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Beyond RGB 2.0: Further improvements to a free, opensource, spectral image processing software application for workflow, analysis, and repeatability

Leah Humenuck and Susan P. Farnand: Rochester Institute of Technology; Rochester, New York/USA

Abstract

*Beyond RGB is a recently developed software application for colorimetric and spectral processing. Two sets of RAW RGB images (a dark current image, a flatfield, target, and artwork), taken under two different lighting conditions are used as the inputs. After processing, the software provides a color calibrated RGB image, along with the calibration accuracy, a spectral stack, and if applicable estimated spectral reflectance of regions of interest may be selected. The updates for this version of the software includes: dual screens for simultaneous file comparisons, updated a*b* and L*C* plots showing the actual and expected values, batch processing, meta data allowing for precision reproducibility for color calibration, and user interface upgrades.*

Introduction

The process of traditional imaging of cultural heritage items typically involves an RGB camera, a broadband light, and one capture of the item under a chosen exposure. However, this process contains inherent imperfections, as cameras and the human visual system differ with processing the same scene, which can lead to color differences in the final image by the camera and how a person sees the scene. Challenges like this can lead to post-processing in order to provide color correction. Spectral imaging is a way to bridge this gap between traditional imaging and human vision through better estimation of what the human eye sees [1]. However, traditionally spectral imaging also came with barriers for this use, which included expensive instruments and specialized training which can inhibit adoption of spectral imaging for small to mid-size cultural heritage institutions. In response to this there have been new developments made to provide access to spectral imaging through lowering these barriers one of which includes Beyond RGB, a free, open-source software application which was first introduced in 2022. Beyond RGB performs processing on images from an RGB camera taken under two lighting conditions [2].

Background: Beyond RGB

Beyond RGB 1.0 provided the foundation for the processing. The artwork is imaged under two different lighting conditions. The lights used for this are two different sets of programmable LEDs which generate different spectral power distributions, where the color appearance of artwork underneath these lights are used to create a reasonable spectra estimation [3]. The software intakes two sets of images each from a different lighting condition. These image sets include an image of the item, the target (or a combined item and target image), a flatfield, and a dark current. This then proceeds through a pre-processing and processing stages. In summary, the preprocessing intakes the RAW images and performs dark current correction, flatfielding, and registration. The processing takes both sets of images and performs concurrent colorimetric transformations (corresponding to CIE XYZ tristimulus values) and spectral reflectance transformations (in the range of 380-780nm at 10nm intervals) to provide a resulting color corrected TIF file along with spectral information. A full description of the pre-processing and processing can be found in Kuzio and Farnand's work, 'Toward Practical Spectral Imaging beyond a Laboratory Context' and 'Beyond RGB: A Spectral Image Processing Software Application for Cultural Heritage Studio Photography' [3-4]. Figure 1 provides a visual summary of the pipeline. Beyond RGB was developed by Rochester Institute of Technology (RIT) undergraduate senior software engineers. To date, there have been three groups who have conceived and improved this software application.

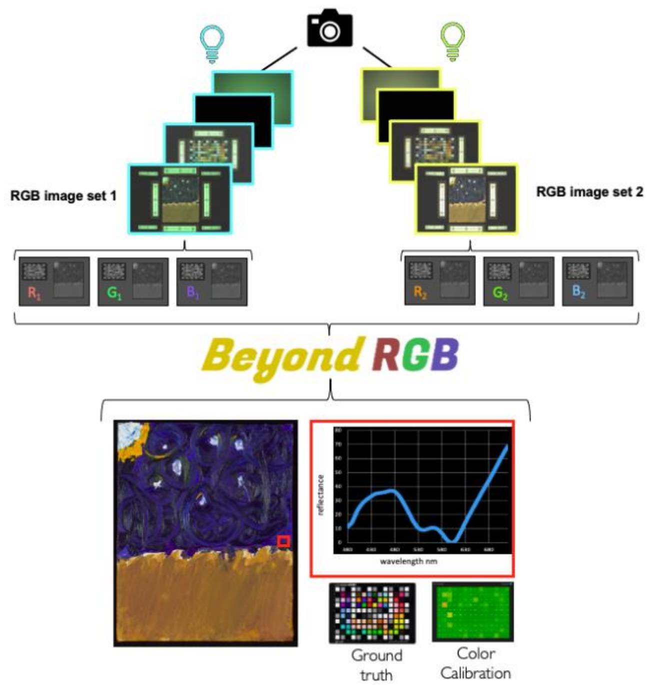

Figure 1. A visualization of the Beyond RGB pipeline

Improvements: Beyond RGB 1.5

Beyond RGB 1.0 was the fully functioning version of the software operating through the main process screens of Welcome, Import Images, Output Destination, Specify Image Roles, Optional Filtering, Target Patch Selection, Processing, Image Viewer, and Calibration Reports. Beyond RGB 1.5 updated specific key areas after user testing and feedback collected from cultural heritage institutions of various sizes and RIT Museum Studies students [5]. Feedback is continuing to be collected and used to inform future updates. The updated areas for 1.5 were introducing the Drag and Drop feature for Import Images, an auto sort for Specify Image Roles, comparison of estimated spectral reflectance curves from different regions of interest in the Image Viewer, an improved calibration report with accessible grayscale option, and a dedicated website.

Further Improvements: Beyond RGB 2.0

Actual and Expected Color Plots

In both previous versions of the software the use of the CIELAB a*b* and CIELCh L*C* plots were limited. Both of these plots provide useful information about the way in which the calculated colors differ from the measured. The CIEDE2000 color difference is used to provide an overall magnitude in difference shown in the color calibration results plot shown in figure 2. However, a total magnitude in color difference does not tell how the colors differ, only that they do. The a*b* plot, shown in figure 3, shows the way in which the colors may vary along these axes, in the CIELAB space, a* being a greenish (-) to reddish (+) shift and b* being a blueish (-) to yellowish (+) shift. The L*C* plot, shown in figure 4. shows the way in which the colors differ in CIELCh space, L* being lightness with darker closer to 0 and lighter closer to 100 and C* is chroma with less chroma closer to 0 and more chroma closer to 95. Together these can give four total ways in which the calculated colors may differ from the measured. In version 2.0, these plots have become improved by creating new symbols indicating the actual and the expected coordinates for these different values. In version 2.0, the actual is indicated by a white outline and the expected is indicated by a black outline, with a legend at the bottom of the chart to guide users. By including this feature, it allows users to understand how different colors in their images may be behaving after calibration.

Figure 2. Screenshot of the Beyond RGB Color Calibration plot. The numbers on this plot show the ΔE_{00} between the calibrated and the measured values.

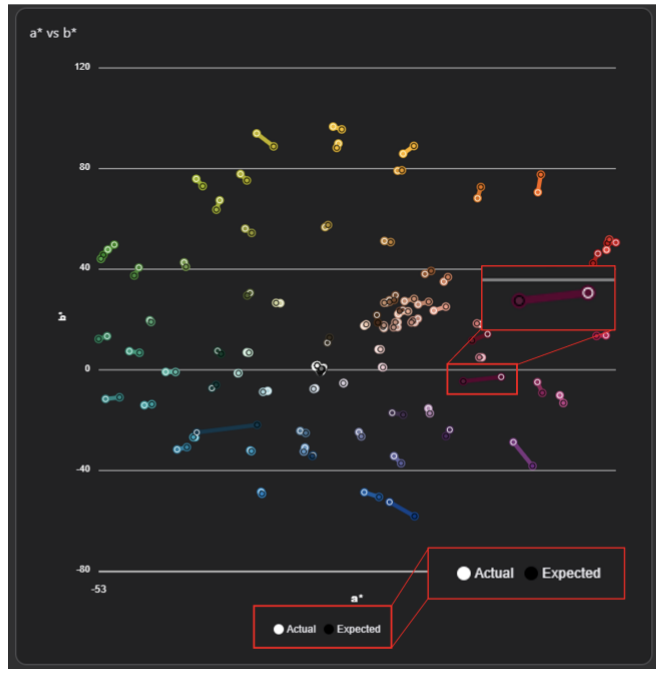

*Figure 3. Screenshot of the Beyond RGB 2.0 a*b* plot with highlighted details showing the changes to the icons and the addition to the legend.*

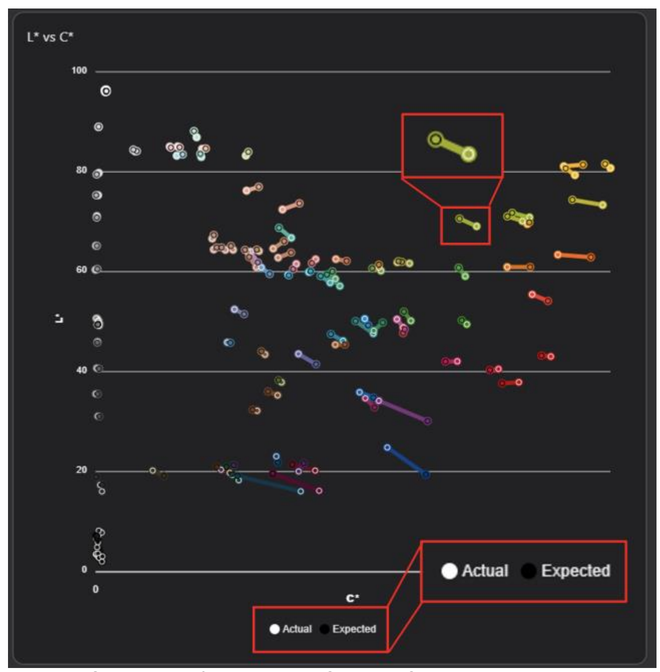

*Figure 4. Screenshot of the Beyond RGB 2.0 L*C* plot with highlighted details showing the changes to the icons and the addition to the legend.*

Batch Processing

One of the biggest additions to the software is the inclusion of batch processing. In the previous versions, only one set of images could be processed at a time. This new feature allows multiple item image sets to be processed in one run of the software rather than uploading all the image sets in new sessions each time. This saves a user time and is a feature needed for studios where typically many items are imaged in one session. The user still retains the option of processing only one set of images as shown in figure 5. The differences between the single and batch processing screens are shown in the comparison of figures 6 and 7. In batch processing, the user selects the dark current, flatfield, and target once and then it applies the processing to all item image sets uploaded into the same session. When the processing occurs, the same visualization happens as with single item image processing. Each item image sets that is processed gets saved in different files in the same destination folder.

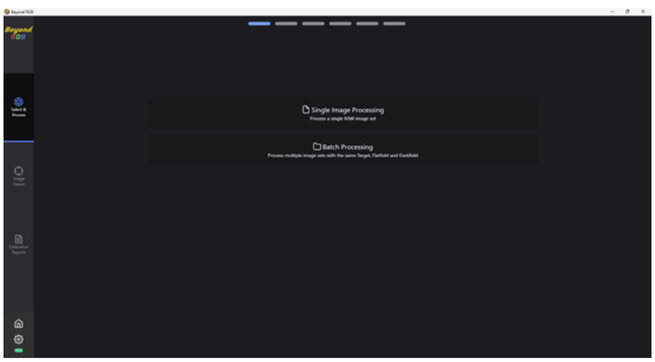

Figure 5. Image of Processing window showing the two options of either single image or batch processing.

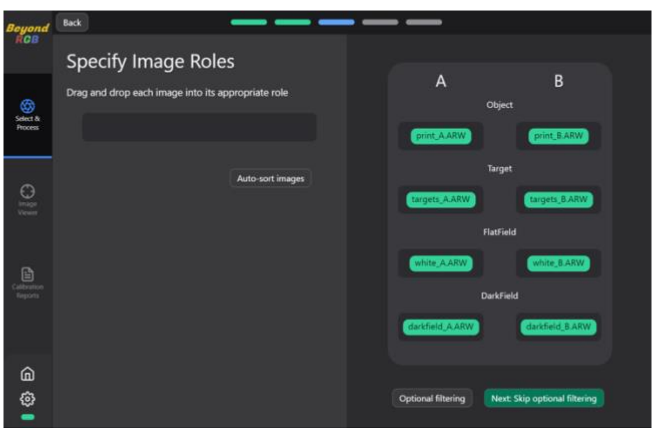

Figure 6. A screenshot of the single item image processing: Specifying Image Roles

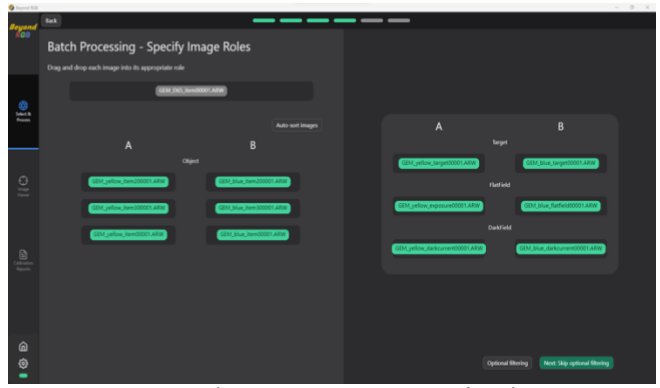

Figure 7. A screenshot of the batch image processing: Specifying Image Roles

User Interface and Other Updates

Reproducibility for Color Calibration

Within the previous versions of the software, when processing the same set of images, depending on what pixels were chosen in the grid selection for the color target, the color calibration could change. Within this new version the pixels chosen for the grid selection are recorded and become part of the final log files provided. The differences are seen between figures 8 and 9, where the display of the pixel locations for each of the corners of the grid are located below the calibration target options in figure 9 and this is absent in figure 8. Should further analysis of this processed image need to occur; the precise grid selection can be used again in order to keep the data as consistent as possible. This increases accuracy and reliability for the user to be as consistent as possible when creating color accurate images and analyzing different aspects such as color differences for the items.

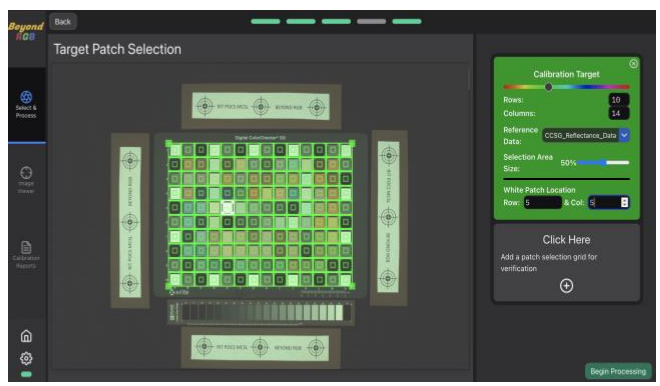

Figure 8. A screenshot of the grid selection window for versions 1.5 and earlier

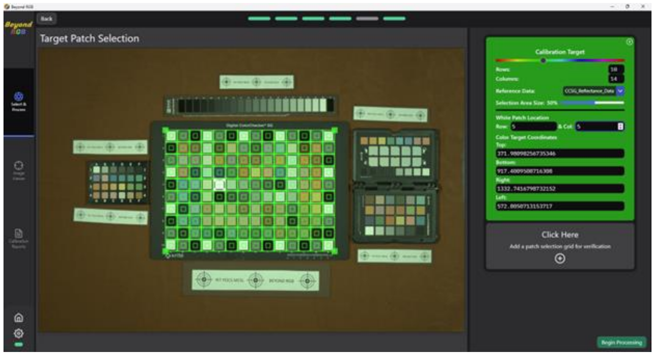

Figure 9. A screenshot of the grid selection window for version 2.0

In-Software Comparison

One of the new features of Beyond RGB 2.0 is that it can open multiple color-corrected files at the same time. Figure 10 shows the new start page with the third option of Create Another Window process. A user can utilize the estimated reflectance spectra to investigate different regions of interest, allowing them to zoom into the same area on both plots, or assessing a*b* plots. This capability allows a user to view and compare item images such as before and after conservation treatment or items from the same artist in different windows of Beyond RGB. This feature will give the user more flexibility within the software without needing to download the information and investigate using other software. An example of this is shown in Figure 11, where the same art piece has been processed two times using two different color targets, respectfully. With this in-software comparison, a user is able to investigate the same region on each color-corrected image and compare the estimated reflectance spectra.

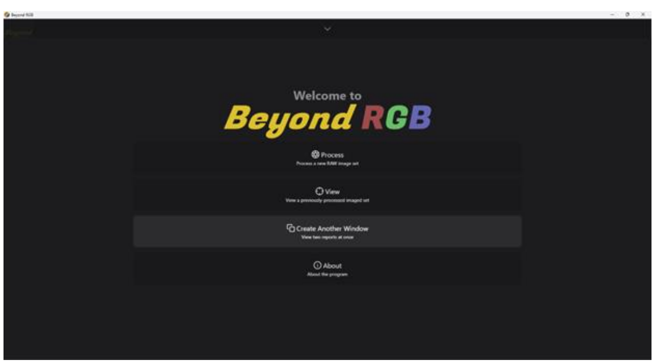

Figure 10. A screenshot of the start window showing the new option of Create Another Window.

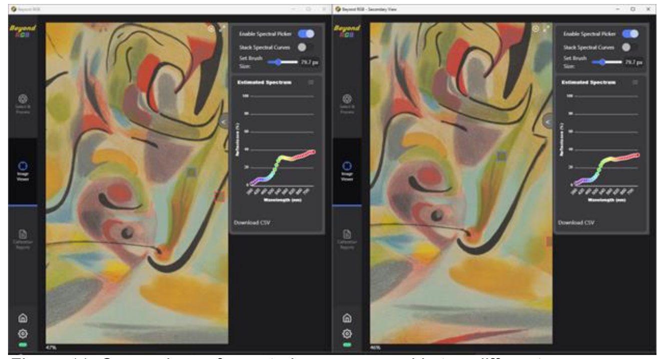

Figure 11. Comparison of an art piece processed in two different ways.

Range of Values

Previous versions of the software gave the output of the reflectance between 0-100. This has now been updated to 0-1. This was minor but necessary step to allow users to use their data easily.

Conclusion

Beyond RGB is a free, open-source, software application that allows small to mid-sized cultural heritage institutions to create color accurate documentation of their items. It utilized a dual-lighting along with the regular RGB cameras producing a color-accurate spectral image without post processing. The software application then utilizes the color-accurate spectral image to provide further investigation and flexibility for institutions with their documentation and research by giving them estimated reflectance spectra. This software application has gone through an update in 2023 which was informed by feedback form various intuitions and users [5]. There were still more areas where improvements could be made which has led to this second update. Additionally, feedback is continuing to come in internationally including the National Gallery, London, UK and locally where use of Beyond RGB is intended in a collaboration with the University of Rochester for documenting items in their rare book collection. These new improvements to Beyond RGB have both smoothed operations for individual users and allow it to be incorporated into workflows. It also increases its adoption to be used for more repeatable and quantifiable analysis of images, color calibration, and estimated reflectance spectra. These new components, combined with the original capabilities, demonstrate how the barrier to entry for accessible spectral imaging has been lowered due to the creation of a user-friendly, spectral image processing software.

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Author Biography

Leah Humenuck is a PhD candidate in Color Science at the Munsell Color Science Laboratory at Rochester Institute of Technology. Leah's research interests are in imaging, reproduction, and lighting for cultural heritage. She is also a book and paper conservator which informs her color science research of archival items. Leah holds a BS in Chemistry from Sweet Briar College and an MA with honors in Conservation from West Dean College of Arts and Conservation.

Susan Farnand is the Graduate Program Director of, and an Associate Professor in, the Program of Color Science at the Rochester Institute of Technology (RIT). Her research interests center around human color vision and perception including individual color vision differences, visual attention, color imaging, image quality metrics, 3D printing, and archiving. Prior to joining RIT in 2006, Dr. Farnand was a Senior Research Scientist at Eastman Kodak Co. working primarily on projects in perceptual image quality measurement and modeling. She holds a BS in Engineering from Cornell University, an MS in Imaging Science, and a PhD in Color Science from RIT. Dr. Farnand is the current IS&T President.