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Short Paper

Multispectral Imaging for Historical Artifacts: A Case Study Using an 8th-Century Biblical Scroll

E. Arnold, I. Moyer, A. Bourgeois, P. Mei, J. Decker, R. Easton, Jr., and D. Messinger

Rochester Institute of Technology
Rochester, NY

Abstract

Many objects of interest in cultural heritage, such as manuscripts, scrolls, and books are faded, damaged, or otherwise unreadable so that useful studies of them are difficult. Fortunately, modern imaging tools, including sensors, lenses, and illumination sources have leveraged multispectral imaging as an accessible method for cultural heritage imaging which has, in turn, increased the demand for its use. To address this, the Rochester Institute of Technology received a grant from the National Endowment for the Humanities (PR-268783-20) to develop a low-cost, portable imaging system with processing software that could be utilized by scholars accessing collections in library, archive, and museum settings, as well as staff working within these institutions. This article gives an overview of this system and uses an 8th-century Hebrew manuscript as a case study to demonstrate the impact of such a low-cost, low barrier-to-entry system on cultural heritage research, preservation, and dissemination.

CCS Concepts

• ***Applied computing*** $\rightarrow$ ***Arts and humanities; Document capture;***

1. Introduction

1.1. Spectral Imaging for Cultural Heritage

Many objects of interest in cultural heritage have been damaged in ways that make useful studies difficult or impossible. For example, palimpsested manuscripts have been erased and overwritten to the point where the original text is unreadable. Fortunately, modern imaging tools, including sensors, lenses, and illumination sources, may help such studies in significant ways. It is now possible to construct inexpensive imaging systems that record images of objects illuminated with different wavelengths of light, including those beyond the range of human sensitivity, and then combine those images to enhance the visibility of the features of interest. The various aspects of the technology are collected under the term "multispectral imaging" (MSI).

The history of multispectral imaging of historical manuscripts arguably dates from 1844-1846, when William Henry Fox Talbot published "The Pencil of Nature," in London [URLc]. Multispectral imaging of historical manuscripts, and particularly of palimpsests, was implemented in the 1890s by Ernst Prinsheim and Otto Gradenwitz. Multispectral imaging with ultraviolet sources was demonstrated by Father Raphael Kögel of the Order of Saint Benedict [Kog20, URLb]. His work led to the publication of the full edition of the palimpsested text Codex Sangallensis 193 in 1913 [Bev13]. This was intended to be the first in a series of published palimpsests that was immediately interrupted by the First World War and never restarted.

1.2. Improvements in Technology

Improvements in the imaging technologies stagnated until the development of digital computers roughly beginning in the 1970s. John F. Benton of Caltech applied digital image processing to manuscripts with significant success [Com78]. The studies of the Archimedes Palimpsest from 2000-2011 further demonstrated the value of MSI in studies of cultural heritage [EKCB03, EN10, DZ19], and the technology has since been applied to a wide variety of objects, including the palimpsests at St. Catherine's Monastery in Sinai, the Ambrosiana Library in Milan, and the Biblioteca Capitolare in Verona. The demonstrated value of MSI has increased the demand for its use. To address this demand, the Rochester Institute of Technology received a grant from the National Endowment for the Humanities (PR-268783-20) to develop an inexpensive portable imaging system with processing software that could be utilized by scholars in library settings. This system is called MISHA (Multispectral Imaging System for Historical Artifacts) [URLb].

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2. System Overview

2.1. Concept: low-cost, low barrier-to-entry

The concept for Rochester Institute of Technology's multispectral system originated in an imaging science undergraduate capstone project in 2015-16 to develop a portable system using accessible materials [Sac16]. Building upon this effort, a prototype was built by imaging scientists at RIT to demonstrate the system and processing capabilities accessible to non-scientist users. Funding to sustain the research effort was secured in 2020 to build the system and share its specifications, and to develop supporting documentation to support the work of scholars accessing collections in library, archive, and museum settings and staff working within these institutions. MISHA was built for only under ten thousand dollars. This can vary due to changes in the supply chain, but MISHA still remains an affordable option to smaller museums, libraires and archives, compared to the high cost of other MSI systems. The system is portable and easy to assemble and use, which opens up access to non-transportable materials. These key attributes offer advantages over more expensive and complicated fixed-in-place systems [KCM21, KDZ21].

2.2. System Design

Full specifications are defined elsewhere [KCM21]: put simply, MISHA comprises three elements: the light source; the camera, sensor, lens, and monochromator; and the platform and housing for image capture. Employing the capacity of multispectral imaging to divide the light spectrum into frequency bands and to record these independently, MISHA uses 16 light emitting diodes (LEDs), with each capture using a specific wavelength ranging from the ultraviolet to the visible and the near infrared. It uses 2 UV bands at 365nm and 385nm, 2 Near Infrared bands at 850nm and 940nm, with the 12 other bands in the visible range. LEDs were chosen instead of a spectral filter system to reduce broadband illumination and maintain mechanical simplicity. The LEDs are affixed to a metal panel that is connected to arms on either side of the central arm of the system (that holds the lens and sensor). The LED panels face down, at a 45-degree angle, to illuminate artifacts and to minimize specular reflections. Imaging is performed in a dark environment, either a darkened room or a provided black enclosure. Figure 1 shows the general setup of the MISHA camera system, without the black enclosure.

MISHA uses a FLIR backfly camera and a Schneider VIS-NIR (Visible/Near Infrared) apochromatic lens. The camera, lens, and sensor are fixed to an arm whose height can be adjusted for working distances from 584.2mm to 304.8mm as in traditional copy stand work and with the lens pointing down at the object to be imaged. A spectralon calibration target is placed near the object and within the field of view as a reference surface for calibration to reflectance.

The LED panels and the lens are anchored to a metal frame with three sides of the housing. As noted above, imaging must be performed in the dark to control the illumination. Operationally, the system elements are framed with black, corrugated, layered, foam board surrounding the three sides. Black cloth is affixed to the front of the rig, completing the fourth wall of the housing for image capture. The darkness of the capture field thus reduces the need to image in a completely dark room.

Figure 1: *The MISHA imaging system (without the black enclosure). Note the positions of the LED panels, the camera, and the table where artifacts are placed.*

2.3. Image Capture

Using software for camera control developed for this application, images are captured when each LED is illuminated. Sixteen different images are collected and registered as bands. Each individual band creates a grayscale image, so that each pixel shows how bright a color is at each point. In order to calibrate images, flatfield images are also captured. Camera height is manually adjusted to achieve the desired combination of Field of View (FOV) and spatial resolution. Additionally, the focus of the camera is manually adjusted to achieve the best possible sharpness of the image whenever the working distance is changed.

2.4. Image Processing

MISHA's image processing employs a user-friendly application created as part of a regional consortium of which RIT was a cofounder, the Rochester Cultural Heritage Imaging, Visualization, and Education group (R-CHIVE) [RCHa]. Researchers at RIT developed the RCHIVE app (Rochester Cultural Heritage Image processing and Visualization Environment), as a no-cost option for reading and processing spectral data [RCHb]. Processing involves creating a data cube from the captured bands, with pixel by pixel (spatial data) in the x and y dimensions, with the spectral data for each pixel in the z, or wavelength, dimension. As the data collected from MISHA lie outside of the visible spectrum of electromagnetic radiation, false color renders are used to display the results. By depicting the bands of light collected from the data and visualizing them as RGB bands that compose a common digital image, users can get an understanding of the spectral data. This data can be manipulated in many ways to return results suitable for cultural imaging purposes, however the most common manipulation is Principal Component Analysis (PCA). PCA is used in data science to reduce variables in large data sets, but still maintain the wealth of information in the large set. It is a common tool in multispectral image analysis in use for many decades as noted in [EN10, DZ19]. For the current use-case, PCA is used to find materials of similar properties that reflect in similar ways and group them together in order to create a contrast from the other materials in the image.

2.5. Limitations

The system however does have its limitations. Multispectral imaging cannot "see" through objects like x-ray imaging can, and is only designated for two dimensional surfaces. As a low-cost, low barrier-to-entry system, the resolution and quality are only as good as the camera and lens used to build the system. A second challenge is that the lens must be manually focused. Third, the resolution decreases as the camera is raised, limiting the field of view of the camera. However, each use case provides an opportunity for improvements to the system and software to be made, and for limitations to be overcome.

2.6. Use Cases

To date, over 120 items have been imaged onsite at RIT or offsite at institutions over the past year. These use cases have validated that MISHA can be used on a variety of substrates, from medieval manuscripts and Renaissance artwork to thermal papers of the 1980s and contemporary glass. Significant, new information about collections has been realized, such as palimpsested material. For instance, a leaf from Otto Ege's Famous Leaves from Medieval Manuscripts, which has been in RIT's Cary Collection for multiple decades, was imaged and was found to be palimpsested. By imaging this object, knowledge about the leaf was enhanced, beyond what was in the catalog and "known." A contemporary use case is seemingly blank thermal papers from fax transmissions in the early 2000s that were thought to be unreadable [URLa]. However, their contents were made visible through image capture and processing with MISHA. From medieval to the modern era, faded 2D surfaces have provided successful use cases for multispectral imaging with MISHA.

3. Case Study

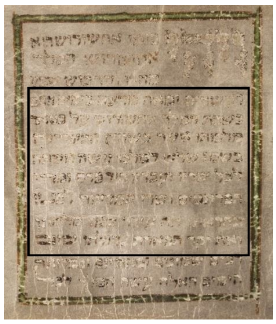
3.1. The "Book of Esther" in RIT's Cary Collection

This case study focuses on the Book of Esther, a Hebrew text written and painted around the year 800 CE. It is a parchment scroll comprising one of the five scrolls read on particular Jewish religious holidays. It is part of the Cary Graphic Arts Collection at RIT (see Figure 2(a)).

The scroll tells the story of the Jewish heroine, Queen Esther and her cousin Mordecai, who devised a plan to rescue the Jewish people from Persia. The scroll celebrates the days of feasting and joy that are commemorated as part of the festival of Purim. In this particular case, most of the first illustration and the two beginning panels of text have worn away as they are located on the outermost portion of the scroll and were touched more often than other areas of the scroll given the nature of scroll-use and pulling from the outer roll to reach any interior portion of the document. The scroll was imaged to see if any of the text and the illustration from the beginning three panels could be recovered. Due to the fact, we already know what it says, readability of text was not a concern.

The text and illustration of the first two panels were imaged. The text was only recovered on one of the two panels (Figures 2(b) & 2(c)). It is clearly enhanced, although we have not yet assessed the readability. However, there were other exciting finds in the illustration in the first panel (Figure 3). First, on the right illustration of the scroll, a lion-like creature is barely visible. However, after imaging and processing, using PCA band 4, PCA band 3, and PCA band 2, this figure can be seen more clearly. It has four legs, a feline-like tail, and what appears to be a mane. Interestingly, this figure does not seem to match the rest of the illustration since it is either "standing up" or is rotated 90 degrees clockwise compared to the orientation of the rest of the illustration.

(a)

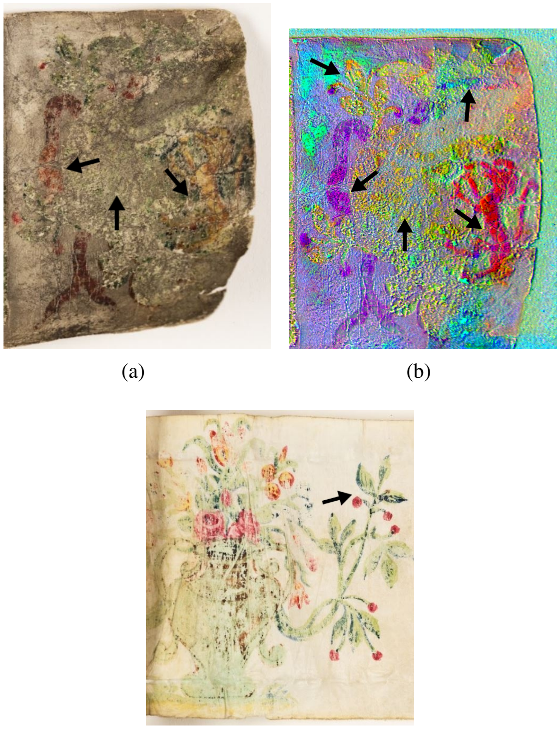


(b)

(c)

Figure 2: *The Esther Scroll from the RIT Cary Graphic Arts Collection (a) The beginning of the Scroll (b) RGB image of second panel of text, (c) false color image of second panel of text (PCA band 1, PCA band 3, PCA band 2).*

A second find involved a snake, or serpent-like creature hanging from a tree with fruit surrounding it (see Figure 3). Again, using PCA band 4, PCA band 3, and PCA band 2, the features of this creature are more pronounced. This false-color image shows a plausible outline of an eye and a curved line that separates the body from the head. These results can be reproduced by taking images with the system and processing using the same software and PCA bands. The rest of the creature's body either ascends through the trees or descends towards the ground, its tail similar to that of a mermaid's.The false-color also reveals further details such as detailed leaves where the snake-like figure is, implying that the animal illustration and another illustration on the scroll (Figure 3(c)) are meant to complement each other. (The second illustration shows the same vegetative design with similarly shaped fruit). The purpose of the snake, however, remains a mystery.



(a) (b) (c)

Figure 3: *(a) RGB image of the first panel illustration in the scroll, (b) PCA false-color image of "serpent" and "lion", (c) Floral illustration elsewhere on the scroll.*

3.2. Future Work

To further render the illustration and the text, a more sophisticated MSI system could be used. Nevertheless, these preliminary results demonstrate the presence of faded and worn images on the scroll, enabling the staff of the Cary Collection to know more about their collections which can possibly lead to new knowledge about this item. Information regarding the creation date and interpretation of this scroll may change as a result of ongoing research. Because the provenance of this object is unknown, beyond being donated from the New York Times Museum of the Recorded Word, additional MSI may help to decipher information about the creation date. Working with this new information, Hebrew Biblical scholars, for instance, can gain access to the images and incorporate these findings as part of research about this item, its symbolism, and the wider context. Due to lack of accessibility to a higher cost, more developed system, the Book of Esther was only imaged with MISHA at the Rochester Institute of Technology, demonstrating the need for wide-spread access to MSI technology. However, the system is meant as an entry system, and future work with a more complex, more specific system is considered.

4. Conclusions and Implications

4.1. Object, collection, institution

As outlined above, MSI has proved useful in non-invasive analysis of cultural heritage objects. In particular, MISHA offers opportunities for professional staff and scholars seeking to use a low-cost, low barrier-to-entry MSI system onsite, in collections, rather than in lab or offsite locations. MISHA is particularly beneficial to those who do not have access to high-end systems nor the staff dedicated to run them. Access to a system such as ours offers an opportunity in democratization of technology that can, in turn, foster more fair and equitable systems of scholarship by putting tools such as MSI into the hands of those who have collections and capacities for use, as well as humanities scholarship and context to interpret and make use of the new information gained through MSI. In these ways, MISHA fosters new knowledge about individual objects, the collections in which they are housed, and the institutions that are stewards of them.

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