Recovery of Lost Text: What Scholars and Scientists Learn from Collaboration

KEITH T. KNOX, Early Manuscripts Electronic Library, HI, USA

Modern multispectral imaging can be applied to erased or damaged manuscripts to help scholars recover text that otherwise is not visible. Several image processing algorithms have been developed over the last two decades to mathematically manipulate the multispectral digital image data to enhance the legibility of the erased writing and suppress the interference caused by any overwriting. This paper will describe three image processing algorithms and the types of processed images that they produce. These methods were developed as a direct result of the interactions and feedback that the imaging scientists received from the scholars on the individual projects. For example, the utility of pseudocolor, to enhance the differences between the ultraviolet and visible light responses of erased iron gall characters, resulted from feedback from the scholars on the Archimedes Palimpsest project. The use of light transmitted through the parchment to reveal erased characters was initiated when a scholar on the Sinai Palimpsests Project saw otherwise invisible writing while viewing a lamp through the leaf. Lastly, the most recently developed algorithm, the triple ratio, resulted from the observation of an anomaly in a single processed image on the Zacynthius Project. When the anomaly was brought to the author's attention, the subsequent investigation resulted in the discovery of the triple ratio algorithm. The key to the development of all of these algorithms is the close collaboration between the imaging scientists and the scholars, and the sharing of ideas and observations between them.

Key words:
Text Recovery, Manuscripts, Palimpsests, Multispectral Imaging.

CHNT Reference:
Keith T. Knox. 2018. Recovery of Lost Text: What Scholars and Scientists Learn from Collaboration.

INTRODUCTION

Multispectral imaging is the process of imaging an object, in this case a manuscript leaf, under many different wavelengths of light. From the different responses of the leaf and the text to the different wavelengths, or colors, of the illumination, it is possible to separate different types of text from each other. Although this sounds very straightforward, the actual process is never this simple or straightforward. Different parts of a given leaf, or different leaves, will be exposed to different environment conditions and therefore undergo different degradations, making their responses to light different, even if all of the text has been written at the same time.

When imaging a manuscript for text recovery there are several decisions that have to be made before and during the process. Before one can start the capture process, the type of imaging modality to be used must be chosen. Among the available choices are the wavelengths of light to be used, whether the light is reflected or transmitted through the manuscript, and whether the color of the fluorescence from ultraviolet illumination will be analyzed. The scholar has likely studied this manuscript for some time and understands the nature of the parchment and its condition. The scientist, on the other hand, understands how different degradations and different inks respond to the various wavelengths of light and methods of illumination. Together, the scholar and the scientist must decide together how to image the manuscript. The scholar knows what he wants to recover, while the scientist understands how images can be captured. Neither one alone can decide what is needed to capture the necessary data.

After capture comes the processing of the data. Again, the scholar is likely familiar with the condition of the inks and the erased writing, while the scientist knows what algorithms can extract low-contrast information from noisy backgrounds. Although the scientist can apply different algorithms, he does not know where to apply them or

Author's address: Keith T. Knox, Early Manuscripts Electronic Library, 2739 Puu Hoolai Street, Kihei, HI 96753, USA; email: knox@cis.rit.edu

whether or not they have been successful. It is the scholar that can direct the scientist to the most promising regions of the parchment and can say whether or not anything was recovered. The scholar does not know what to apply, or what the results might mean, but he knows what he is trying to read. The scientist knows what techniques to apply and how to interpret the results, but not where to apply them. The two must work together to be successful.

In the last step, extended image processing is done to recover everything possible. This step takes the most time of all three steps. It happens after the imaging and the first round of processing are complete. It consists of multiple iterations of scholars requesting regions to be processed and evaluating what the imaging scientists can produce with additional sophisticated processing algorithms. The scholar knows the language of the manuscript and can distinguish real characters being revealed from noise that is being enhanced. On the other hand, the scientist knows the algorithms and can identify artifacts that might be produced by a specific algorithm. The scientist can also use a variety of methods to maximize the visibility of the recovered text. This extended processing step absolutely requires that the scholar and scientist work together closely to accomplish the goal of recovering the text.

MULTISPECTRAL IMAGING

Multispectral images are made by using a digital camera to capture the response of the inks and parchment to different wavelengths of light. There are two ways of accomplishing this capture. One is to illuminate the leaf with white light and to filter the light entering the camera to restrict to specific wavelengths of the light on the sensor. The difficulty with the method is that the filters will introduce shifts into the images that misalign the spectral images. This makes the spectral analysis of the leaf difficult, since the pixels of the images do not line up.

The second way of capturing multispectral data is to filter the light that illuminates the parchment leaf. Any shift in the illumination does not shift the captured digital images. In that way, the spectral analysis of any portion of the leaf is now possible since the digital images at every wavelength are in perfect alignment, given that the manuscript does not move during the multiple exposures at the different wavelengths. At the same time, because the illumination is filtered, less light in total falls on the manuscript.

This system of illuminating the manuscript with light of different wavelengths is the method used in the MegaVision imaging system [Easton et al. 2010] shown in Fig. 1. On either side of the camera and the copy stand are two panels of LEDs, which contain several LEDs that emit light at different wavelengths. To make the system work over a broad range of wavelengths, from ultraviolet to the near infrared, requires a special lens that is designed to remain in focus across that broad range of wavelengths.

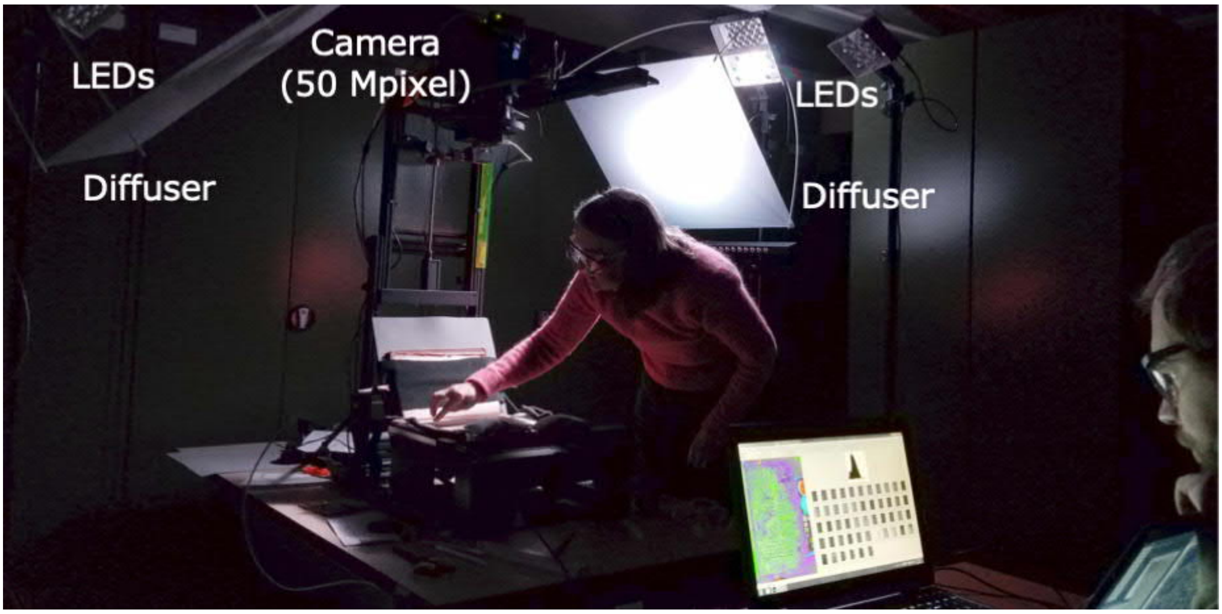


Fig. 1. The MegaVision Archival and Cultural Heritage Imaging System being operated by Dale Stewart and Ivan Shevchuk at Berlin's State Library in 2016

The fifteen wavelengths at which the LEDs emit are shown in the graph in Fig. 2. Note that the wavelength range of each LED is narrow, but all of them overlap to cover the complete range of sensitivity of the camera sensor, i.e. from ultraviolet to the near infrared, as shown in Fig. 2. Although the camera can see in the ultraviolet and the infrared regions, the human eye can only see visible light, i.e. at the blue, green, and red wavelengths.

How the illumination interacts with the manuscript leaf is also shown in Fig. 2. Of the light that falls on the leaf, some is reflected, some is transmitted through the leaf, some is absorbed, and some (mainly ultraviolet light) is absorbed and re-radiated at a longer wavelength. This re-radiated light is called fluorescence. Typically, ultraviolet fluorescence is re-radiated at visible wavelengths, converting it into light that the eye can see.

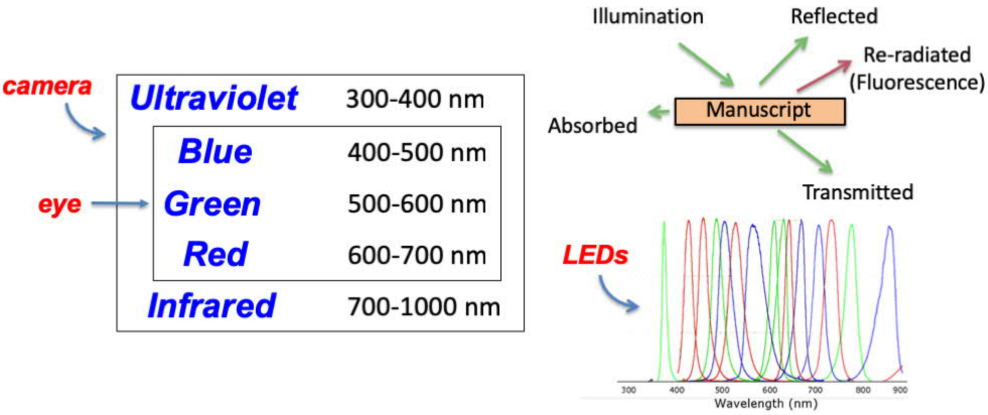
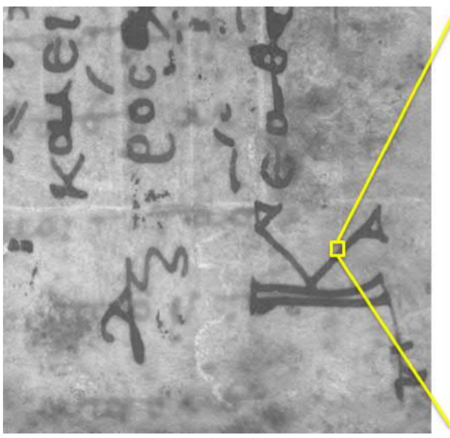


Fig. 2. Light from individual LEDs at specific wavelengths interact with the manuscript to reveal erased text

Shorter wavelength light, i.e. ultraviolet, only penetrates the leaf a short distance before it is absorbed. On the other hand, light of longer wavelengths, i.e. infrared, penetrates deeper into the leaf and is more likely to be transmitted through the leaf. By placing underneath the leaf, a light sheet that emits visible and infrared light upward, the transmitted light can be captured by the camera. As will be seen in a later section, this transmitted light will be useful in recovering characters that are no longer visible, but have eroded into the parchment making it thinner.

IMAGE PROCESSING

The camera in the multispectral system captures a digital image of a manuscript leaf. The camera is panchromatic, meaning that it responds to any wavelength of light from the ultraviolet to the near infrared. Each digital image results from illumination of only one wavelength of light, and by itself is a monochrome or black & white image.



156	159	162	160	159	157	154	150	147	141	136	132	125	115	106
153	159	156	155	156	154	152	147	142	134	132	128	119	106	099
155	160	154	149	148	147	148	150	143	134	129	119	111	101	097
157	159	158	152	148	146	146	147	143	133	124	111	103	097	097
156	158	157	154	148	147	143	142	139	131	120	105	100	098	097
157	159	157	155	152	147	142	138	130	116	107	102	101	099	097
156	158	157	154	152	146	139	129	119	108	100	099	098	097	096
155	153	154	150	147	141	132	122	114	102	097	096	096	904	093
152	148	145	141	140	129	117	110	108	100	094	097	099	096	094
148	146	143	137	133	117	106	100	100	096	094	098	100	098	099
146	146	140	130	119	105	099	097	097	094	094	097	098	097	100
141	137	130	119	107	098	099	097	096	093	094	097	097	097	099
135	128	120	107	098	099	100	100	097	093	093	095	098	099	097
127	118	111	099	097	098	098	101	098	094	095	095	099	100	098
119	109	101	096	097	096	095	096	096	094	093	094	096	099	100

Fig. 3. A digital image is an array of numbers that represent brightness variations in the image seen by the camera

An example digital image, shown in Fig. 3, is actually just an array of numbers that are captured by the camera and stored in the computer. The numbers that correspond to a very small section of the image on the left, outlined in yellow, are enumerated on the right. The numbers are larger where the image is brighter and smaller where the image is darker. The dark edge of the character can be seen in the decrease in values from top left to lower right.

Normal images appear as regions of light and dark and are seen by the eye. The camera converts such images into an array of numbers. If that array is converted back into regions of light and dark, turning large numbers into bright regions and low numbers dark, then an image again can be seen by the eye. That is what has been done in Fig. 3.

Image processing is the act of performing mathematical computations on the arrays of numbers that represent an image, so that when the numbers are reconverted back to bright and dark regions, the appearance of the image has changed. In this way, low contrast erased text can be enhanced – making it more visible to the scholar.

There are two types of image processing that are applied to manuscript data. The first is a simple combination of individual multispectral images of different wavelengths, which enhances one writing and suppresses the other. The second type consists of very sophisticated statistical processing methods that utilize many individual multispectral images to look for slight changes. These methods are able to extract low contrast information from the data.

It is the first type of image processing, simple combinations of individual multispectral images, that is the subject of this paper. These image processing methods operate without human intervention and can be automated. As a result, these are the methods that are first applied to the data, immediately after capture. The development of the routines described here has happened over the last two decades as a direct result of interactions with the scholars working on these projects. It is possible that these routines would not have been developed without this interaction.

PSEUDOCOLOR IMAGES

The pseudocolor image, for manuscript imaging, was developed on the Archimedes Palimpsest project [Knox 2008] as a direct result of feedback from the scholars on the project, as described below. The pseudocolor image was made by combining images taken under ultraviolet illumination and visible illumination into a single, color image.

The Archimedes Palimpsest [Netz and Noel 2007] is a parchment manuscript, written in iron gall ink, that was erased and overwritten. Under ultraviolet illumination, the parchment fluoresces, glowing in a nice blue color. Because the parchment fluoresces, the erased characters, which do not glow, have a much higher contrast and they become visible. In an image taken under visible light, the underwriting is very faint and barely visible, especially through the red filter. The ultraviolet, visible (red filter) and natural light images are shown in Fig.4.

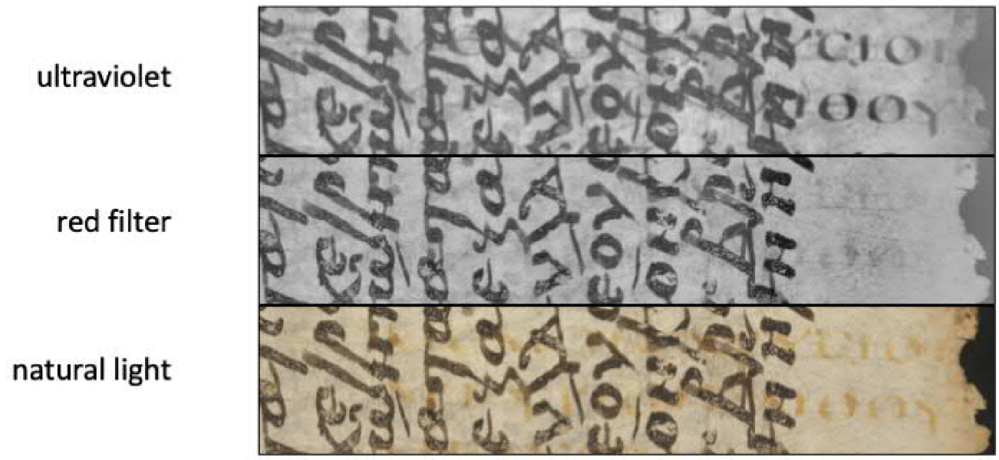


Fig. 4. The parchment and the inks respond differently to different wavelengths of light. Illuminated with natural light (bottom), the erased iron gall ink appears as red stains. Under red light (middle), the reddish stains disappear. Under ultraviolet illumination (top), the contrast of the erased text is significantly increased. © St. Catherine's Monastery of the Sinai, used with permission

The first concept that the imaging scientists tried [Easton 2011] was to use the visible image to suppress the overwriting in the ultraviolet image, by forming a difference image. In this way, only the erased writing was left on the page. From a distance, the difference image appeared to be filled with the erased writing, now made visible. From the imaging scientists' viewpoint, it was a complete success.

From the viewpoint of the scholars on the project, Reviel Netz and Natalie Tchernetska, this difference image was not helpful. The problem was, by making the overwriting disappear, i.e. look like the parchment, it left gaps where the overwriting had been. The scholars complained that when they came to a gap, they could not tell if it was a real gap, or if it was a place where the underwriting had been overwritten. Instead of using the difference image, the scholars would read the ultraviolet image, until they came to a region of overlapping characters, then they would refer to the visible image to distinguish between the underwriting and the overwriting.

After listening to the scholars' feedback, it was determined that the solution was to use the difference information, between the ultraviolet and visible images, to enhance the underwriting rather than suppress the overwriting. By combining the ultraviolet and visible (red filter) images in a single pseudocolor image, the overwriting is still visible but neutral, i.e. gray or black, while the underwriting can be enhanced with color, e.g. turning the underwriting red.

The pseudocolor technique was further developed in the Sinai Palimpsests Project[1], a five-year effort to recover text from over 70 palimpsests in the library of Saint Catherine's Monastery in the Sinai Desert in Egypt. An example of a pseudocolor rendition of a portion of a Greek palimpsest from the Saint Catherine's Library is shown in Fig. 5, compared to its natural light image.

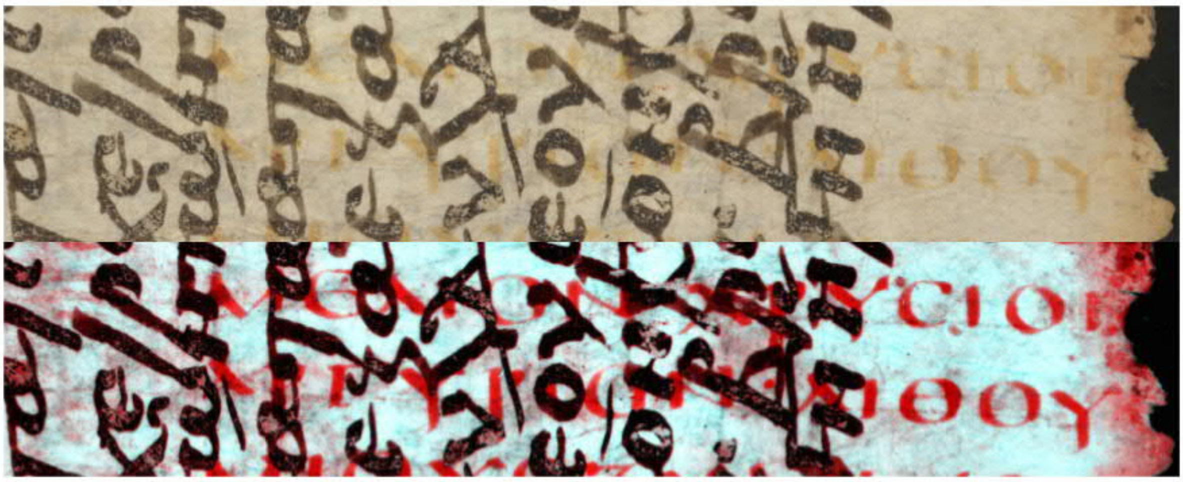


Fig. 5. The natural light image (top) compared to the pseudocolor processed image (bottom). The increased contrast of the pseudocolor image makes the erased text legible, even in the regions that overlap with the overwriting. © St. Catherine's Monastery of the Sinai, used with permission

In the natural light image in Fig. 5 (top), the horizontal underwriting is barely visible, and is slightly red. With red illumination, or under white light and a red filter, the underwriting essentially disappears, as it does in Fig. 4. Under ultraviolet illumination, both the overwriting and underwriting become darker and higher contrast. The pseudocolor image is constructed by putting the visible (red filter) image in the red separation of the pseudocolor image, and the ultraviolet image in the green and the blue separations. Since the overwriting is dark in all three color separations, it shows up as a neutral color, i.e. as gray or black. On the other hand, the underwriting is dark in the green and blue separations and bright in the red separation, making it appear red in color.

The goal of the pseudocolor image was to fill in the gaps of the difference image, and put both the visible and ultraviolet images in one pseudocolor image. In this way, the scholars did not have to refer back and forth between the two images to read the underwriting. That was accomplished, but there was an additional unforeseen advantage resulting from this combination. By combining the two images, the black & white contrast of the underwriting in the

[1] http://sinaipalimpsests.org/

ultraviolet image was maintained, but in addition, by rendering of the underwriting in color, the black & white contrast was augmented with color contrast. The combination of the black & white contrast along with the color contrast, gives the underwriting even higher visual contrast than either the ultraviolet or visible images have by themselves. The scholars on the Archimedes Palimpsest project were adamant in their conclusion that the pseudocolor image made the underwriting more visible than any other rendition done before it [Netz and Noel 2007].

Note that enhancing the underwriting in red is not required. Other color enhancements are possible. A small percentage of scholars will be red-green color blind and the red enhancement will therefore not be as effective for them.

TRANSMISSION RATIO IMAGES

One problem that was encountered in the Archimedes Palimpsest project occurred when there were no erased character stains in the parchment. The chemical residuals had eroded the parchment leaving slight cavities in the parchment. Because there were no stains in these locations, there was nothing to suppress the fluorescence of the parchment, and the erased characters did not become visible under ultraviolet illumination. In the Archimedes Palimpsest project, this occurred on only four pages. For those pages, the writing could be read by using with raking light, i.e. light hitting the leaf at a very shallow angle. The raking light casts shadows that make the missing characters visible.

This occurred again in the Sinai Palimpsest project in an interesting way. At the beginning of the project, the director of the project and scholar, Michael Phelps, was reviewing the manuscripts in the library, looking for good examples of palimpsests to image. While looking at one manuscript with a colleague, the two of them concluded that one particular page had no erased writing at all. However, when the colleague turned the page, a bright light across the room crossed behind it and a flash of white characters were revealed on the page. After an investigation, they realized that there was erased writing on the page, but that the characters had eroded away, leaving no residual stains. In addition, the resulting cavities were exactly in the shape of the missing characters. What had been discovered was that transmitted light would reveal eroded characters that were otherwise invisible. This led to the development by William Christens-Barry of a light sheet to send light through the leaf from underneath.

In Fig. 6 are shown two images of a manuscript from the library of Saint Catherine's Monastery, for which the manuscript is illuminated from below with infrared light (940 nm) and separately, from above with infrared light. Note that in the upper image, the transmission image, the erased characters appear as white characters on the parchment. There are no stains in those regions, but the parchment is thinner, and the localized cavities are in the shape of the characters. Because the parchment is thinner where the characters are located, light coming from underneath is scattered less by the parchment there, and more light comes through, making the characters brighter than the surrounding parchment. Note also that the visible ink on both sides of the leaf block the light and they therefore show up as dark characters in this image.

The lower image in Fig. 6 is an infrared reflectance image. It also shows the existing ink on the front surface, as does the transmission image. Curiously, though, the erased characters show up dark in infrared light. Since the infrared light penetrates deeper into the parchment and is scattered sideways and upwards, there is less parchment in the region of the letters to scatter light upwards. This makes the erased character regions darker in infrared reflectance.

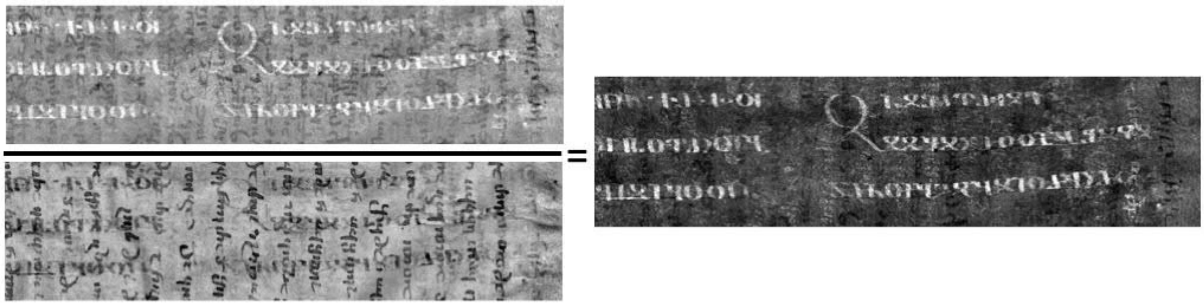


Fig. 6. When the infrared transmission image (top) is divided by the infrared reflectance image (bottom), in the ratio image (right) the erased text is enhanced (white) and the overwriting is suppressed. © St. Catherine's Monastery of the Sinai, used with permission

The infrared transmission image (upper image in Fig. 6) has white erased characters and dark overwriting. As described earlier, the reflectance image has dark erased characters and dark overwriting. By taking the ratio of the two images, the erased characters are enhanced, while the overwriting is suppressed. Dividing by dark characters (small numbers) makes the numerator image brighter (larger numbers). Dividing the white characters by dark characters makes them brighter. Dividing the dark characters (overwriting) by dark characters suppresses their visibility. The ratio of the transmission image and the reflectance image is shown in Fig. 6, on the right. The erased characters are now clearly visible as white characters on a dark background. One advantage of this method is that if the light can get through any of the overwriting, then the white characters will be complete without gaps. This is different from the normal circumstances with ultraviolet imaging, where the overwriting blocks the underlying erased writing.

This occurrence of erased characters eroding the parchment occurs more frequently on the flesh side of the leaf. Characters are seldom eroded on the hair side. The characters on the hair side are made visible with ultraviolet light.

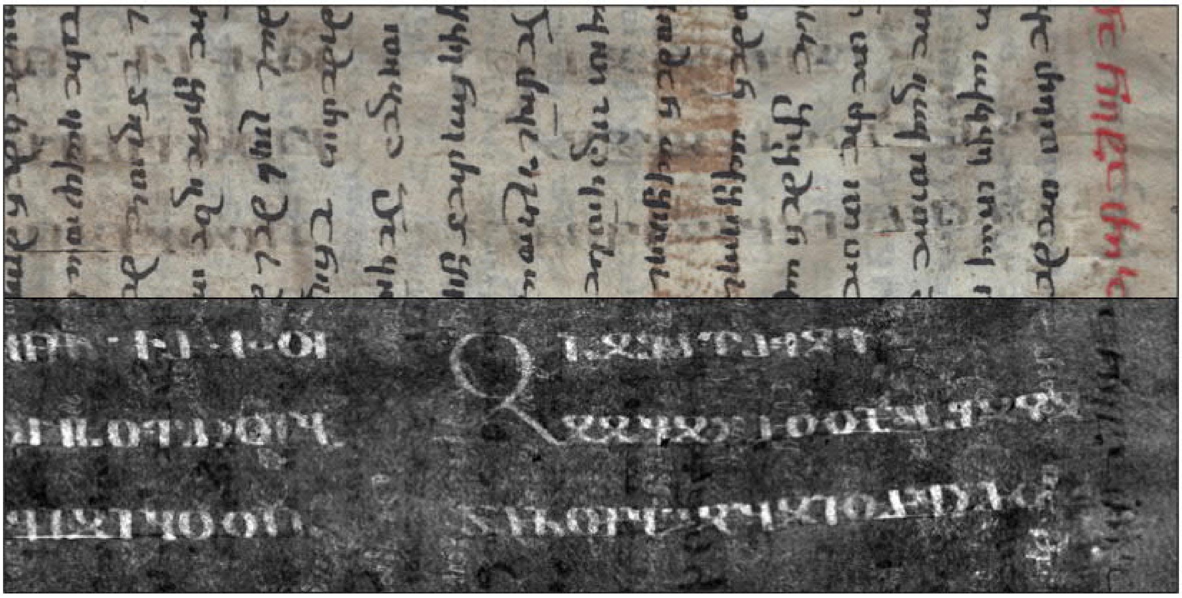


Fig. 7. A comparison of the natural light image (top) with the transmission ratio image (bottom) of the same region. © St. Catherine's Monastery of the Sinai, used with permission

In Fig. 7, the natural light image of the leaf is shown with the transmission ratio image. The erased characters are barely visible in natural light, but are very clear in the transmission ratio image. The erased characters in the natural light image appear to be neutral in color, rather than reddish as iron gall stains appear. As with the infrared illumination, this is because the stains have been eroded away, leaving cavities. These cavities scatter less light back to the camera making them darker than the parchment around them, but neutral in color.

TRIPLE RATIO IMAGES

In July 2018, the manuscript codex Zacynthius was imaged at the University of Cambridge Library in Cambridge, England. The manuscript is a Greek New Testament codex [Greenlee 1959] thought to have been written in the 8th Century and then erased and overwritten in the 12th or 13th Century.

For the first step in processing, the standard pseudocolor processing (described earlier) was completed. In Fig. 8, the natural light image is shown on the left, with the pseudocolor image in the middle and a sharpie image on the right. The sharpie image [Easton et al. 2010] is merely the difference of the two color separations contained in the pseudocolor image. This suppresses the overwriting, emphasizing the underwriting, but leaving gaps where the overlaps occur.

Fig. 8. A small region of one leaf of Codex Zacynthius. The natural light is shown on the left, the pseudocolor image in the middle and the sharpie image (difference image) on the right

In the natural light image, in Fig. 8, the erased text is horizontal and appears as reddish markings against a lighter reddish parchment. To confuse the issue, there are red inks marks in the overwriting. These red marks show up red in the pseudocolor image, seen in the middle of Fig. 8. They are easily confused with the enhanced red erased text. They are less confusing in the sharpie image, seen on the right in Fig. 8. Even so, neither the pseudocolor image nor the sharpie image was fully satisfying to the scholars for legibility.

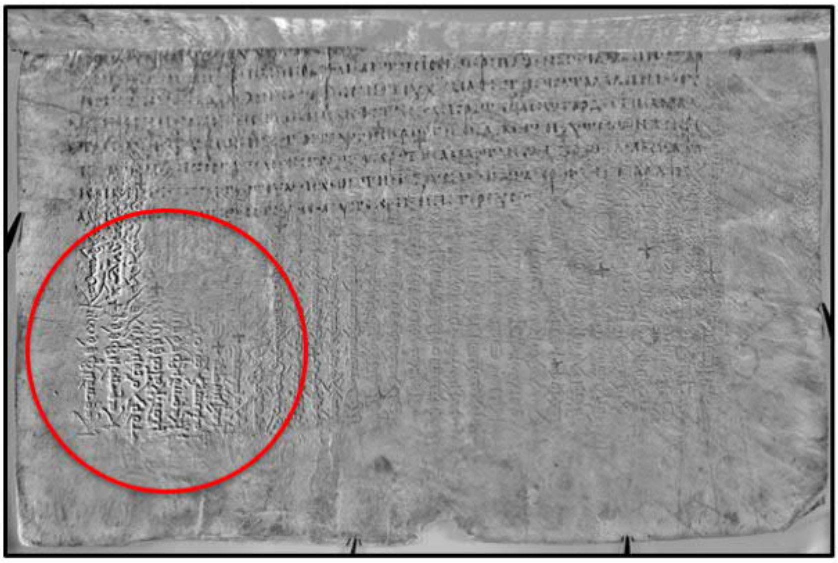


Fig. 9. A difference image of one complete leaf of Codex Zacynthius. Within the red circle the overtext shows edge effects that might indicate a localized shift between the two images used in the difference calculation

Near the end of the imaging session a problem was pointed out by the imaging scientist Roger Easton that the sharpie of one leaf (and only one leaf) had a very specific problem, as seen in Fig. 9. Within the red circle is a region where the text in one image appears to be locally shifted with respect to the other image. This might have occurred if a corner of the leaf curled up as the series of exposures that were taken, making one image different from the rest.

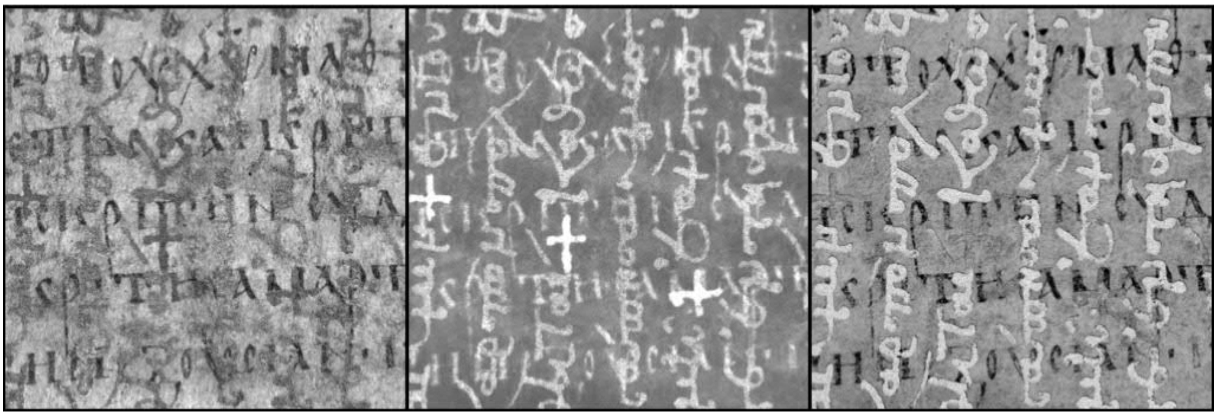


Fig. 10. Three different ratios of individual wavelength images. On the left is the ratio of two images through an orange filter with different wavelengths of ultraviolet illumination. In the middle is the ratio of two fluorescence images through a blue filter. The right image is the ratio of the red and green reflectance images

The way to test the hypothesis that one image is shifted from another is to take the ratio of the two images. A shift of one image in a ratio causes significant edge effects with white line and black lines at the edges of the characters. Something similar appears in Fig. 9, leading to the conclusion that a shift might be involved.

To test this hypothesis, the ratio was computed of the two potential shifted images, the reflectance images under red and green light. This ratio is shown in Fig. 10, on the right. No shift was evident, but a surprising result occurred – the erased text was beautifully rendered, much better than in any other rendition. In addition, the overwriting was suppressed, making the erased text even more visible. A study of several other ratios showed that ratios of fluorescence images also revealed the underwriting, but in different ways. That led to the possibility of combining three different ratios into one color image. A new type of image, called a triple ratio, was formed by putting in the red separation a ratio of two fluorescence images taken through an orange filter, in the green separation a ratio of two fluorescence images through a blue filter, and in the blue separation, a ratio of the red and green reflectance images.

Fig. 11. The natural light image (left), compared to the pseudocolor image (middle), and the triple ratio image (right). The scholars concluded that the triple ratio image gave the best legibility of the erased text

A comparison of the new triple ratio image can be seen in Fig. 11. The natural light image, the pseudocolor image, and the triple ratio image are shown from the left to right, respectively. While the erased text is visible in the pseudocolor image, its visibility is reduced by the high contrast of both the red overwriting and the black overwriting. On the other hand, the erased text in the triple ratio is very high contrast, both in black & white contrast and in color contrast between it and the parchment. In addition, the overwriting has greatly reduced contrast, and therefore it introduces much less interference with the legibility of the erased writing.

The new triple ratio image was very easy to implement and all 352 sides of the 176 leaves of the manuscript were processed in this manner. The scholars on the project were very pleased with the results and are busy transcribing the manuscript. In time, there may be a need for additional processing using statistical processing methods, but for now the triple ratio will provide the scholars with most of the information they need to transcribe the erased text.

What caused the glitch in that one image of the one leaf was never determined, but the investigation into that glitch led to the discovery of a new method that will recover almost all of the erased text of Codex Zacynthius.

CONCLUSIONS

Multispectral imaging has been applied for many years to the problem of text recovery from palimpsests [Gippert 2007; Rabin, et al. 2015; Easton et al. 2018; Easton and Kelbe 2014]. Within the last two decades, the power of new digital imaging technologies and digital imaging processing techniques has been added to the toolset being applied to the problem. Even with all of these new capabilities, there is no one method that is guaranteed to recover text from ancient parchment manuscripts.

When these manuscripts were created, the processes of making parchment and ink varied from region to region. There are similarities to these processes, so some general image processing techniques can be applied, with some success. On the other hand, there are enough differences in the ways that the manuscripts were created, or were treated over time, that every new imaging project has required new methods to recover the erased text.

Given that new methods are likely to be needed on a new manuscript, it is imperative that the scholars and the imaging scientists work closely together, as described in this paper, to achieve the maximum recovery of the erased text. The scholar understands the nature of the text. The imaging scientist understands how an algorithm extracts low-contrast information. Neither understanding is sufficient by itself to recover the erased text. Only when the scholar and the scientist pool their knowledge and their efforts can the text recovery be successful.

ACKNOWLEDGEMENTS

The author acknowledges the efforts of the EMEL team (Early Manuscripts Electronic Library) for providing the opportunities, the equipment, the technical know-how, and the camaraderie over the last two decades on several multispectral imaging projects. The members of the team include, Michael Phelps, director of EMEL and scholar, Dr. Roger Easton, Jr., Prof. of Imaging Science at Rochester Institute of Technology, Damianos Kasotakis, EMEL Director of Imaging, Kenneth Boydston, CEO MegaVision, and Prof. Ira Rabin, University of Hamburg. The author also wishes to acknowledge the many scholars that have influenced this work, including Reviel Netz, Stanford University, Jost Gippert, Goethe University of Frankfort, Hugh Houghton, University of Birmingham, and Jana Gruskova, Comenius University Bratislava.

REFERENCES

Roger L. Easton Jr., Keith T. Knox, William A. Christens-Barry, and Kenneth Boydston. 2018. Spectral Imaging Methods Applied to the Syriac-Galen Palimpsest. Manuscript Studies 3, 1, 69–83.

Roger L. Easton Jr. and David Kelbe. 2014. Statistical Processing of Spectral Imagery to Recover Writing from Erased or Damaged Manuscripts. Manuscript Cultures 7, 35–46.

Roger L. Easton Jr. et al. 2011. Ten Years of Lessons from Imaging of the Archimedes Palimpsest. *Commentationes Humanarum Litterarum* 129, 5–34.

Roger L. Easton Jr. et al. 2010. Standardized system for multispectral imaging of palimpsests. In Computer Vision and Image Analysis of Art. Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 7531, D1-D11.

Jost Gippert. 2007. The Application of Multispectral Imaging in the Study of Caucasian Palimpsests. In Bull. Georg. Natl. Acad. Sci., 175, 1 (2007). 168-179.

J. Harold Greenlee. 1959. The Catena of Codex Zacynthius. In Biblica, 40, 4 (1959). 51–59.

Keith T. Knox. 2008. Enhancement of overwritten text in the Archimedes Palimpsest. Proc. SPIE 6810, Computer Image Analysis in the Study of Art, 681004 (29 February 2008).

Reviel Netz and William Noel. 2007. The Archimedes Codex, London: The Orion Publishing Group, 214-216.

Ira Rabin, Roger L. Easton, Jr., Keith T. Knox, Kenneth Boydston, Gregory Heyworth, and Timoty Leionardi. 2015. initial inspection of reagent damage to the Vercelli Book, Comparative Oriental Manuscript Studies Bulletin, 1, 1, 34-45.

Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.
Authors are responsible for the contents and copyrights of the illustrations/photographs.