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# Spectral Imaging for Preservation Documentation

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## Abstract

*The refinement of non-invasive imaging provides new layers of scholarly and preservation data by capturing images of heritage materials in distinct wavebands of the visible and non-visible spectrum. Advancing these capabilities has allowed new interpretations of such important historical documents as those of the U.S. founding fathers documents. Image processing of large datasets generate a wealth of information, and require careful consideration of the metadata and processing to ensure no that no false imaging artifacts are produced. These imaging technologies have been expanded to gather a range of preservation information including the non-invasive characterization of colorants, and comparative ink analysis. A further advantage is the ability to undertake predictive assessment of the impact of environment and treatments. Baseline imaging allows for more data-driven decisions to be made for exhibition, and conservation treatments for stabilization.*

## Introduction

The refinement and development of non-invasive imaging technologies – multi and hyper-spectral imaging – provide a depth of information from cultural heritage objects that has previously remained hidden. These spectral techniques provide new layers of scholarly and preservation data by capturing images of heritage materials in distinct wavebands of the visible and non-visible spectrum. Advancing these capabilities has enabled obscure and ambiguous aspects of historical documents to be revealed allowing new revelations early national documents that amend or confirm received interpretations. Image processing of the large datasets generated allow for a wealth of information to be garnered, and requires careful consideration of the metadata and processing tracking to ensure no imaging artifacts are produced that do not represent actual features of the documents.

Both preservation research and digital humanities studies of libraries, archives and special collections are embracing this technology and moving beyond simple camera red-green-blue (RGB) three channel imaging or scanning sources for image capture; expanding these capabilities to include a range of technical collection capabilities such as multispectral and hyperspectral imaging. Utilizing non-invasive integrated digital imaging systems such as spectral imaging, provides the preservation specialist, scientist, conservator, curator digital humanist and researcher with a tool that can reveal useful, hidden, unknown and preservation information about an artifact. Simply looking at an object does not reveal everything contained within the original material. The unaided eye often cannot detect features such as writing and inks that have been erased, hidden by overwriting or varnish, or faded because of environmental factors, or identify important provenance components such as colorants. These features on photographs, manuscripts, maps, and other heritage objects are important for scholars, for authentication, "fingerprinting" and the care of collections. Looking at documents at various magnification levels and with a range of illumination modes can capture these elusive features. The method of integrating different types of illumination is paramount to the expansion of spectral imaging techniques. The utilization of specific illumination modes include raking or side-lighting to highlight topography and indented writing, transmitted light that enhances density changes and the impact of erasures or treatments, reflected light, that exposes surface features and spectral responses, and the integration of lighting to separate fluorescence components that can enhance separation of similar materials and different wavelengths) The application of hyperspectral imaging to the preservation analysis and study of cultural heritage artifacts is a powerful, non-invasive technique to characterize colorants and pigments, track changes over time, assess the effectiveness of treatments, and monitor objects on long-term exhibition. The process can extract and reveal hidden and redacted text and original author intent, and allow for changes or modifications with different inks to be easily revealed and documented, with even nonvisible fingerprints brought to light. Imaging with light emitting diodes (LED) illumination throughout the visible and non-visible, in 16 spectral bands as well as raking and transmitted light for preservation studies, provides a system with safe conservation lighting that is integrated with the camera to minimize light on the object.

### *Imaging Challenges*

Spectral imaging refers to the imaging of documents and other objects in a range of wavebands, usually extending from the ultraviolet through the visible and into the infrared. While a selection of systems have integrated the illumination without filtering at the camera, thus allowing full registration without additional processing, many institutions have imaging systems that require careful registration of the stack of separate images generated since the separation of the wavebands through filters can introduce a pixel shift between images in the stack due to the filter modifying the response and essentially sending various layers in the stack out of focus.. The importance of avoiding this challenge is that the pixel shift distorts variation between wavebands since the images are not completely registered, so potential erroneous artifact can be generated.

With a large number of institutions having digital spectral imaging equipment, this plethora of imaging systems necessitates the need for a standardization of approach to ensure interoperability of spectral data, and ease of interaction for users of the spectral datasets. This standardization and integrated approach should extend both to the spectral capture and the image processing, to assure that information generated from processing of the data remains accurate to what is contained within the original document. This standardized methodology has implications not only for cultural heritage but also within the forensic field – both for document examiners and to assess provenance and forgeries. For image processing there are many software packages and one

 

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component to be aware of is the potential differences in information captured through different processing techniques.

Two main processing techniques are used at the Library of Congress to both capture obscured or hidden information and to characterize materials and detect changes in condition. The first widely used process is principal component analysis (PCA) which is essentially a method of separating components with the stack of images based upon their unique chemical and spectral response. From the PCA process pseudocolor images can then be created using a selection from the image stack, to separate materials that appear similar in the visible region.

As shown in Figure 1, more information can be made visible through this processing technique. The upper image shows what can be seen with the unaided eye, the lower image illustrates the same section of a map after processing where the faint green lines now appear broader (pseudocolor purple) and indicate the spread of verdigris – a corrosive copper containing pigment – into the parchment causing potential damage. Other multivariate image processing techniques can be used to enhance obscured text, or heavily redacted texts.

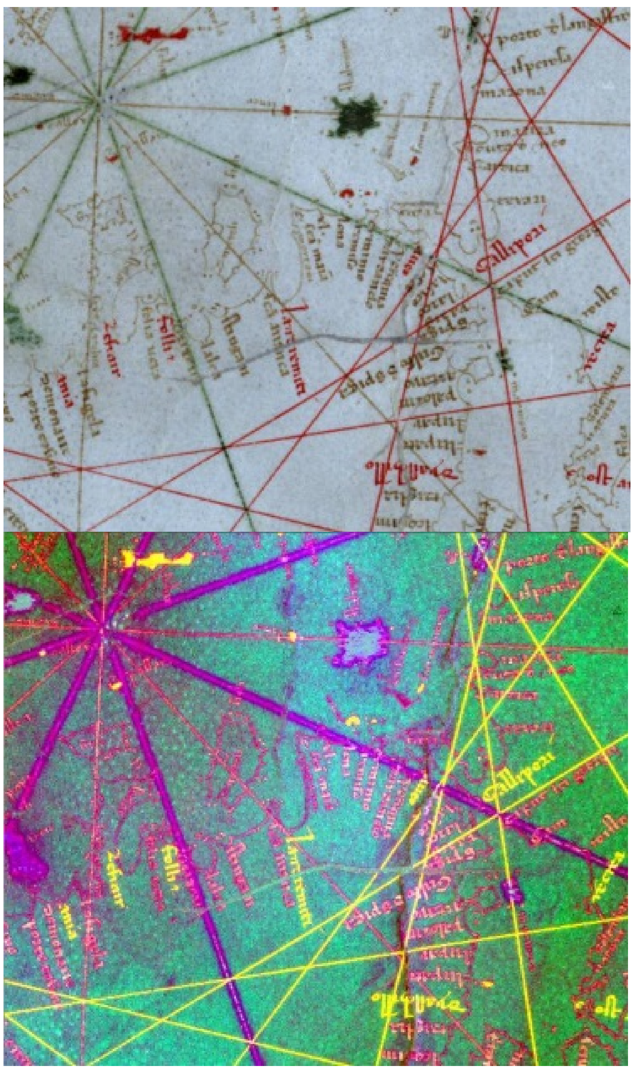

***Figure 1**. Principal Component Image Processing]*

The second extremely useful technique is the generation of spectral curves, whereby a specific curve can be created from a unique pixel (or pixels) location on the image. Analyzing spectral curves from the same pixel location throughout the range of wavebands derives a unique spectral curve for the specific materials – colorants, inks or substrates – that can be compared with reference spectral collection materials, and detection of change by comparing before and after treatment, exhibit or exposure to specific environments. These imaging technologies have been expanded to gather a range of preservation information including the characterization of colorants non-invasively, and comparative ink analysis. A further advantage is the ability to undertake predictive assessment of the impact of environment and treatments – both historic and modern [1]. Baseline imaging and tracking changes over time allow for more objective decisions to be made for exhibition and storage of heritage materials, and the ability to ensure the effectiveness of conservation treatments for stabilization. Imaging technologies have advanced the capacity to better preserve, understand degradation, and capture scholarly information in cultural heritage materials.

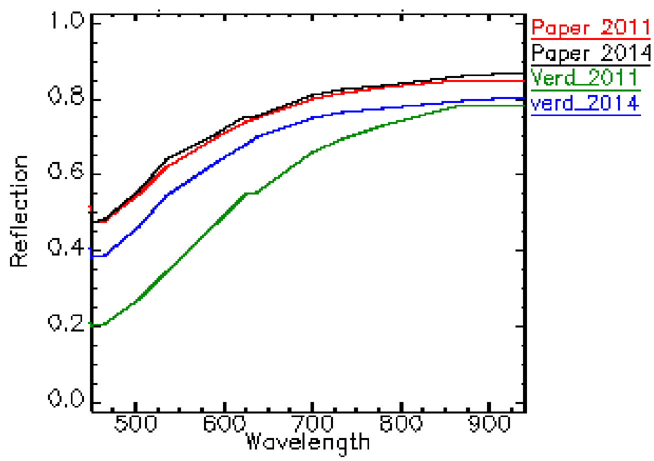


***Figure 2.** Spectral Curve Processing*

Figure 2 illustrates tracking change due to a treatment that removed offset verdigris to assure no new components are introduced into the document, and that the unique spectral curve for the discolored region started to shift back towards the spectral curve of the pure paper.

In order to accurately characterize and identify materials spectrally a uniquely characterized spectral reference library is required. The Library of Congress (LC) Preservation Research and Testing Division (PRTD) has developed the Center for Library Analytical Scientific Samples (CLASS) where scientific reference samples are collected and generated and then aged both naturally and through controlled accelerated aging methods. All data is then stored in the digital web-accessible database (CLASS-D) to enable interoperability of data for sharing internationally [2].

Research into the response of modern twentieth century pens and inks revealed a unique spectral shift in inks on collection items that that were light sensitive that had at some period in their history been exhibited. Having access to the original ink sources used allowed the generation of reference samples that could be added to the spectral library, and as can be seen in figure 3 below, this

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allowed identification of fugitive materials that did not match when the pure unaged samples was compared to the collection item ink spectral curves.

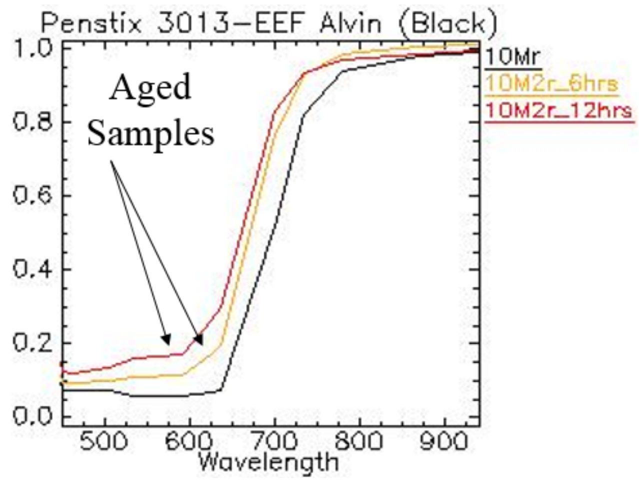


***Figure 3**. Spectral Reference Samples and Changes in Spectral Response*

As with any new technology, there is a rush to embrace the new capabilities, sometimes with a lack of understanding of the complexities of the various components and the concomitant need to view the system with a methodical and analytical approach. A spectral imaging system consists of both the hardware and software; hardware components including camera, lenses, illumination source and modalities, imaging surfaces, diffusion layers and selection of the appropriate imaging background; while the imaging software includes both the integrated connection between the image capture and digital files created and the processing of the images to generate derivatives and renderings from processing the stack of images. A coordinated approach to documenting the imaging parameters ensues that researchers can easily understand how the image was captured. This information aids in understanding the resulting processed images, since these renderings and derivatives will differ depending on the types of illumination and selection of image capture parameters.

Spectral imaging captures a series of images of the same document at different regions of the visible and non-visible regions and as noted previously, if there is filtering at the camera, the potential for images in the stack not to be in registration with each other adds another level of potential for offset in relation to linking information and spectral data between image layers, and essentially for artifacts to be produced in the image processing that may lead to erroneous data and interpretation. The need to standardize and create documented procedures for spectral image capture and data management is a critical component of assuring the utility of these imaging technologies in heritage preservation.

The illumination modalities utilized can generate information that captures additional features of the document or object. In addition to the capture of reflected illumination from the surface of heritage materials, transmitted spectral imaging is advantageous for detecting changes in density in documents such as with watermarks, as well as density changes from documents that have been modified (deliberately or through degradation) and due to the impact of treatments.. A component of the standardization is ensuring accuracy in capturing effective metadata as well as a structured file naming system and nomenclature that links all aspects of image capture with the image stack that is generated, and, the processing.

Additionally, this mode can be used for imaging through stacked layers of paper an information; layers obscured when documents have been treated by lamination, a method that compressed layers of a document together between two layers of cellulose acetate using high temperature and pressure. An example of this is a music manuscript where four layers of the score were laminated obscuring access to the original score and only allowing visibility of the later changes. A combination of reflected and transmitted light imaging and processing allowed the original score hidden within four layers to become visible. The lower image in figure 4 shows the darker pseudocolor underscore of the original manuscript.

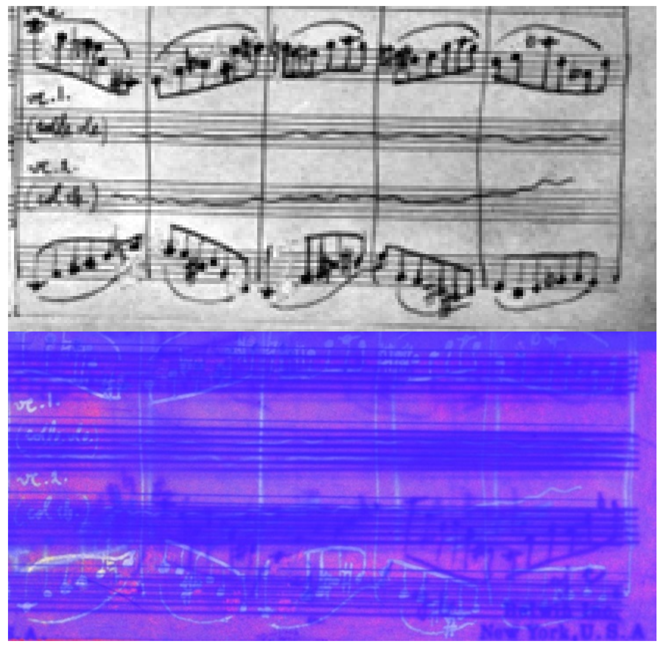

***Figure 4**. Bartok's Final Concerto for Orchestra – Transmitted Processing*

## *System Standardization*

The Preservation Research and Testing Division (PRTD) has taken, since the inception of spectral imaging at the Library, a structured and pragmatic approach to the standardization of image capture and processing, including the collection of all scientific data for preservation and analysis of collection items. This is critical both for revealing hidden text, and for the baseline imaging, to track changes due to environment, exhibition or treatments, since all imaging system components need to be the same throughout the period of time that monitoring or potential change may be occurring. In addition, spectral imaging and image processing of historic and contemporary heritage materials are non-invasive methods to capture a wide range of non-visible information revealing the creators intent; even when this original content was modified by the author/creator and not intended to be part of the final creation. The ethics of revealing author intent from heritage materials creates a juxtaposition between the final version that the author/creator put forward, and the redacted or erased information: this allows historians and researchers to capture original intent and thought processes of the creator. Inserting the use of new technologies into the preservation of cultural heritage enhances the effectiveness of long-term preservation, allowing conservators and preservation scientists to expose and better understand previous treatments, but also can create a potential ethical dilemma when later references or papers are found noting that the author/creator intended to conceal the information (now exposed) contained within the original document [3].

The impact of treatments and environment on heritage materials is an important area for assuring preservation of original sources; being able to detect changes before they are apparent in the visible region assists in the understanding of degradation mechanisms. This is especially important in relation to interactions between treatment compounds that may have an impact on substrate and media of historic and modern heritage materials. Non-invasive illumination and spectral imaging techniques in transmitted, reflected and raking modes are effective methods to map the spectral response of substrates and media on historic materials, and detect and track changes due to specific treatments, or the impact of natural aging and environmental parameters [4].

The use of non-invasive technologies minimizes impact or change to the original material while capturing information that assists preservation. This allows preservation information about materials – characterization of pigments and colorants, assessing state of substrates, mapping spectral response across an entire object – to be captured without intrusion upon the heritage object, providing information and options for dialogue prior to any intervention.

### *Image Processing Considerations*

The use of new imaging technologies can reduce conflict and misunderstandings between what had been assumed to be creator intent and the actual information contained within the original source material. Image processing can be used to reconstruct original renditions in the digital realm and this leads to a two-fold advantage – both better preservation of collection items due to reduced handling by researchers, and the capacity to provide researchers and scholars with more information and content knowledge than could be obtained from visual assessment of the collection materials.

When heritage materials are in the digital realm complications with ethics and the potential for intervention expand. Standardizing the documentation of image reconstruction to show the original creators' intent needs to ensure accuracy in renderings, while at the same time aware of the need to prevent change with digital iterations. Digital forensics provides the capacity for more effective tracking of modifications to artistic intent but is not generally widely used in the realm of spectral imaging. Tracking changes and modifications through the use of algorithms and macros start to directly link analog and digital collections, creating a more comprehensive and integrated approach to preservation documentation, and a more effective workflow for data management. Essentially, with all digital renditions being digitally linked or overlaid with the original, it becomes more challenging to introduce components not consistent with the original document. In addition, as with all data management, accurate metadata should be captured and linked to each imaging file in both the image capture and image processing modes.

Structured workflow manuals have been developed to ensure reproducibility of image quality, accuracy and repeatability. These detailed manuals have been created and are constantly revised and updated for both image capture (in a range of illumination modes) and image processing manuals (for at least three different software packages). This has allowed a comprehensive, reproducible methodology for spectral imaging to be developed and sustained. This approach allows for ease of teaching spectral techniques to a range of heritage professionals, while assuring an inclusive approach to the integration of advanced technologies. Wee documented standardized procedures allow sharing of data and the potential for international standards to be developed.

## Conclusions

The utilization and development of spectral imaging as an effective cultural heritage documentation tool requires a pragmatic and thoughtful approach to the implications of both physical imaging components, and the potential challenges of non-standardized image processing. As with any new technology, users must have a thorough understanding of how the digital files and processed image renderings relate to the original object and the potential for inaccurate data to be created if a standardized approach is not utilized. Spectral imaging for capture of original author intent and monitoring changes through spectral imaging must include careful data management and a reproducible documentation of all processes to ensure long-term capabilities for preservation documentation.

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## Author Biography

*Dr. France, Chief of the Preservation Research and Testing Division at the Library of Congress, researches spectral imaging techniques and addressing integration and access between scientific and scholarly data. An international specialist on environmental deterioration to cultural objects, her focus is connecting mechanical, chemical and optical properties from the impact of environment and treatments. Serving on standards and professional committees for cultural heritage she maintains collaborations with colleagues from academic, cultural, forensic and federal institutions.*