Multispectral (or Multiband) Imaging Workflow for *Objects*

Authors: Caroline Roberts and Suzanne Davis, Kelsey Museum of Archaeology, University of Michigan

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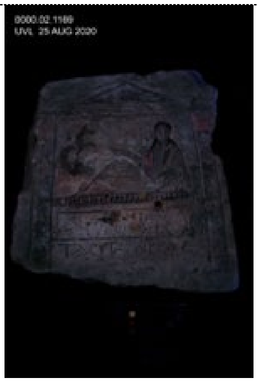
About Multispectral Imaging

Multispectral imaging (MSI) is a nondestructive photographic technique that can be used to identify pigments, dyes, and fibers and to map their locations on an object.

At the Kelsey Museum, we conduct MSI using a camera that has been modified to detect visible, ultraviolet, and infrared light, and our two-step workflow includes image capture and processing. We use the following set of equipment:

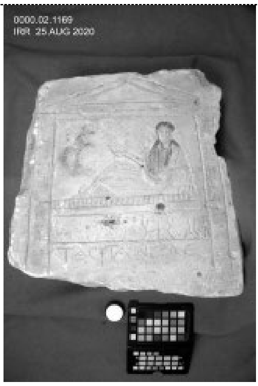
- Nikon D80 DSLR camera with a “full spectrum” modification, mounted on a tripod
- Longwave UV, visible, and infrared light sources (listed below)
- A set of bandpass lens filters, which allow the camera to capture characteristic reflectance or luminescence from dyes and fibers, while blocking unwanted radiation
- Magnetic ring adapters to make changing filters quick and easy—the filter is held in place with a magnet, eliminating the need to screw it on and off the lens
- Calibration standards, including a color checker and 99% diffuse reflectance standard
- Adobe Photoshop for image processing

Imaging Techniques

Visible light (VIS) Visible light is what most people use in day-to-day photography. VIS images capture the reflectance and absorption of visible light off the surface of an object, a phenomenon our eyes perceive as color. In MSI, the VIS image is used as a reference to compare with other images and for processing false color images (more on this below).	
Ultraviolet-induced visible luminescence (UVL) This technique’s light source is a longwave UV–generating black light, and although we can see some purple light that emerges with it, we can’t actually see UV light with our eyes. The energy in longwave UV can “excite” electrons in the atoms of certain materials, causing them to emit a characteristic colorful glow that we *can* see (a phenomenon known as fluorescence or luminescence) in materials such as **shellac** and **madder lake**. Other materials (such as modern restoration paints and ancient copper mineral pigments) can appear very dark under UVL. These characteristics make UVL useful for pigment and binder identification, pigment mapping, and—in rare cases—revealing ancient painted inscriptions on artifacts.	

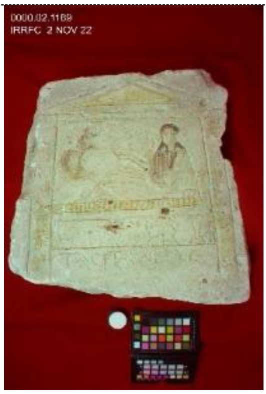
Infrared reflectance (IRR)

Infrared light is used in many imaging applications, from night vision to astrophysics. As with UV light, IR is invisible to our eyes, but materials still absorb and reflect it in characteristic ways. Infrared imaging is often used to visualize **underdrawings** on paintings and can sometimes reveal hard-to-see **inscriptions** on artifacts. The resulting image is in grayscale.



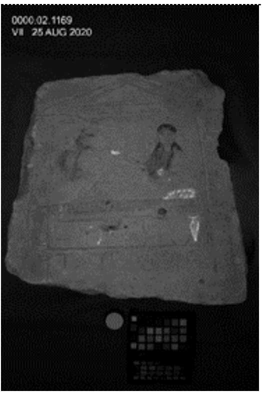
Infrared reflected false color (IRRFC)

IRR and VIS images can be combined through RGB channel substitution in Photoshop to create an infrared “false color” image that indicates reflectance/absorption characteristics in a colorant. For example, **indigo** appears red in IRRFC images, while red **iron oxides** appear brownish yellow. More on this in the “Image Processing” section below.



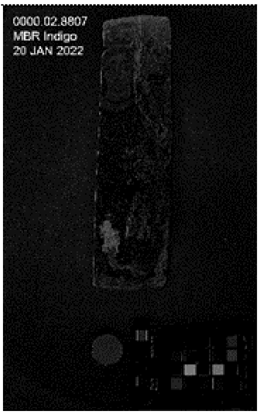
Visible-induced IR luminescence (VIL)

Like UVL, this technique involves excitation—but in this case, the light source is in the visible range and luminescence is captured in the infrared range. This is because **Egyptian blue** pigment (and a few others, including Han and Maya blue and some cadmium-based pigments) luminesces at 960 nanometers. The resulting image is in grayscale, and if Egyptian blue is on the object, it will appear as a white glow.



Indigo subtraction (MBR Indigo)

Indigo dye molecules absorb light at a high level (660 nanometers, the end of the visible light range) and reflect light at a high level (735 nanometers, the start of the infrared light range). These contrasting behaviors can be captured by using lens filters that allow the camera to record these specific wavelengths. Images captured at 660 and 735 nm can then be combined using the “difference” blend mode in Photoshop. The resulting image is in grayscale, and areas that contain indigo (which absorbs and reflects at those specific wavelengths) appear white.



Light Sources and Filters, In Order of Operation

Technique	Light Source	Filter(s)	Camera settings*
1. VIS	Impact VC 500-LR monolights, ~2700 K (or similar, such as Scandles lamps)	PECA #916 Visible Pass Filter or similar, such as B&W UV-IR filter	• Exposure: Start with 1/3 second and bracket (increase/decrease shutter speed by one step) as needed • White balance: Pre-Set Manual
2. UVL	Blak-Ray longwave UV lamp, ~6500 K	PECA #916 Visible Pass Filter or similar, such as B&W UV-IR + 2e filters	• Exposure: Start with 13 seconds and bracket as needed • White balance: Shade
4. IRR	Impact VC 500-LR monolights, ~2700 K (any IR-irradiating source will do, such as an incandescent floor or desk lamp)	PECA #914 (89B) Filter or similar, such as X-Nite 330	• Exposure: Start with 1/3 second and bracket as needed • White balance: Pre-Set Manual
5. VIL	Vidpro Z96K Visible LED light array (a fluorescent floor lamp will work too)	PECA #904 (87) Filter or similar, such as X-Nite 330	• Exposure: Start with 10 seconds and bracket as needed • White balance: Pre-Set Manual
6. MBR Indigo	Overhead fluorescent light banks (or any fluorescent lamp)	MidOpt 735 + 660 filters	• Exposure: 15 seconds for 735 nm filter, 5 seconds for 660 nm filter—bracket for each • White balance: Pre-Set Manual

* These settings are ideal for the Kelsey Museum's imaging setup—yours may need to be adjusted depending on the specific camera, light sources, and filters you select for your technical imaging kit.

A Note on Image Calibration and Additional Equipment

- The workflows presented here are optimized for the equipment and processing techniques used at the Kelsey Museum. They produce useful and consistent, but not *calibrated*, images
- Calibrated images are good if you wish to publish the images or compare them between institutions; we recommend following the MSI capture and processing guidelines in Dyer et al. (Dyer, J., G. Verri, and J. Cupitt. 2013. *Multispectral Imaging in Reflectance and Photo-Induced Luminescence Modes: A User Manual.*) to produce calibrated images: (https://www.academia.edu/7276130/J_Dyer_G_Verri_and_J_Cupitt_Multispectral_Imaging_in_Reflectance_and_Photo_induced_Luminescence_modes_a_User_Manual_European_CHARISMA_Project)
- To aid in future calibration, we include color and reflectance standards in each of our images (see Figure 2). These include:
    - Calibrite ColorChecker Passport
    - Spectralon Diffuse Reflectance Standard

Image Capture

The first step in performing MSI is to capture your visible, UV, IR, and VIL images in their "raw," unedited formats (see table below for examples). You will save and process these images in Photoshop later. Note that the equipment brands and models referenced below are specific to the Kelsey Museum; you may be using different brands or models.

Helpful Hints

- Do not move the camera or lens while shooting
- Be careful not to disturb the camera or lens when changing lens filters (magnetic ring adapters make this process easier)
- Make sure battery-powered light sources (if applicable) are charged and ready to go

Camera Checklist

☐ Charge battery
☐ Format memory card
☐ Attach desired lens to modified D80 camera
☐ Screw XUME magnetic lens adapter onto lens. Screw XUME filter holders onto each lens filter.
☐ Set image file quality at **RAW + JPEG fine**
☐ Change to lowest ISO setting (ISO 100) for use with tripod
☐ Switch mode to **Manual (M)**
☐ Set exposure compensation at 0 (+/- button)
☐ Set meter to **Center Weight** (minimizes influence of background on light metering)
☐ Make sure remote shutter release is ON—this will help minimize camera movement, which is important for certain image-processing steps

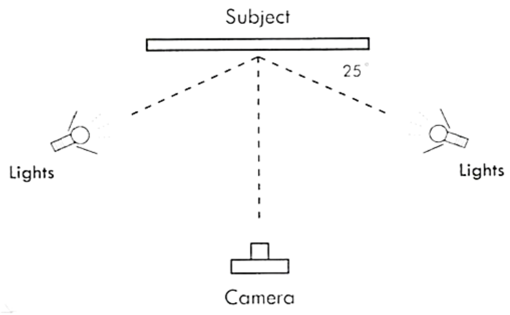


Figure 1. Object photography setup, Frey and Warda 2008, 55

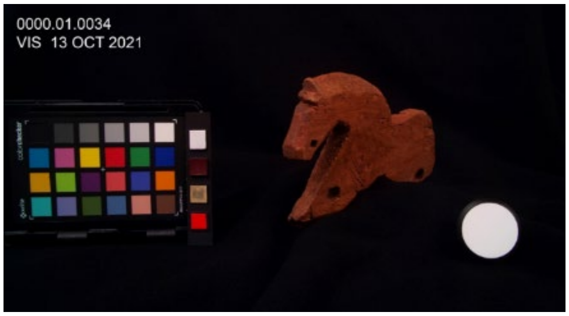
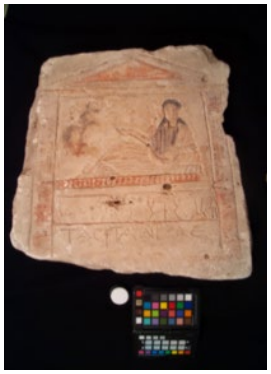


Figure 2. An example of a labeled visible light image with color checker and reflectance standard in the shot

Visible Light (VIS) Image

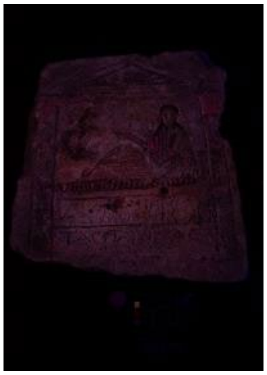
1. Position Impact monolights ~25° from the object (see Figure 1); turn on lights.
2. Attach **PECA #916** filter to camera lens.
3. Position your object.
4. Open Calibrite ColorChecker Passport and Labsphere color and reflectance standards and place them in your shot. Make sure they aren't obscured by shadows.
5. Select **F13** on the camera (or F11 if the object has a relatively flat painted surface, as is the case with the stelae pictured at right).
6. Set white balance at **Pre-Set Manual**.
7. Set focus to **Manual** on both the camera and the lens. Bring shot into focus by positioning the camera, keeping camera lens <u>fully zoomed out</u>. This is important for image alignment in Photoshop. Use fine focus ring to make final adjustments.
8. Set shutter speed to **1/3 second**. Bracketing is recommended to ensure correct exposure.
9. Capture your shots. Check results on camera.



Unprocessed VIS

UV Luminescence (UVL) Image

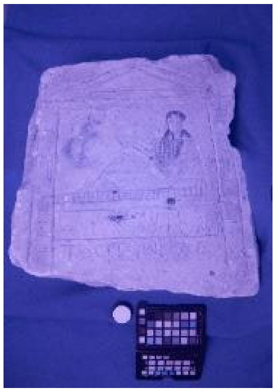
1. Put on UV-protective glasses. Plug in and switch on UV lamp.
2. Set camera white balance at **Shade.**
3. Set shutter speed to **13 seconds**; bracket as needed.
4. Set camera to detect the remote shutter release.
5. Turn off monolights. Release the shutter while moving the UV lamp evenly over the object.
6. Check results on camera. Keep UV lamp on if imaging a series of objects.



Unprocessed UVL

Infrared Reflectance (IRR) Image

1. Turn on monolights.
2. Remove #916 filter and attach **PECA #914** filter.
3. Set camera white balance at **Pre-Set Manual**.
4. Set shutter speed to **1/3 second**; bracket as needed.
5. Set camera to detect the remote shutter release.
6. Capture images. Check results on camera.

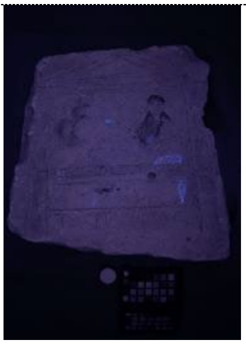


Unprocessed IRR

Visible-Induced Infrared Luminescence (VIL) Image

1. Remove #914 filter and attach **PECA #904** filter.
2. Keep camera white balance at **Pre-Set Manual**.

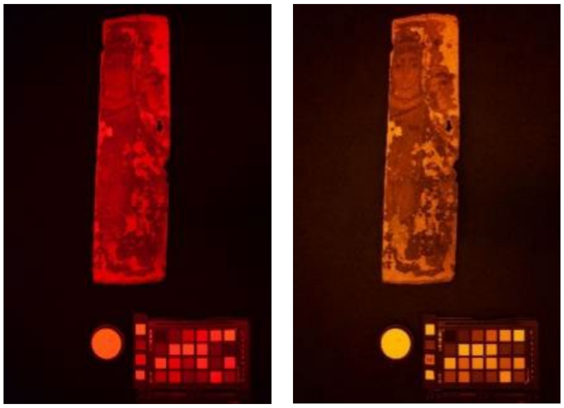
3. Set shutter speed to **10 seconds**; bracket as needed.
4. Set camera to detect the remote shutter release.
5. Turn off monolights, switch on Z96K light array. Release the shutter while moving the array evenly over the object.
6. Check results on camera.



Unprocessed VIL

MBR Indigo Images (2 total)

1. Turn on room lights, including light bank above the photo table (halogen lights are optimal for this technique).
2. Attach #735 filter to lens. Do not alter the focus of the camera or change position of the object.
3. Set shutter speed to **15 seconds**; bracket +/- 1–2 steps (correct exposure is important for post-processing these particular images).
4. Capture first image using remote shutter release.
5. Remove #735 filter and attach #660 filter to lens.
6. Set shutter speed to **5 seconds**. Capture second image, bracketing +/- 1–2 steps.



Unprocessed 660 nm (l) and 735 nm (r) images

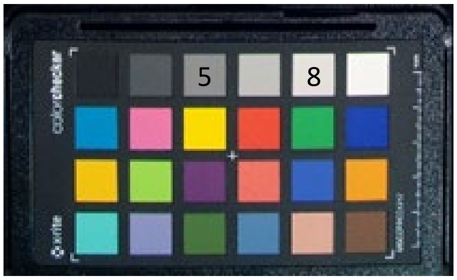
Next, working with images for one object at a time, you will process the images. Create an object folder for your images. Transfer the images from the camera to your computer and save them in this folder.

Image Processing

The second step in performing MSI is to process your UV, IR, and VIL images. Each processing step can be carried out in Adobe Photoshop and Camera Raw (also part of Adobe Creative Suite). Note: There can be slight variations between different versions of Photoshop. These instructions were written for Photoshop 24.3.0.

DNG Conversion and Camera Raw Corrections

An important first step is to convert your Nikon NEF (or Canon CRW) files to DNG. DNG files are considered the standard RAW format for conservation photography because they are more universally accessible than camera manufacturer file formats and because they preserve metadata in the file.



Color checker showing Neutral 5 and Neutral 8 squares

1. Convert your images from NEFs to DNGs using Adobe DNG Converter. Save the DNGs in the object folder you've created for unprocessed images.
2. Open the DNG images in Camera Raw. Camera Raw is Adobe's processing platform for RAW image files. It will launch automatically when you open your DNG files. Choose "Open," navigate to the folder with the DNG files, and select the images. The images will open in a filmstrip along the bottom of the Camera Raw interface. Once you've completed your Camera Raw corrections (steps 3-5), you'll then proceed to Photoshop (step 6).
3. Color correct the VIS image. Select the VIS image and hover Eyedropper tool (next to the White Balance tool drop-down box in the "Edit (E)" tab) over the Neutral 8 gray square on the ColorChecker (the light gray square directly next to the white square; see figure above). The "R" in the RGB values on the square should be between 150 and 200—the closer to 200 the better. Use the Exposure tool to adjust this value as needed. Color correct the image by clicking the gray Eyedropper tool onto the Neutral 5 square (this is the gray square three to the left, or three above/below, the white square, depending on orientation of the ColorChecker; see figure above).
4. Color correct the UVL image. Select UVL image and color correct by dragging the Temperature slider down to ~4000 and the Tint slider down to -75. This will approximate what the eye sees when examining the object under the UV lamp.
5. Select IRR, 735 nm, and 660 nm images. Use the Eyedropper tool to check the RGB values of the Neutral 8 gray square. Again, the R value should be as close to 200 as possible. Also note: The R value of the 660 nm image should be slightly lower than that of the 735 nm image.
6. No modifications are needed for the VIL image in RAW.
7. If you wish to crop or rotate the images, select all photos and use the Crop and Rotate tools in RAW.
8. Select all photos, then click Open button in Camera Raw to open images in Photoshop.

Photoshop Corrections

The images will automatically open in Photoshop, where you will continue your post-processing.

1. UVL image: Erase lint if necessary using Spot Healing Brush (band-aid icon).
2. IRR, 660 nm, and 735 nm images: Convert to Grayscale.
3. VIL image: Look for Egyptian blue luminescence—if you are using this equipment set and protocol, it will appear as a bright blue color in your unprocessed image. If there is no luminescence, you can proceed to IRRFC.
    a. Click on the Channels tab (next to Layers) and select the image's Blue channel.
    b. Duplicate the Blue channel, and covert this image to Grayscale (Image → Mode → Grayscale).
4. Save your images as JPEGs in the folder alongside your DNGs with _VIS, _UVL, _IRR, _VIL, _660, and _735 after their file names for future reference.

Generating Infrared Reflected False Color (IRRFC) Images

Creating false color images requires an additional Photoshop processing step that combines elements of the VIS and IRR images using channel substitution.

1. Open Photoshop. Go to File → Automate → Photomerge. Select Auto, unclick Blend Images. Use Browse to select VIS and IRR image source files, click OK.
2. Photoshop will align your VIS and IRR images in a new image tab, with each one appearing as a separate layer (if desired, check alignment by dropping the Opacity of the top layer to 50%. Return it to 100% before proceeding).
3. Perform channel substitutions in the VIS and IRR layers. Channel substitution is detailed below by copying and pasting one channel into another—green into blue, red into green, and then IRR into red. The IRR layer can be discarded when the substitutions laid out below are complete.
    a. **Green → Blue:** Click on the Green channel window and press Control+A to select it, then Control+C to copy it. Click onto the Blue channel and press Control+V to paste Green into the Blue Channel.
    b. **Red → Green:** Click on the Red channel window and press Control+A to select it, then Control+C to copy it. Click onto the Green channel and press Control+V to paste Red into the Green Channel.
    c. **IRR → Red:** Go to your IRR image and bring its Channels window into view. Click on the IRR channel window and press Control+A to select it, then Control+C to copy it. Return to the VIS image, click onto the Red channel, and press Control+V to paste IRR into the Red Channel.
4. Click on RGB in the Channels window to see the final IRRFC image. If the color is off on the white reflectance standard, move to the Adjustments tab and select the middle dropper tool in Levels. Click the dropper on the Neutral 5 gray square on the ColorChecker to color correct if needed (color squares should be consistent between different IRRFC images).
5. Save color image with "_IRRFC" in the file name.

Generating Indigo Subtraction (MBR Indigo) Images

Creating indigo subtraction images involves combining your 660 nm and 735 nm images in Photoshop.

1. Open Photoshop, go to File → Automate → Photomerge. Select Auto, unclick Blend images. Use Browse to select 660 and 735 image source files, click OK.
2. Photoshop will align your 660 and 735 images in a new image tab, with each one appearing as a separate layer (if desired, check alignment by dropping the opacity of the top layer to 50%. Return it to 100% before proceeding).
3. Right click the top layer and select Blending Options. In the pop-up window, select Difference from the Blend Mode drop-down. Right click the top layer again and select Merge down.
4. Save image with "_indigo" in the file name.

Image Data Management

- Discard any NEF files after you've finished the conversion to DNG
- Do not discard the DNGs—these capture important data and can be used to generate calibrated images using the British Museum protocol
- Discard any underexposed or overexposed VIS, IRR, or 735/660 nm images (and any others you did not use to generate blended images)

Bibliographic Resources

Bradley, L., J. Ford, D. Kriss, V. Schussler, F. Pozzi, E. Basso, and L. Bruno. Evaluating Multiband Reflectance Image Subtraction for the Characterization of Indigo in Romano-Egyptian Funerary Portraits. In *Mummy Portraits of Roman Egypt Emerging Research from the APPEAR Project*. First edition. Ed. C. Cartwright and M. Svoboda. J. Paul Getty Museum, 2020, 68 – 78.

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Webb, E. K., R. Summerour, J. Giacci. 2014. A Case Study using Multiband and Hyperspectral Imaging for the Identification and Characterization of Materials on Archaeological Andean Painted Textiles. Textiles Specialty Group Postprints Vol. 24, American Institute for Conservation 42nd Annual Meeting, San Francisco, CA, May 2014, 24 – 35.