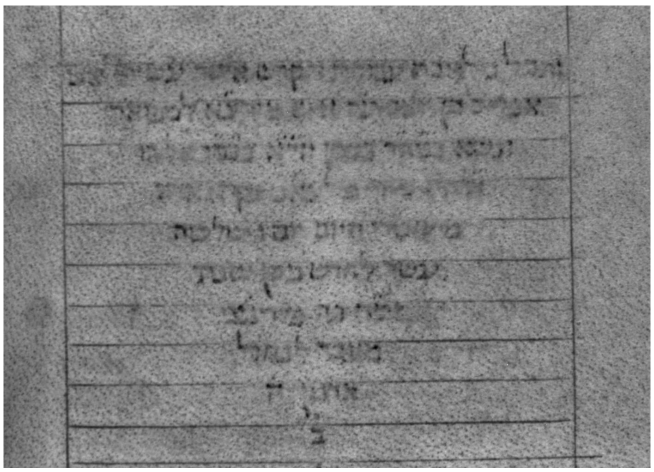

Figure 7. The ultraviolet reflectance from the colophon.

Figure 8. The UV reflectance image smoothed and enhanced.

In order to reduce the noise in the image and further help the scholars read the colophon, a simple smoothing was implemented followed by an edge sharpening. This result is shown in Figure 8. This increased the contrast of some of the characters, making them more legible. This is not a sophisticated image processing technique and perhaps other noise reduction techniques, applied to Figure 7, might be able to increase the legibility.

As a result of inspecting Figure 8, the scholars have identified that the manuscript was written in Florence, Italy, in the latter part of the 1400's. The best estimate of the date from this image is 1488. The names of the scribe and patron are not visible from these images, but they have been deduced from other historical information about the manuscript.

A further unanswered question is why did the scraped writing become visible with ultraviolet reflectance when it did not respond at all to the ultraviolet fluorescence of the parchment? It may be that the answer lies in the different ways in which the two manuscripts were erased.

Conclusion

Ultraviolet illumination is a valuable tool in revealing erased or faded writing on parchment. In the case of the Archimedes Palimpsest, we found that the erased ink on the manuscript becomes more visible in the blue light emitted by the parchment as it fluoresces under ultraviolet illumination. In the case of the scraped colophon in the Hebrew prayer book, fluorescence imaging did not help but imaging of the ultraviolet reflectance of the manuscript revealed many new characters.

For the case of an overwritten manuscript, such as a palimpsest, we found that the use of pseudocolor provides a significant increase in character contrast, thereby dramatically increasing the legibility of the erased writing.

Acknowledgments

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Biography

Keith T. Knox received his B.S. (1970) in electrical engineering and Ph.D. (1975) in optics from the University of Rochester. He joined Xerox Corp. in 1974, where he conducted research in digital imaging for 27 years, and has since retired. His research interests include astronomical imaging, digital halftoning, and image restoration of ancient documents. He is a Fellow of IS&T and OSA.

Roger L. Easton, Jr. attended Haverford College, the University of Maryland, and the University of Arizona, where he received the Ph.D. in Optical Sciences. He is a faculty member in the Chester F. Carlson Center for Imaging Science of the Rochester Institute of Technology, where he teaches imaging mathematics, optics, and digital image processing. In 1997, he received the IS&T Professor Raymond C. Bollman Award for undergraduate teaching.