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Incorporating High Dynamic Range into Multispectral Imaging for Cultural Heritage Documentation

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Abstract

The dynamic range that can be captured using traditional image capture devices is limited by their design. While an image sensor cannot capture the entire dynamic range in one exposure that the human eye can see, imaging techniques have been developed to help accomplish this. By incorporating high dynamic range imaging, the range of contrast captured is also increased, helping to improve color accuracy. Cultural heritage institutions face limitations when trying to capture color accurate reproductions of cultural heritage objects and materials. To mitigate this, a team of software engineers at RIT have developed a software application, BeyondRGB, to enable the colorimetric and spectral processing of six-channel spectral images. This work aims to incorporate high dynamic range imaging into the BeyondRGB computational pipeline to improve color accuracy further.

Introduction

Human vision has a superior dynamic range in comparison to conventional imaging devices. While an eye can perceive a much broader luminance range, an image sensor falls short at capturing the same luminance range within a single image capture. High dynamic range imaging is a way to mitigate this issue. The most common technique consists of capturing multiple single-exposures images of the same scene and fusing the images together in post-processing [1]. This helps to ensure that all the pixels are properly exposed in one or more of the images. The computation also includes an image-alignment technique as objects, the camera, and the light source do not remain still between exposures. Some procedures have been developed to extend the dynamic range of a single image [2]. Recently, high dynamic range imaging has been applied to cultural heritage documentation [3-6].

Photography is an important aspect in the recording and documentation of historical objects to accurately capture the color and texture within objects and scenes [7, 8]. Wheatley points out issues within archaeological recording, particularly within high-contrast scenes. Three case studies were presented, all with high-contrast characteristics and the incorporation of high dynamic range imaging significantly increased the quality of the illustrative photography.

Cultural heritage institutions would benefit from switching to spectral imaging systems, as they allow for superior color reproduction in comparison to conventional RGB imaging. However, most cultural heritage institutions are deterred from incorporating these systems into their workflow due to the high cost and complexity of the process. Current research has worked towards addressing these limitations and creating a spectral imaging system with a lower barrier to entry and at a lower cost [9, 10].

A team of software engineers at Rochester Institute of Technology have developed a software application, BeyondRGB, to enable in the colorimetric and spectral processing of six-channel spectral images [11]. The software was created with the user in mind to create a simple and intuitive experience. The computational pipeline has three phases: pre-processing, processing, and rendering and output. To start, six-channel spectral image sets composed of pairs of RGB images are inputted into the system. The camera signals are extracted from color target patches, and colorimetric and spectral reflectance calibrations are done. The software outputs a color-calibrated 16-bit ProPhoto TIFF along with colorimetric and spectral calibration data files. Additionally, the spectral calibration enables interactive estimation of spectral reflectance of the pigments used within the artwork. The research described here was motivated by a desire to combine high dynamic range imaging with the low barrier-to-entry spectral imaging process to render a color-accurate image for the documentation of cultural heritage objects.

Methods

Stimuli

Three high dynamic range (HDR) and three low dynamic range (LDR) cultural heritage artworks were used as stimuli. Medium dynamic range artworks were excluded to focus on the low and high extremes. Visual assessment, which was verified with quantitative measurement, was used to select the stimuli as some institutions do not have the means to collect information about the dynamic range. In addition to visually assessing the artworks, images were also taken with the RAW+ app rather than the Photos app as it is known that smartphone cameras generally boost contrast; however, there will always be some manipulation done on all images taken with smartphones. To visually assess the luminance of the artworks, the image from the RAW+ app was manipulated within the Photos app by turning the saturation slider down to only assess luminance, which can be seen in Figure 1. The HDR and LDR artworks are labeled accordingly. This allowed for better visualization of the dynamic range of the artwork, which some institutes may use to briefly categorize the dynamic range of the artwork without other means of data collection. A visual assessment by four individuals within the Program of Color Science agreed with the low and high dynamic range artwork choices.

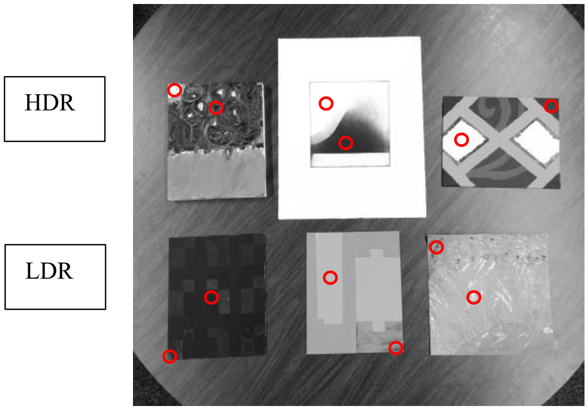

***Figure 1**. Stimuli imaged with the RAW+ app, then manipulated within the Photos app to eliminate saturation to only assess luminance.*

The lightest and darkest parts of all six artworks were measured with the CR-250 spectroradiometer under D65 illumination of the SPECTRA TUNE LAB lights at 0/45° geometry to obtain estimates of the maximum and minimum luminance values. The measured points of each artwork are indicated by the red circles in Figure 1 and the spectral power distribution of the D65 setting can be seen in Figure 2. The final maximum and minimum values, listed in Table 1, were an average of 5 luminance measurements. The direct contrast ratio was calculated by dividing the maximum luminance value by the minimum luminance value.

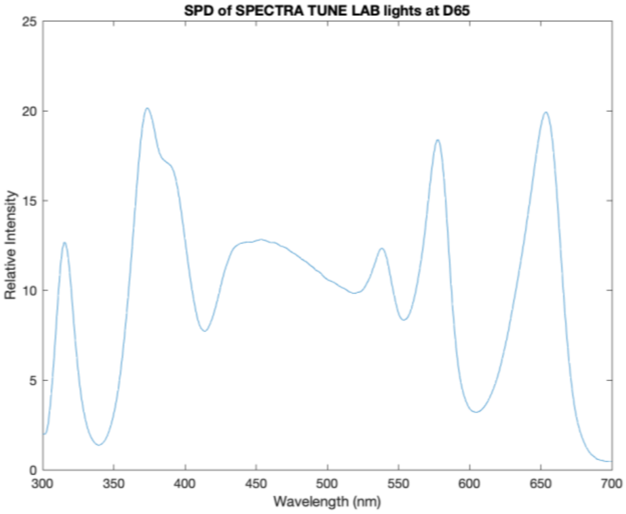

***Figure 2**. Spectral Power Distribution of SPECTRA TUNE LAB lights at their D65 setting.*

Table 1: Average measured luminance values for the six stimuli

Artwork	**Maximum**	**Minimum**	**Direct Contrast Ratio**
1	10.5	8.1	1.3:1
2	139.7	38.0	3.6:1
3	107.6	27.2	3.9:1
4	157.3	8.3	18.9:1
5	155.3	7.3	21.3:1
6	162.3	7.4	21.9:1

Imaging

Image capture follows the dual RGB illumination protocol and the Beyond RGB Pipeline [11, 13]. All images were taken with a modified Sony α7RII, for which the internal infrared filter has been removed. SPECTRA TUNE LAB spectrally tunable LEDs were used to generate two lighting conditions as described in [12, 13]. The lights and camera were set up at a typical 0/45° geometry. To start, flatfield and dark current correction images were taken under the two different illuminations, which were optimized within previous work [12, 13]. Images of the Digital Color Checker SG were then taken underneath both lighting conditions, and then replaced with the artwork. 26 images were taken for each artwork, 13 exposures underneath each lighting condition ranging from 3 stops above and below the starting exposure.

As described previously, the current computational pipeline includes three phases: pre-processing, processing, and rendering and output. The proposed HDR merge will be inputted into the pre-processing phase between the dark current and flat-field corrections and the registration of image channels. A flow chart of the pipeline can be seen in Figure 3, with the incorporation of the proposed new step included which is highlighted in black.

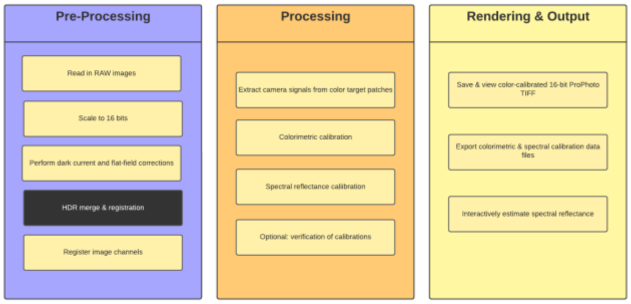

***Figure 3**. Proposed new computational pipeline.*

To start, the optimal exposure will be run through the pipeline to obtain a baseline of color accuracy without the incorporation of high dynamic range imaging. The image sets will be merged utilizing the High Dynamic Range Toolbox in MATLAB. The additional six image sets will run through the pipeline and compared to the baseline. The goal is to identify the proper number of exposures for minimal loss in color accuracy for both high and low dynamic range artworks.

Table 2: Breakdown of HDR image sets

Image	Exposure	Total # of Images	Increased Range
Set 1	Starting exposure (SE)	1	
Set 2	SE ± 0.5 stop	3	1 stop
Set 3	SE ± 1 stop	5	2 stops
Set 4	SE ± 1.5 stops	7	3 stops
Set 5	SE ± 2 stops	9	4 stops
Set 6	SE ± 2.5 stops	11	5 stops
Set 7	SE ± 3 stops	13	6 stops

Results

The experiments are underway and preliminary results will be available in the upcoming weeks. Results and discussion will be complete prior to May 15th.

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Author Biographies

Gabrielle Brogle is an MS student in the Program of Color Science at Rochester Institute of Technology. She holds a BS in Photographic Sciences with a minor in psychology from RIT.

Susan Farnand is an Assistant Professor at Rochester Institute of Technology. Her main research areas center around human vision and perception and include visual attention, color imaging, image quality metrics, 3D printing, and archiving. Prior to joining RIT in 2006, Dr. Farnand was a senior research assistant at Eastman Kodak Co. working primarily on projects in perceptual image quality measurement and modeling. She holds a BS in engineering from Cornell University, and an MS in imaging science and a PhD in color science from RIT. Dr. Farnand is IS&T President.