The Petra Scrolls

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Abstract

The Petra papyri were found in an opulent Byzantine church during excavations conducted in 1993 by the American Center of Oriental Research (ACOR) in conjunction with the Department of Antiquities of Jordan. A total of 152 scrolls dating from 513 AD to 592 AD were found. The scrolls were carbonized in a fire that destroyed the Church around A.D. 600. The black ink on a charred background presented serious difficulties for conventional photography because the carbonized scrolls were extremely fragile and were mounted between glass plates. Attempts to photograph them without the glass failed because the fragments curled. A team from FARMS and CPART, both part of Brigham Young University, performed multispectral imaging (MSI) on samples of the Petra scroll fragments during a diagnostic trial in 1999 at the ACOR facility in Amman, Jordan. For these tests, electronically tunable filters were used to provide MSI spectra from 650 nm. through 1050 nm. The MSI revealed variations in ink/papyrus contrast even within a scroll. Due to the damaged nature of these carbonized scrolls, the image resolution of the multispectral data was selected to have the same clarity as a microscope. These MSI data are now being assembled into complete plate images. Previously multispectral imagery had focused on imaging only troublesome portions of texts. Because the entire Petra scroll collection was charred, very high resolution multispectral imaging was performed on the entire scroll collection. This was the first multispectral imaging production of a complete collection.

Introduction

Multispectral imaging is an image data recording technique in which multiple images of the same scene, each viewed at a separate wavelength or color, are collected to form a multispectral image cube. Multispectral image cubes are generally collections of less than 100 monochrome images of the same scene; however, specialists often distinguish data sets with hundreds or thousands of images in a single image cube by the term "hyperspectral imaging" or "ultraspectral imaging," respectively. In this document the term multispectral imaging will be used throughout to describe this imaging process, although occasionally the resolution employed in the sensor bandwidth may not fit perfectly with the standard definitions (Bleokon et al., 1997). In archaeological applications, the literature reports several significant multispectral imaging successes using the spectral region extending from the ultra-violet to the infra-red (Bearman & Spiro, 1996; Kamal et. al., 1999; Booras & Seely, 1999; and Ware, et. al., 2000). Once the multispectral image cubes are collected, any of several image processing techniques extant in the literature may be used to extract hidden information or enhance contrast. It has been our experience through imaging thousands of pages of archaeological documents that most of the benefit obtained from multispectral imaging can be obtained by collecting an image cube with only a few frequency bands (typically 5 or less), but these bands must be carefully chosen.

Petra Data Collection

The Petra scrolls were discovered under several meters of stone in the ruins of an ancient Byzantine Church in the city of Petra (Peterman, 1994), which is located between the Dead Sea and Elat in ancient Edom. Figure 1 shows the familiar entrance to this city in modern-day Jordan. The precise details surrounding the destruction of the Church are not known, but the scroll fragments became carbonized presumably when the Church was set ablaze. The possibility that the Church had been destroyed in one of the earthquakes which occurred on 10 May 363 or 9 July 551 was dispelled when it was found that some of the Petra Church documents contain information dating to 583.

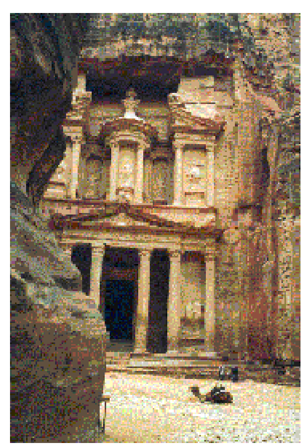

Figure 1. Entrance to Petra showing the Treasury

Examination of the carbonized scroll in the photograph of figure 2 gives a glimpse into the daunting task that faced the original discoverers of the scrolls. Try to imagine how one might unroll the scroll in the photograph which has the appearance of a charcoal briquet. The rolled scrolls are approximately 30 centimeters in width and 13-20 centimeters in diameter. Similar scrolls discovered at Herculaneum many decades earlier were reported to have been used as fuel for fire before it was discovered that those briquets contained writings. The Petra scrolls primarily contain text written in cursive Greek and are now housed at ACOR in Amman, Jordan. The 152 papyrus scroll fragments which were obtained in the conservation process of unrolling occupy about 400 glass plates.

Figure 2. Carbonized scroll

Multispectral Imaging

Multispectral imaging of the unrolled carbonized scrolls was accomplished during two separate excursions to ACOR using a Kodak Megaplus Camera (Model 4.2i) with a spatial sensor array of 2024 by 2044 pixels. Initial tests were conducted during January 1999 using Cambridge Research & Instrumentation VariSpec tunable LCD filters. One LCD filter was used to cover the visible light spectrum from 400 through 720 nm. and the second was used to provide data collection in the infra-red region from 650 through 1050 nm. These LCD filters have bandwidths of 20 and 7 nm. respectively, but were both were stepped through the frequency spectrum in increments of 20 nm. A variety of scrolls in different states of decay and preservation were scanned with the electronically tunable filters to determine the number of multispectral images required to adequately construct an image cube for this application.

The second expedition to ACOR occurred during the period from October through December 1999. In this second data recording process, optical interference filters were mounted in a filter wheel which rotated the fixed filters into position between the lens and focal plane array. These fixed filters had a bandwidth of 10 nm. and were selected with center wavelengths of 550, 650, 750 and 950 nm. An additional filter of 450 nm. was also employed for the multispectral recordings.

Petra Scroll Analysis

The multispectral images of the Petra scrolls revealed significant variations in the spectral response of the papyri while the response of the carbonized ink remained somewhat constant for the fragments. It is conjectured that the variation in the Petra scroll papyri response is due to a variation during burning which undoubtedly created thermal hot spots. Ware, et. al., (see reference 6) combines spectral images of the Petra scroll fragments to display a pseudo-color image where the color mappings support the hypothesis of non-uniform burning. The response of the ink, however, remains spectrally uniform. This result of the multispectral imaging supports the hypothesis that the ink used on the scrolls was carbon based.

Several issues complicate the processing of the Petra scroll multispectral image cubes. First, the contrast of the carbonized ink to the black papyrus background makes the task of enhancing these image cubes rather tedious. Fortunately, it is observed from the Petra scroll data set that the selection of a single multispectral image often provides sufficient separation between the ink and papyrus to allow enhancement with standard histogram modification software.

Second, the number of multispectral image cubes is immense since the data was imaged to achieve a spatial clarity which matched or exceeded that which would be observed under a microscope. Due to the high resolution, images of a single fragment often extend beyond the spatial domain of a single image cube. To accommodate the task of image reconstruction, an automated x-y positioning table was employed. Then, once the individual fragments are reconstructed, the individual fragments need to be combined to provide larger scroll images.

Image Enhancement

The multispectral image cubes were analyzed to determine the best manner in which to enhance the contrast of the scroll text to make it legible. Figure 3 shows a photograph of a scroll fragment. Areas on this scroll fragment image were manually identified as containing either the papyrus background or ink. Histograms were then made across the image cubes for each of the respective ink and papyrus areas. The histograms shown in Figure 4 reflect the average separation between the ink and the adjacent papyrus background for the scroll fragment from plate 49, roll 10, for the visible region of the spectrum. A second histogram is shown for another scroll fragment using the same technique, but in this instance the histogram is determined for the infra-red spectral region. By selecting the best spectral image from an image cube one can be assured of obtaining a resulting separation between the ink and papyrus which is better than this composite histogram.

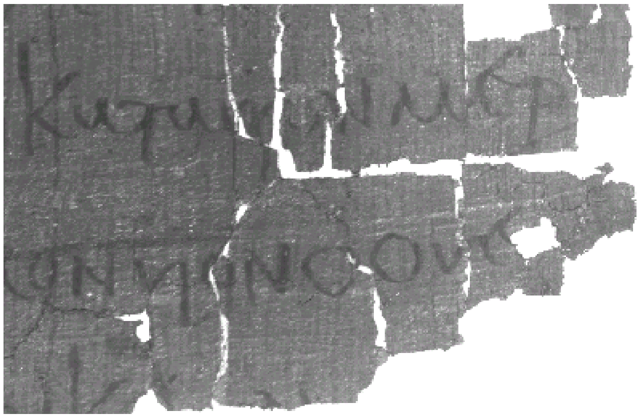

Figure 3. Original Petra scroll image from plate 49, roll 10.

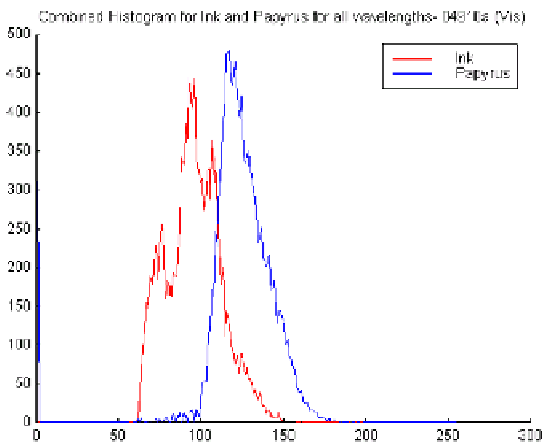

Figure 4. Histogram showing the separation between plate 49, roll 10, scroll areas with ink (shown in red) and papyrus (shown in blue). The scroll fragment images are from the visible spectrum.

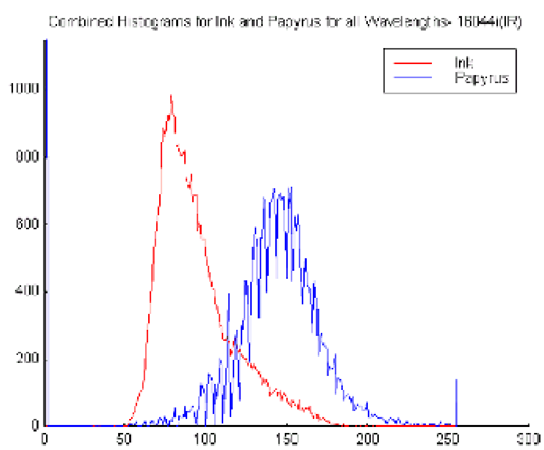

Figure 5. Histogram showing the separation between plate 160, roll 44, averaged over the infra-red spectrum.

The particular multispectral image frequency that provides the best histogram separation varied from fragment to fragment, even within the same scroll. However, once the image with the best separation is selected, the results exceed those one might expect based on a histogram averaged over the entire image cube spectrum. To demonstrate this, Figure 6 shows the same scroll fragment from plate 49, roll 10, after processing with histogram enhancement. Other image processing techniques were applied but did not appear to yield additional legibility.

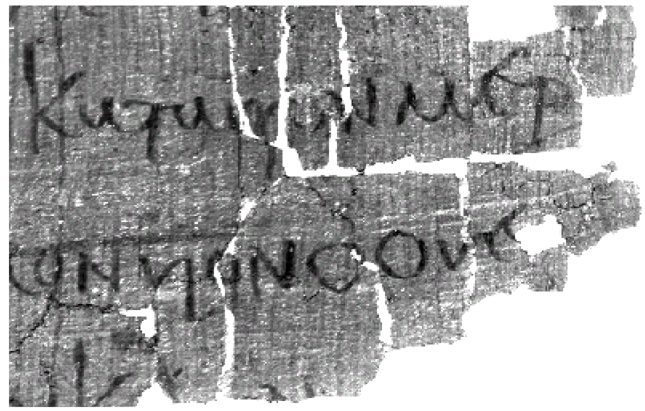

Figure 6. Contrast enhanced fragment from plate 49, roll 10.

Figure 7. Petra Scroll plate 49, roll 10.

Image Reconstruction

Once the multispectral cubes are used to provide suitable images for final processing, the images are stitched together using appropriate software. Figure 7 shows plate 49, roll 10, prior to multispectral imaging. Figure 8 shows the computer aided reassembly process. This process is accomplished in two steps. First the individual images are reassembled into fragments. Then the fragments are juxtaposed and stitched into scrolls to the extent possible given the state of the scrolls. Careful examination of the three smaller block images in the upper left portions of

Figure 8 give an indication of the overlap used for the imaging of the Petra scrolls. With the positioning data from the x-y positioning table, the images are laid on the grid according to their respective spatial orientation.

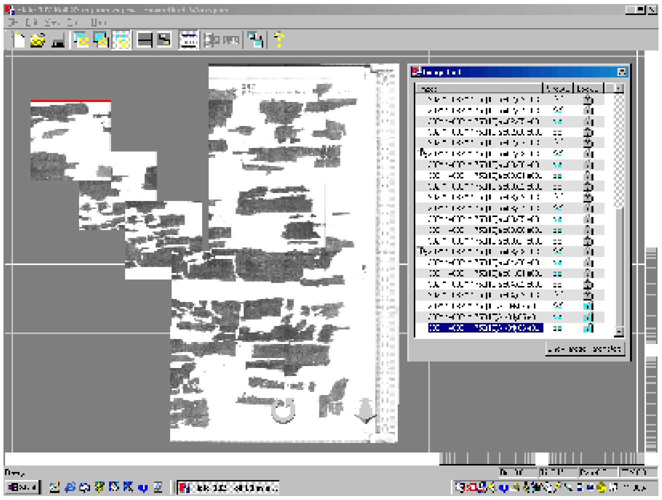

Figure 8. Computer screen showing stitching process.

Petra Results

The multispectral characteristics of the Petra scrolls differ significantly from those obtained in Herculaneum. These differences are primarily attributed to differences in ink and the manner in which the scrolls were carbonized. A significant result is that the ink in the Petra collection has relatively uniform spectral response, yet there is substantial variation in the response of the underlying papyrus. By proper selection of the multispectral image slices, the scrolls may be recorded and characterized with a very small number of filter bands. Multispectral analysis has been shown to be an effective tool in the examination and documentation of carbonized scrolls.

Imaging with a digital camera provided several key advantages. First, it was possible to observe images immediately without the intervening step of film developing. This is particularly crucial when imaging in the near infra-red region with the attendant difficulty in handling IR film. Further, the use of spectral filters in the near IR band provides cleaner images than those collected over the broader spectral band characteristic of IR film. Second, the scientific grade digital camera had excellent response over a very broad range of light exposure. Third, the calibration of the camera combined with the digitally sampled image allows ready application of several image processing algorithms. And finally, as the spectrum of the imaging filters was varied from the UV to near IR, real-time observation of the image allowed precise focusing of the optics.

During the first experiment with the scrolls, the combination of the Kodak digital camera coupled with the electronically tunable LCD filters provided an invaluable tool for determining the necessary coverage of the multispectral image cubes. This led to the use of a reduced number of filters in the multispectral image collection process for the complete Petra scroll collection.

Currently, BYU personnel are working in close communication with ACOR to finalize the first composite scroll sets. These scrolls contain mostly legal transactions between family members of two groups regarding marriages, bequests, properties and out of court settlements.

Acknowledgments

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Figures 3 and 6 are used by permission of the Center for the Preservation of Ancient Religious Texts (CPART), Brigham Young University, in conjunction with the American Center of Oriental Research.

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Biography

Douglas M. Chabries received the BSEE from the University of Utah, MSEE from Caltech, and the PhD in 1970 from Brown University. He is a Professor of Electrical and Computer Engineering at BYU and Dean of the College. He has worked extensively in the field of digital signal processing, including image processing. Currently, he is the Chairman-elect of the Institute for the Study and Preservation of Ancient Religious Texts (ISPART) at Brigham Young University.