Multispectral Imaging (MSI) with a Modified Monochrome DSLR Camera

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Introduction

Monochrome Modification:

UV-VIS-IR modified single-lens reflex cameras (DSLRs) are used to record the reflective response of artifacts in various wavelengths using lens filtration or controlled illumination to determine the specific wavelengths recorded. In these cameras, the IR blocking and anti-aliasing filters are removed to allow recording of UV and IR wavelengths, but the RGB color filter array (CFA) is left in place to permit standard color photography. The CFA, however, compromises accurate recording of spectral response. The difference in spectral sensitivity of sensors with or without CFA is illustrated in Figure 2.

In monochrome modified cameras, the CFA is also removed, making it possible to record actual spectral response at each pixel site. An additional advantage of this modification is improved UVA and NIR imaging because the CFA attenuates in these regions.

MSI Components

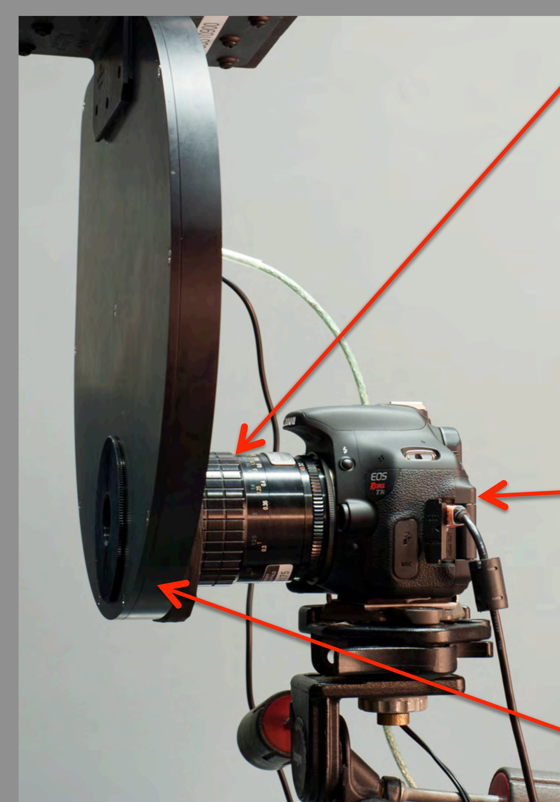
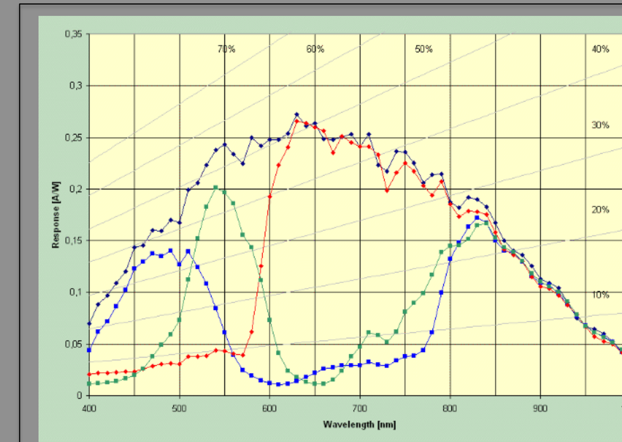


Figure 1: Camera/Lens/Filter Wheel Setup

A. **CoastalOpt® UV-VIS-IR 60mm Apo macro lens** (Nikon mount) with an **Rayqual Nikon F Lens adaptor** to permit mounting on Canon body. This lens is apochromatic from 315 nm to 1100 nm and thus requires no focus adjustment when imaging outside the visible region. This is advantageous as it eliminates the image size changes that occur with focus shifts thus making perfect registration easy to achieve when stacking image sets or creating false-color images.

B. **Monochrome modified Canon T3i Rebel camera from LDP LLC**: 18MP APS-C sensor; Color Filter Array, IR blocking, and anti-aliasing filters removed. Provides Live View and tethering to a computer with free Canon EOS Capture software.

C. **A set of 14 Andover narrow bandpass filters** is used to control the wavelength range reaching the lens. (Visible and IR filters are +/-10 nm bandwidth; UVA filter is +/-25 nm bandwidth.) The set consists of 25mm diameter filters with peak transmission wavelengths of 365, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, and 1000 nanometers. The filters are mounted in a computer-controlled Finger Lakes Instrumentation CFW-3-20 20-slot **motorized filter wheel** (see Figure 3). The camera lens is positioned closely behind the filter slot opening to minimize vignetting.



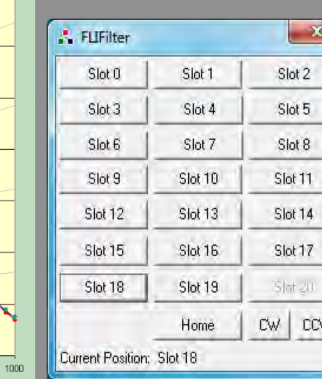


Figure 2 (left): Typical response curve for CCD and CMOS image sensors studied by LDP LLC. The top dark blue curve shows the quantum efficiency of an unfiltered image sensor. The Red, Green and Blue curves show the transmission response after the light passes through the Color Filter Array on the image sensor.

Figure 3 (right): Software panel for Finger Lakes Instrumentation motorized filter wheel. The filter set occupies the slots from 1 to 14. Filters are changed simply by clicking the slot button.

Method for Determination of Exposure Compensation for Wavelength

The monochrome sensor is not equally sensitive to every wavelength. As the spectral curve in Figure 2 shows, the sensitivity falls off at shorter and longer wavelengths. In order to compensate for this non-linearity, exposure taken through filters transmitting in these regions must be increased. A set of four Spectralon Diffuse Reflectance Standards was used to determine the exposure adjustment for each filter. These standards have equal or nearly equal spectral responses from 350 nm to 1100 nm, with reflectance of 99%, 75%, 50%, and 2% from white to black (see Figure 4).

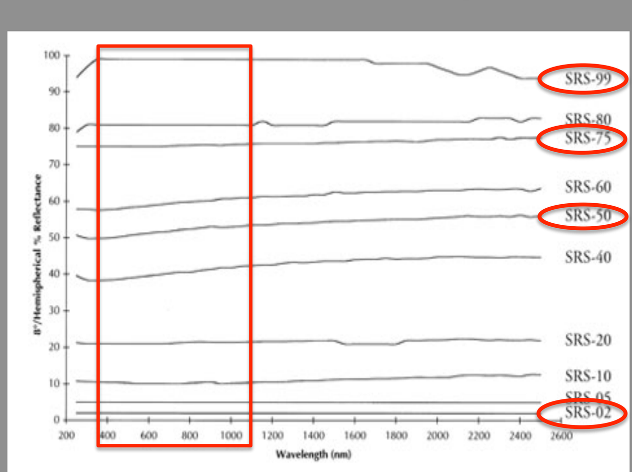


Figure 4: A set of Spectralon Diffuse Reflectance Standards was included in each image. The spectral responses for these standards (SRS-02, SRS-50, SRS-75, SRS-99) between 350 nm to 1100 nm are highlighted by the red box to the left.

A reference set of images covering all filters was created. The images were processed and assessed in Adobe Camera Raw (ACR) as follows: All ACR default settings were zeroed (area A below); Saturation was set to -100 (B); and the Linear Point Curve (C) selected. Camera exposure was adjusted to set the RGB values of the white 99% reflectance standard at 248 (D & E). This value was selected to minimize the risk of clipping in any area in the white standard. For greatest accuracy, the camera shutter speed was adjusted so that no more than 1/3 stop of ACR exposure adjustment (F) of the raw file was required to set the standard at 248.

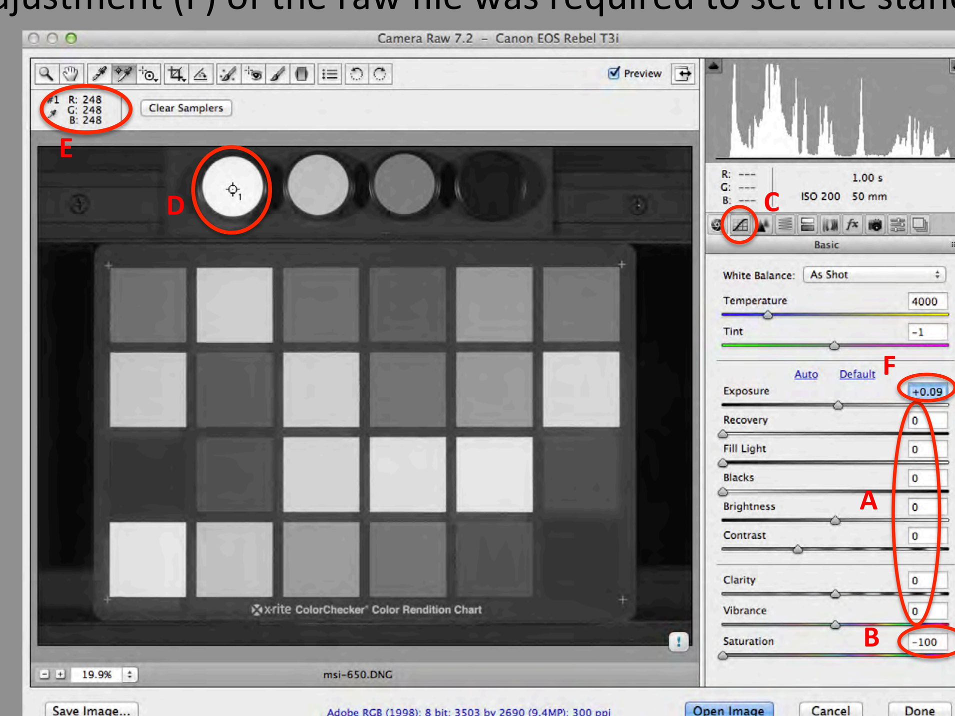


Figure 5: Image processing in Adobe Camera Raw.

Suggested Exposure Compensation Chart

Using the exposure time for the 650 nm filter as a base (the sensor's peak sensitivity), a reference chart (right) was created listing the variation in exposure required for each of the filters.

For future image sets, the 650 nm filter is imaged first to determine the base shutter speed. The variations in exposure times required to set the white standard at 248 for images taken through the remaining filters are then made by referencing the chart. This greatly simplifies the setting of exposure so that ACR exposure adjustments can be kept to the desired 1/3 stop minimum.

slot	nm	stops
14	365	+2/3
13	400	+3 2/3
12	450	+2 1/3
11	500	+1
10	550	+2/3
9	600	0
8	650	0
7	700	0
6	750	+2
5	800	+1/3
4	850	+2/3
3	900	+1
2	950	+1 2/3
1	1000	+4

Table 1

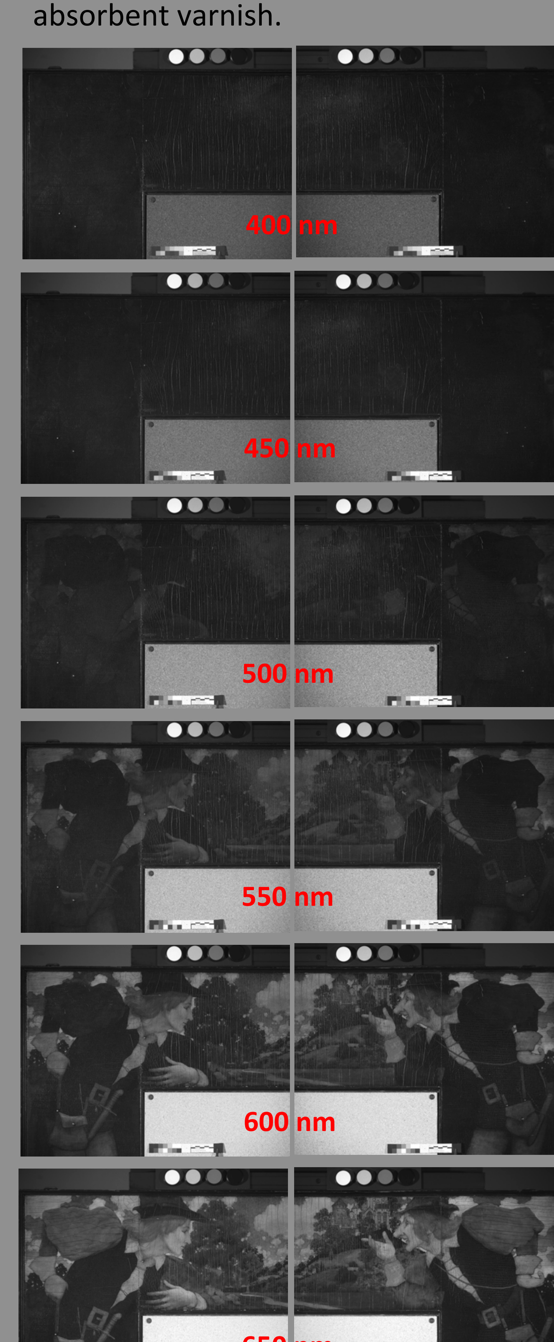
Image Capture Process Summary

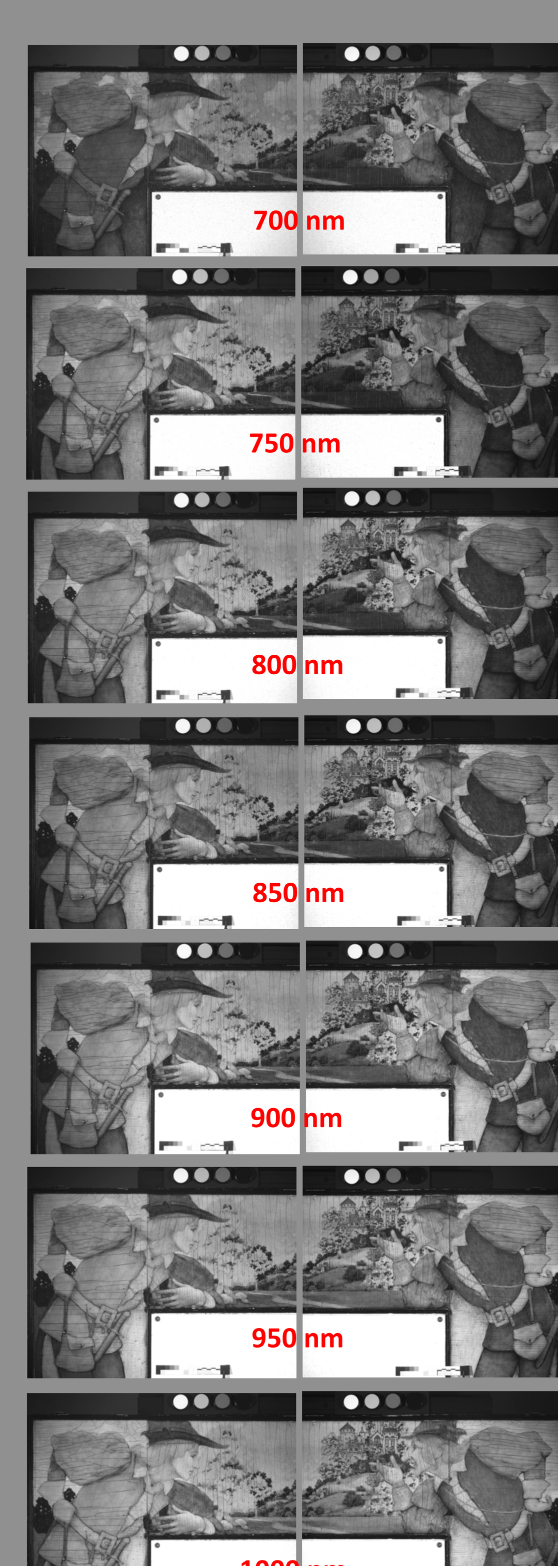
1. Arrange subject and the diffuse reflectance standards under normal illumination with incandescent lights.
2. Determine the base exposure by capturing the first image with the 650 nm filter.
3. Capture the visible and IR image set with the remaining 400 nm to 1000 nm filters. Set camera exposure by using the suggested exposure compensation (see Table 1) and finalize the exposure to make sure that the RGB values of the white standard are set at 248 with no more than 1/3 stop ACR exposure correction.
4. Capture the 365 nm image with the UVA source according to suggested exposure compensation and adjust to make sure that the RGB values of the white standard are at 248. (The positions of the UVA lamps should be similar to those used for the initial exposure compensation chart test set.)
5. After processing, save all raw format images as DNGs.

Figure 6: "Bulletin Board", oil and varnish on board, by ***Maxfield Parrish***, 35 1/8" x 44 7/8" x 1 5/16", 1896, collection of the Twentieth Century Club of Buffalo.

An Example

Figure 7: The right and left figures of the upper portion of the painting are recorded with MSI from 400 nm to 1000 nm. The painting was not imaged at 365 nm because of its thick UV-absorbent varnish.





The green vests in both figures begin to appear different at 700 nm, with a big jump at 750 nm where the vest of the left figure shows a sharp drop in absorbency. The vest of the right figure, however, exhibits only a very gradual decrease in absorbency out to 1000 nm. The details of the painting are not very visible in the 400 nm, 450 nm, and 500 nm because of the thick discolored varnish.

False-Color Images derived from the multispectral image set can be very helpful in distinguishing different materials. The false-color images below clearly show that the green vests of the two figures are painted with different materials. The belts are also different. The wall color behind the figures appears not to have been used elsewhere in the painting. The material used to paint the vest on the right figure may be the same as that for the hills in the background.

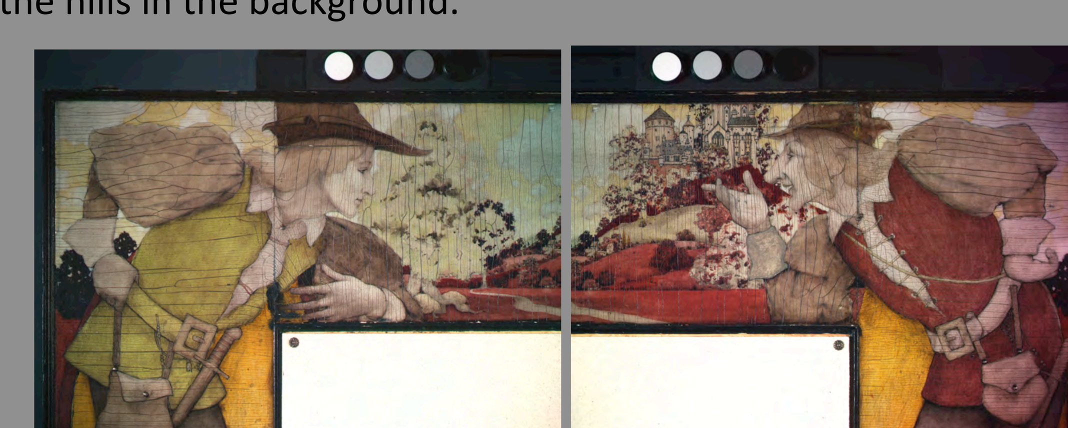


Figure 8: These false color images were created by copying the 700 nm, 800 nm, and 1000 nm images into the blue, green, red channels respectively.

The multispectral image set can also be used to create basic **reflectance spectra**. Note the significant difference in the shapes of the spectra of the two vests. The shape of the curve may be used to assist in the identification of the material.

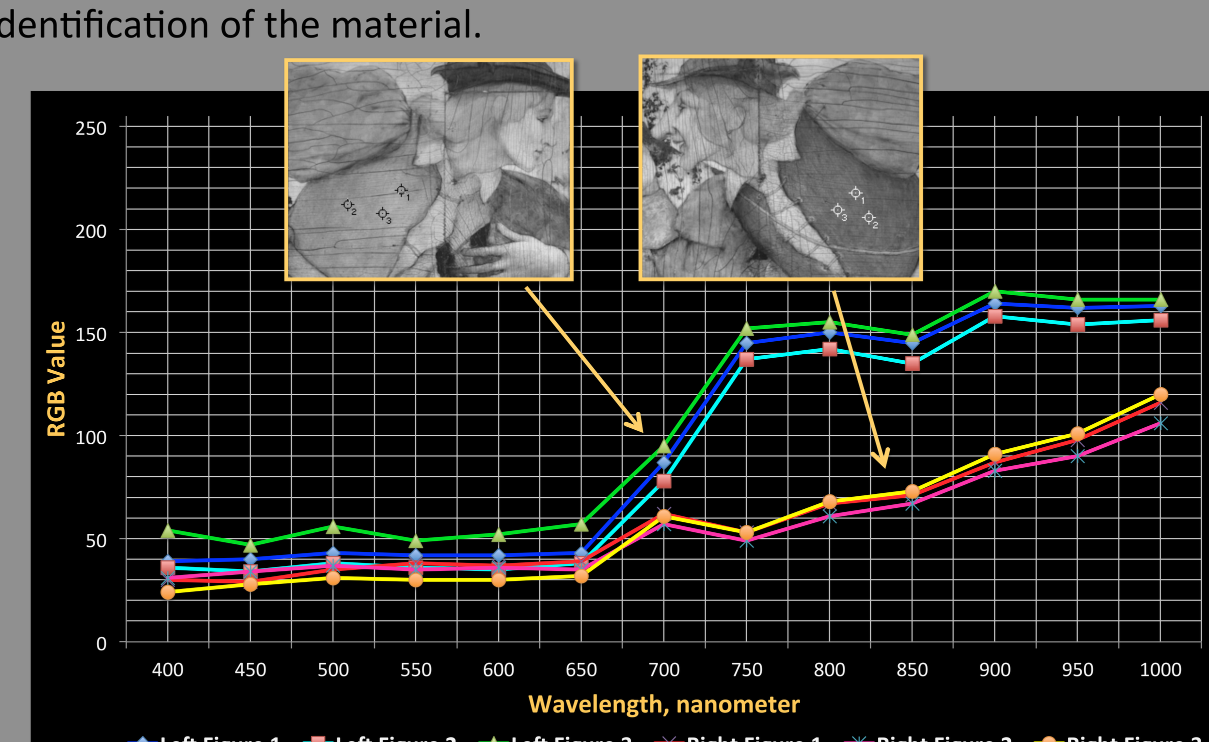


Figure 9: RGB values from all 13 images were recorded from the three locations indicated by the Adobe Camera Raw samplers 1, 2, and 3 above, and charted using Microsoft Excel.

COST OF THIS MSI SYSTEM:

1. **Filter wheel:** $1,950.00
2. **Set of 14 filters:** $2,351.00
3. **Monochrome Modified Canon camera** from LDP LLC: $2,315.00**
4. Rayqual Nikon F to Canon EOS Camera Body **Lens Adapter:** $175.00
5. **CoastalOpt® UV-VIS-IR 60mm Apo macro lens:** $0
   (Lens previously purchased for earlier multiband imaging. Current cost: $5,750.00)

TOTAL COST: $6,791.00 ($12,541.00 if lens is included)

**LDP now also offers a monochrome modified Nikon D800, which is $6,050.00.

For more information about this system, please send inquires to chenj@buffalostate.edu.

NEXT STEPS:

1. Incorporation of Robin Myers Imaging EqualLight® for flat field correction.
2. Investigation of options to improve post-capture processing utilizing reflectance of all four Spectralon Standards as well as the development of a corresponding profile to apply to the raw files. In the future, we plan to obtain a complete set of all eight standards and to develop a more precise profile.
3. Determination of an appropriate MSI analysis software to enable the creation of image cubes for spectrography and mapping.

Acknowledgements

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