https://doi.org/10.2352/issn.2168-3204.2023.20.1.38

Build, Select, Reshuffle: Uncovering Distinct Features of Cultural Heritage Objects with Multispectral Imaging

J. Falotico, K. Schultz, E. Arnold, I. Moyer, M. Maali Amiri, J. Decker, D. Messinger, R. Easton, Jr.; Rochester Institute of Technology, Rochester, New York, USA

Abstract

Some cultural heritage collections such as manuscripts, scrolls, books, sheet and folia that are faded, damaged, or otherwise unreadable present challenges for curators, collections professionals, scholars, and researchers looking to understand collections more fully. Seeking to uncover distinct features of objects, they have employed modern imaging tools, including sensors, lenses, and illumination sources and thus positioned multispectral imaging as a critical method for cultural heritage imaging. However, cost and ease-of-use have been prohibiting factors. To address this, Rochester Institute of Technology received a grant from the National Endowment for the Humanities (PR-268783-20) to fund an interdisciplinary collaboration 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 addresses our open source and extensible software applications, from the first iteration of software in 2020 to our current effort in 2022-23 which seeks to simplify both processes. An overview of the image capture and processing software to capture and visualize the spectral data offers a basis for demonstrating the possibilities for low-cost, low barrier-to-entry software on cultural heritage imaging, research, preservation, and dissemination.

1. Introduction

Multispectral imaging (MSI) is a technique used in cultural heritage imaging that involves taking numerous images of an object at different wavelengths of light—including those beyond the range of human sensitivity—to yield a digital "stack" of images that can been enhanced by bringing out different features of the item, such as undertext, that are not apparent to the naked eye. With the increase in popularity of multispectral imaging over the past few years, image scientists and researchers in cognate disciplines, as well as digital humanists and professionals working in libraries, archives, and museums have employed a range of image processing software (ENVI and Hoku, for instance) to capture and visualize the spectral data, However, many of the image processing software platforms are not optimized for spectral analysis and have a high barrier of entry, including licensing costs and extensive training to be proficient with each program.

At Rochester Institute of Technology (RIT), we have developed two open-source software applications, called the RIT MISHA Image Capture App and the RIT Spectral Analysis App, that are more user-friendly and accessible for individual and institutional use. The first of these prioritizes guided image capture for use with the low-cost, end-to-end multispectral imaging system we have developed (described below), while the second software offers easy-to-use spectral image processing for files created by our system or by other means. Importantly, easy-of-use has been a core principle, enabling users to create, calibrate, and process multispectral imagery, as well as visualize and output the results.

The software effort is part of our National Endowment for the Humanities-funded project (PR-268783-20) to develop a low-cost, portable imaging system which also seeks to provide information for building one's own multispectral imaging system, known as MISHA (Multispectral Imaging System for Historical Artifacts) **[1]**. Together, the system and software can increase the accessibility of multispectral imaging systems and software so that researchers, scholars, and staff of small-to-medium-sized institutions can have access to the tools they need to uncover distinct features in cultural heritage objects to better know, understand, contextualize, and share their collections.

2. Software Overview

2.1. Image Capture (RIT MISHA Image Capture App)

We achieve multispectral imaging through colored illumination, without the use of spectral filters. MISHA employs camera control software developed for this application such that images are captured (in a darkened environment) when each LED is turned on. (Figure 1). Each spectral band corresponds to an image collected under illumination by an individual or discrete set of LEDs. Sixteen different images are collected in wavelengths ranging from 365-940 nm. Each image is collected and stored as a separate TIFF file, and all 16 images are combined into one multispectral image cube stored in the ENVI image format. If images are collected with a spectral calibration target in the scene, the final image cube is also calibrated to estimated material reflectance.**[2]**

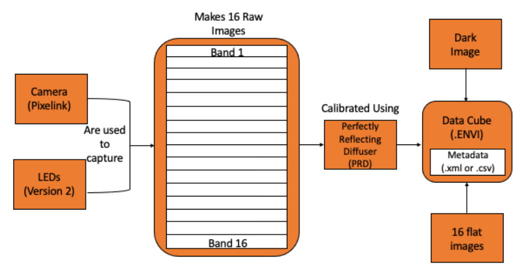

***Figure 1**. RIT MISHA Image Capture software demonstrating the "stack of images" consisting of TIFF files, each corresponding to LED illumination at a particular wavelength. The stack is created during Image Capture (Figure created by Izzy Moyer)*

Importantly, users have the ability to add and edit metadata for each item imaged, so that the documentation about the item can be tied to the image, rather than disconnected from it. Figure 2 shows the metadata input window enabling users to record information about the items imaged by MISHA.

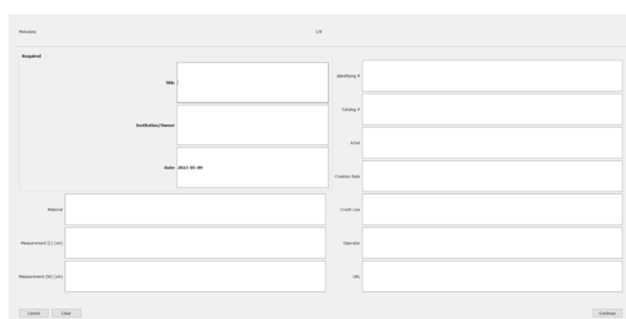

***Figure 2**. RIT MISHA Image Capture App Metadata Input*

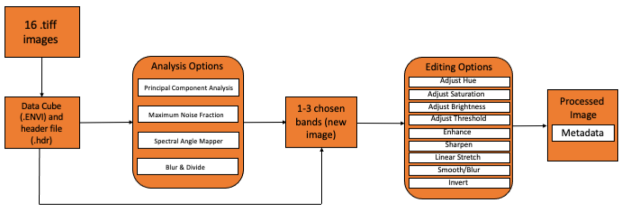

***Figure 3**. RIT Spectral Analysis Software (Figure created by Izzy Moyer)*

2.2. Image Processing (RIT Spectral Analysis App)

After image capture, the RIT MISHA Image Capture App will automatically recognize the calibration target (if required) and create an image cube of the estimated material reflectance using the multispectral images captured with our spectral imaging system. Then in the Spectral Analysis App the cube can be run through various image analysis techniques such as Principal Component Analysis (PCA), Minimum Noise Fraction (MNF), and Spectral Angle Mapping (SAM).

Processing images captured through MSI involves creating a data cube from the captured bands with spatial and spectral data. Whereas the image capture software (RIT MISHA Image Capture App) is specific for use with our system, the image processing software (RIT Spectral Analysis App) may be used with multispectral imagery collected with our system or others. For instance, our application can process imagery collected with the MEGAVISION EV multispectral imaging system **[3].** The RIT Spectral Analysis App can be used with any spectral imaging data formatted in ENVI binary format.

The goal of this process is to enhance features on the cultural heritage item that are not visible, or are very low contrast, to the naked eye. The Spectral Analysis App provides several image processing tools that can be used to enhance and transform the multispectral image. Results from these processing algorithms can be rendered as black and white or “pseudocolor” images by combining spectral bands from the image cube and processing results in a rendering that improves the visibility and legibility of features such as erased or faded text **[4, 5]**.

The preferred method we use for image processing is Principal Component Analysis (PCA). While PCA is used in data science to reduce variables in large data sets, and still maintain the wealth of information in the large set; in image processing, PCA is used to identify materials of similar properties that reflect light in similar ways and group them together in order to create a contrast from the other materials in the image.

While text can be recovered through the aforementioned statistical processing, if the text is damaged beyond recognition the standard processes such as PCA and MNF may not be sufficient enough to visualize the undertext. In such cases, multiple rounds of image processing may need to occur **[6]**. Additional processing may include adjusting the hue, saturation, and brightness of the image to provide a better visual representation of the under text. The RIT Spectral Analysis App is capable of running the image through several image stretch functions, including histogram equalization, linear, and Gaussian. Users can also apply algebraic math to the bands of any image cube, which has been shown to sometimes be successful in enhancing contrast. **[6]**

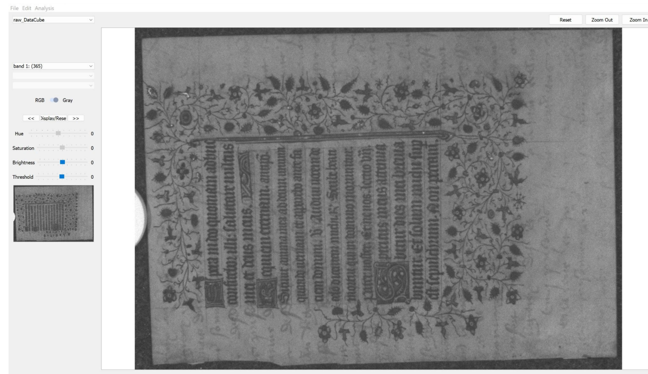

***Figure 4**. Screenshot from RIT Spectral Analysis App*

2.3 System Constraints

With the launch of the grant effort in 2020, we sought to build such an accessible, low barrier-to-entry software as a companion to our low-cost, low barrier-to-entry hardware system, MISHA. Because the primary objective of our project is to design a multispectral imaging system and software to support its use that would be easily accessible to a non-technical audience, we focused on two key aspects in order to achieve this goal: reducing the cost of the system and simplifying the imaging and processing software. These goals lead to limitations such as using a camera with limited spectral range and spatial resolution. Expanding the resolution and spectral range of the camera would dramatically increase the cost of the imaging system and therefore move us away from one of the primary objectives of our effort. Additionally, we focused the Spectral Analysis App on the most commonly used processing and visualization methods, with a simple graphical user interface. Thus, the system design constraints of cost and ease of use by non-technical practitioners and scholars have determined the parameters as well as the limitations of the software.

Nevertheless, the capture and processing software are free and open-source, and users can incorporate their own desired tools and processing techniques because the code base is Python, PyQT5 with a GUI toolkit, NumPy, and a Python library. It is possible, for example, that if a user wants to employ binarization for text identification, they can add it with ease. Thus, while the software implements image processing techniques that have been shown over time to be the most beneficial in recovering faded or erased text, users have the flexibility to tailor the tools and processing techniques to their liking.

2.4 Yielding Results

With the goal of ease-of-use on the part of the end user, the processing software, in particular, strives to enable greater exploration and opportunities for discoverability. For example, the bands rendered into a PCA cube are processed through a series of actions deliberately taken by the user and evaluated by the user to determine where to look for areas of interest. More specifically, the bands rendered into a PCA cube (or from the original image itself) can be selected and “shuffled” to identify meaningful visualizations.

After selecting and assigning each band to either Red, Green, or Blue, they are re-shuffled through the combination of these RGB values until a visualization displays the features of interest, as shown in Figure 5. The process continues, the bands are reshuffled until a desired outcome uncovers distinct features of the object.

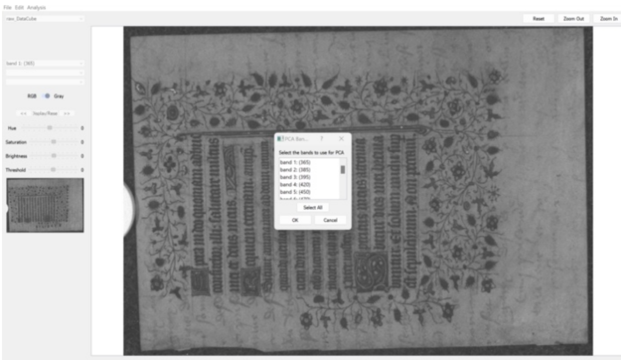

***Figure 5**. MISHA Processing Software PCA Band Selection*

Figure 6 shows an example of the utility of the MISHA hardware and software. On the left of Figure 6 is an RGB image of the back page of the *Statuta antiqua et nova ordinis Cartusiensis* (RIT Cary Collection), a late 14th century manuscript that has had the cover removed. Consequently, the back page is heavily damaged with significant portions of the text worn off. Additionally, annotations are visible in the side and bottom margins with varying levels of contrast. On the right of Figure 6 is the result of processing the multispectral image collected with MISHA through the Spectral Analysis App using Principal Component Analysis and producing a false color representation of the result. Of interest is the dramatically increased contrast of worn away text in the upper left, lower left, and lower right corners. Additionally, the annotations in the bottom margin have been greatly enhanced after processing, yielding opportunities to read the Latin text.

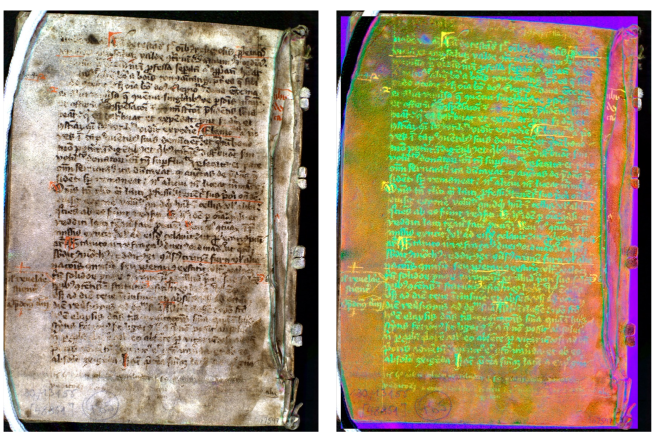

***Figure 6**. Back cover of the Statuta antiqua et nova ordinis Cartusiensis, imaged with MISHA and processed with the RIT Spectral Analysis App. Note the improved contrast of the text in the upper left and lower right corners, as well as in the bottom margin. Courtesy RIT Cary Collection*

3. Conclusion and Further Implications

Use cases extend beyond medieval manuscripts such as the Statutes of the Carthusian Order described above, as noted by our employ of the system and software throughout our development process. Since summer 2021 when we had an earlier iteration of a system and software in place, we have garnered significant interest from, and engagement with, smaller museums and libraries, further educating them about what multispectral imaging is and how it can be used to enhance their collections. To date, we have imaged approximately 200 items across manuscripts, scrolls, books, sheet and folia held in private collections as well as public libraries, university collections, and museums—focusing on small-to-medium sized collections. **[7,8]** These use cases have validated that MISHA can be used on a variety of substrates, from medieval manuscripts, Renaissance artwork, and autograph letters from the 19th century to thermal papers of the 1980s and contemporary glass. **[9]**

The system and software have been used on privately held material, enabling the legibility of information to be improved. For instance, passages from a collection of handwritten Civil War letters authored by Private Theron Theodore Loomis (1846-1923), Company G. of the 43rd Regiment of Wisconsin Volunteer Infantry had faded. Owned by the writer's great-granddaughter, the autograph letters disclose daily life of a soldier while expressing a longing for home, especially around the holidays, care and concern for family, and exposure to new people, places, and things. Written in pencil on bi-folded paper sheets commonly used for correspondence in the 19th century, the letters span 1864 to 1865 and their messages yield incomplete knowledge. This application demonstrates the capacity for uncovering illegible, faded, or erased text on comparable material. Often while conducting image processing, data other than, or in addition to, the under text may be revealed. For example, during the processing of these letters, non-textual information was recovered: multiple sheets of paper revealed fingerprints along the right side of the sheet (Figure 7). The prints are perhaps, Private Loomis, or of any number of the future readers of these letters since the Civil War evidencing how a connection between the current owner and previous generations of owners can be recovered along with textual information.

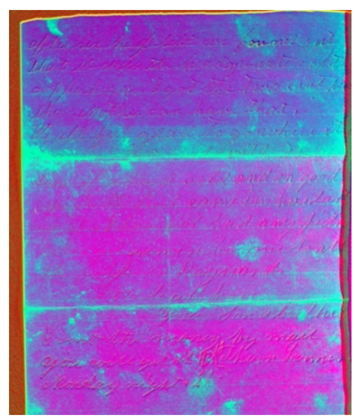

***Figure 7**. Processed Image of Letter from Private Theron Loomis, Company G. of the 43rd Regiment of Wisconsin Volunteer Infantry. Fingerprints are visible on the right side of several portions of the paper sheet. Courtesy Donna Fae Dadson.*

With this capture and processing system, 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." **[10]** A contemporary use case consists of seemingly blank thermal papers from fax transmissions in the 1990s in the Vignelli Center for Design Studies that were thought to be unreadable. However, their contents were made visible through image capture and processing with MISHA.

Widely available on our project webpage at the conclusion of the grant in the spring 2024, our specifications for our imaging system and software offer opportunities for curators, collections professionals, scholars and researchers to understand their collections more fully as a result of capturing images of collections with our low-cost multispectral imaging system and/or using our accessible, easy-to-use, and robust capture and processing software. The software, in particular, allows users to calibrate and process multispectral imagery, visualize both the raw data as well as the results of image processing, and save those results into formats suitable for integration with content management systems. Users can also edit administrative and descriptive metadata to suit their own metadata requirements, thereby offering novel capabilities and affordances of multispectral imaging to small- and medium-sized institutions in an easy-to-use manner. These users will be able to understand their collections better, produce novel visualizations of the digital imagery, and enhance the digital representations of their collections.

Our next steps include wrangling the metadata from our use cases and user feedback as part of an effort to consider mapping relationships between schema in use at libraries, archives, and museums and the sparse metadata collected by MISHA. While metadata elements are uniform, in some instances, greater attention will need to be paid to leveraging existing cataloging systems and their metadata schemas to determine where multispectral images might reside in a home repository. Such efforts will involve intellectual mapping as well as a technical mapping achieved only by working in tandem with collections professionals and programmers and developers to map relationships between common software systems in use in libraries, archives, and museums and MISHA's output.

Acknowledgements

Authors Messinger and Decker received a grant from the National Endowment for the Humanities (PR-268783-20) to fund the development of a low-cost, portable imaging system with processing software known as MISHA (Multispectral Imaging System for Historical Artifacts). All authors would like to acknowledge the software engineering team: Cecelia Ahrens, Mallory Bridge, Eric Gao, Troy Potter, Rob Maron, and Larry Kiser; Steven Galbraith, Curator of the Cary Graphic Arts Collection, RIT; Jennifer Whitlock, Archivist, Vignelli Center for Design Studies, RIT; and Donna Fae Dadson, great-granddaughter to Theron Loomis and custodian of the Loomis letters.

References

[1]https://securegrants.neh.gov/publicquery/products.aspx?gn=PR-268783-20.

[2] T. Kleynhans, M. L. Carr, and D. W. Messinger. "Low-Cost, User Friendly Multispectral Imaging System for the Recovery of Damaged, Faded or Palimpsested Historical Documents." *Proc. SPIE 11727* Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imaging XXVII, 117270F (April 12, 2021). https://doi.org/10.1117/12.2585629.

[3] https://mega-vision.com/products/#.

[4] Roger L Easton., et al. "Spectral Imaging Methods Applied to the Syriac-Galen Palimpsest." *Https://Www.Cis.Rit.Edu/~rlepci/Syriac-Galen_paper/Penn_Paper_RLE_KTK_BCB_KB.Pdf*, 2018. Accessed 11 May 2023.

[5] Roger L Easton, Keith T Knox, William A Christens-Barry, Kenneth Boydston, et al. *Standardized System for Multispectral Imaging of Palimpsests*. 16 Feb. 2010, https://doi.org/10.1117/12.839116. Accessed 5 May 2023.

[6] Alexander J Zawacki., et al. "Fragments under the Lens: A Case Study of Multispectral versus Hyperspectral Imaging for Manuscript Recovery." *Digital Philology: A Journal of Medieval Cultures,* vol. 12, no. 1, 2023, pp. 123–143, https://muse.jhu.edu/issue/49139.

[7] https://arcg.is/1fy5Df.

[8] https://arcg.is/1P9n5S.

[9] E. Arnold, I. Moyer, A. Bourgeois, P. Mei, J. Decker, R. Easton,Jr., D. Messinger. "Multispectral Imaging for Historical Artifacts: A Case Study Using an 8th-Century Biblical Scroll." GCH 2022 - Eurographics Workshop on Graphics and Cultural Heritage, Proceedings 2022. https://diglib.eg.org/handle/10.2312/gch20221231.

[10] Zoë LaLena. "Imaging Palimpsests in the Otto F. Ege Collection, Zoe LaLena" Presented at International Congress on Medieval Studies, 2021.

Author Biographies

James Falotico is a third-year Museum Studies student at Rochester Institute of Technology.

Kyra Schultz is a third-year Museum Studies student at Rochester Institute of Technology.

Etta Arnold is a third-year Museum Studies student at Rochester Institute of Technology.

Izzy Moyer is a third-year Museum Studies student at Rochester Institute of Technology.

Morteza Maali Amiri is a Post-Doctoral Researcher in the Chester F. Carlson Center for Imaging Science at Rochester Institute of Technology.

Juilee Decker is Professor of History and Director of the Museum Studies Program in the College of Liberal Arts at Rochester Institute of Technology.

David Messinger is Professor and Xerox Chair in the Chester F. Carlson Center for Imaging Science at Rochester Institute of Technology.

Roger Easton, Jr. is Professor in the Chester F. Carlson Center for Imaging Science at Rochester Institute of Technology.