A PRACTICAL GUIDE TO PANORAMIC MULTISPECTRAL IMAGING

By

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Panoramic Multispectral Imaging is a fast and mobile methodology to perform high resolution imaging (up to about 25 pixel/mm) with budget equipment and it is targeted to institutions or private professionals that cannot invest in costly dedicated equipment and/or need a mobile and lightweight setup. This method is based on panoramic photography that uses a panoramic head to precisely rotate a camera and shoot a sequence of images around the entrance pupil of the lens, eliminating parallax error. The proposed system is made of consumer level panoramic photography tools and can accommodate any imaging device, such as a modified digital camera, an InGaAs camera for infrared reflectography and a thermal camera for examination of historical architecture.

Introduction

This paper describes a fast and mobile methodology to perform high resolution multispectral imaging with budget equipment. This method can be appreciated by institutions or private professionals that cannot invest in more costly dedicated equipment and/or need a mobile (lightweight) and fast setup. There are already excellent medium and large format infrared (IR) modified digital cameras on the market, as well as scanners for high resolution Infrared Reflectography, but both are expensive. Also, scanners must be arranged for the dimensions of the painting being documented, while panoramic photography has virtually no size limits. Furthermore, self-assembled equipment can be modified for specific tasks and upgraded with comparatively little incremental funding, following technical and scientific developments in the consumer market, e.g. upgrading to a new digital camera with higher pixel count. The economical, fast and mobile system suggested in this paper is composed of tools used in consumer level panoramic photography. Essentially, represented here in a down-scaled form, is the method employed by Google Art Project to produce gigapixel images of artworks in museums around the world, and it can be applied to any other imaging device, such as thermal cameras for diagnostics of historical architecture. This article focuses on paintings, but the method remains valid for the documentation of any 2D object such as prints and drawings. Panoramic photography consists of taking a series of photo of a scene with a precise rotating head and then using special software to align and seamlessly stitch those images into one panorama.

Multispectral Imaging with a Digital Camera

A digital camera can be modified for “full spectrum”, infrared-visible-ultraviolet photography. There are companies that provide the modification of commercial cameras for a small fee. It is recommended to use a Digital Single-Lens Reflex (DSLR) camera which can be tethered to a computer since this feature allows the user to achieve sharp focusing in non-visible modes (IR and UV) using live view mode. A strongly recommended reading is the AIC guide to digital photography [1] which provides plenty of information on photography practices for museum professionals and it has a valuable section on multispectral imaging. However, it must be mentioned that this article uses a different terminology and set of acronyms than those employed in the AIC guide. Here it is

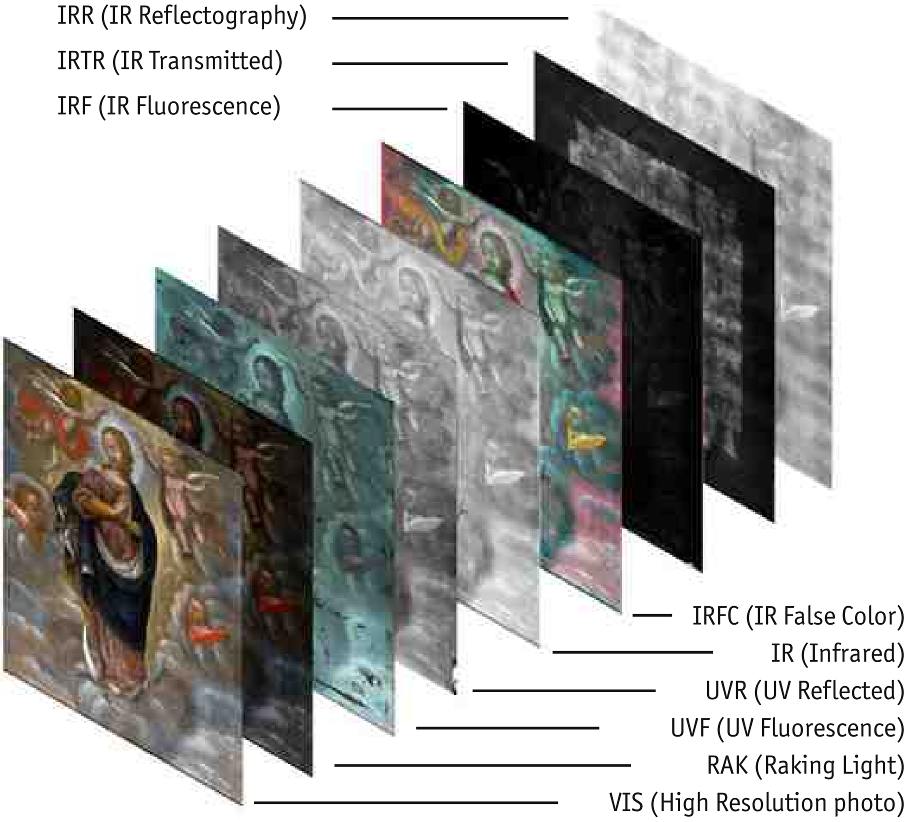


Figure 1. Multispectral imaging terminology and acronyms adopted in this article. Early 1900 Sicilian devotional art, oil on canvas, 80x66 cm, private collector.

preferred to highlight first the spectral range, followed by R (Reflected), F (Fluorescence), FC (False Color), TR (Transmitted) (Figure 1). The multispectral (MSI) images in Figure 1 have a pixel dimension of 12000x1000 and have been collected with a modified Nikon D800 (36 MP, CMOS sensor) with a Nikon Nikkor 200 mm F4 AI telephoto lens, and are composed of a total of 12 stitched shots for each image. The same set of multispectral images can be viewed on IIPImage server [2].

Panoramic Head

A motorized panoramic head such as the lightweight Gigapan EPIC Pro makes high resolution imaging fast. The head can be programmed to automatically rotate the camera around the entrance pupil of its lens and release the shutter in order to take pictures without parallax error. It works with all the major brands of digital cameras. No risk anymore to forget to shoot a picture in whatever complex panorama. There are lighter panoramic head models but it is recommended to choose a model that can accommodate heavy lenses. As a note, Google Art Project team uses panoramic heads CLAUSS RODEON VR Head HD and CLAUSS VR Head ST [3]. These have the same concept but are much more sturdy and expensive. Google Art Project gigapixel images of paintings represent the cutting edge of panoramic photography for art documentation in the visible range of the spectrum and they provide a macro documentation of the entire artwork with extraordinary details. However, the goal of this article is to suggest a version which is both affordable and specifically meant for multispectral imaging (MSI) to suit the actual workflow of professionals involved in art documentation. This article will highlight the specifics of the components necessary to achieve resolution on the order of 20 pixel/ mm for a medium size painting about 1x1 m in dimension, such as the one in Figure 1. Indeed, it must be kept into account that an MSI documentation of a painting, both front and back, could result in around 12 images. In order to allow a comparative examination through the different spectral ranges, those images are uploaded on the layers of a single document file in an image editing software such as Adobe Photoshop or GIMP.

This image file would be too big to allow agile manipulation by a consumer level computer if the size of each MSI image was on the order of gigabytes. Actually, a solution to this problem is an IIPImage server [4] which delivers the images over the internet and doesn't overload the user's computer. Streaming from the image server is tile-based, the same method used by Google maps for satellite view, which allows the user to navigate and zoom gigapixel size images without downloading them to the computer being used.

Camera

The recommended camera to achieve the desired resolution of about 20 pixels/mm is the Nikon D800, 36 MP (image size 7360x4912 pixels). The mirror up function in the camera must be activated for sharper images since it is necessary to eliminate any vibration due to the relatively long exposure time required by the telephoto lens. A sturdy tripod will complete the set-up. Focus and exposure must be set in manual mode and the images can be saved in RAW format for further editing, but eventually the images must be exported into a compressed format such as TIFF or JPEG in order to be uploaded by a stitching software.

Lens

The Gigapan Epic Pro supports camera and lens combinations up to 4,5 Kg (10 lbs) but for MSI we would not use such a heavy, extreme telephoto lens. There are a number of reasons to keep the telephoto lens within a 200 mm range (zoom lenses are slower and must definitely be avoided): ultraviolet and infrared fluorescence have low intensity; complex lenses are likely to give flares in the infrared and ultraviolet photography; and telephoto lenses over 200 mm only accommodate filters with diameter greater than the common and affordable 52 mm. The cost of filters used for scientific MSI can grow considerably with their diameter. For this article, a Nikon Nikkor 200 mm f/4 AI manual focus lens was tested. At its minimal focus distance of 2 m and coupled with Nikon D800, it delivers a considerably good resolution of about 27 pixel/mm. In Figure 2, the 2 cm scale bar in the AIC Photo Documentation (PhD) Target [5] represents 540 pixels in the image.

For smaller paintings, it is possible to use a faster telephoto lens with a shorter focal length, which will shorten exposure times. This is a valuable property for dim illumination techniques such as UV Fluorescence and IR Fluorescence. The Nikon Nikkor 85 mm H f/1.8 has minimum focus at 1 m and delivers (coupled with Nikon D800) images with resolution of about 20 pixel/mm, as calculated above with the AIC PhD Target.

Other issues to take into account are lens distortion and infrared hot spot. Lens distortion can be

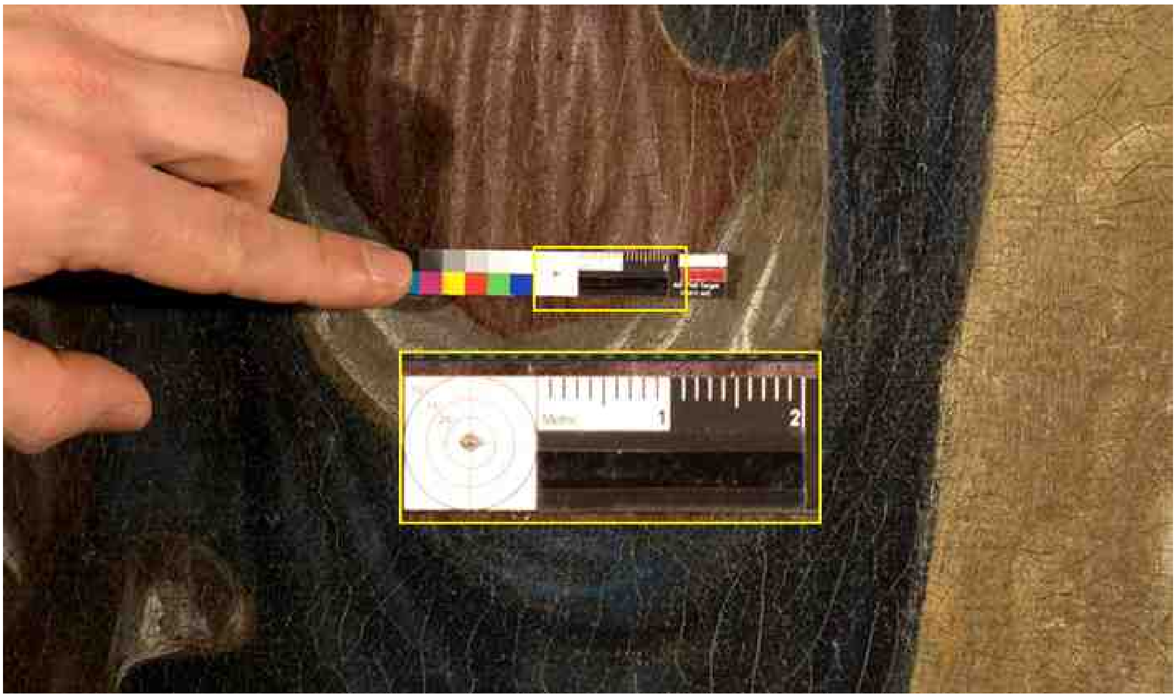
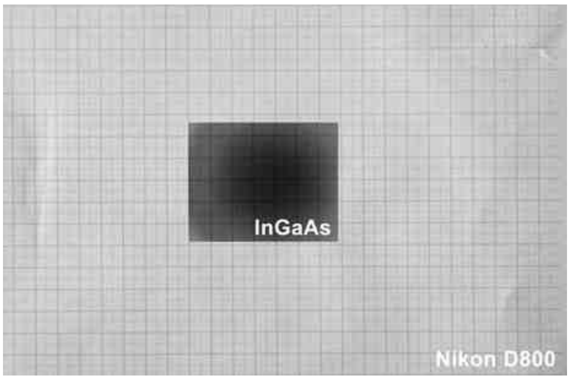


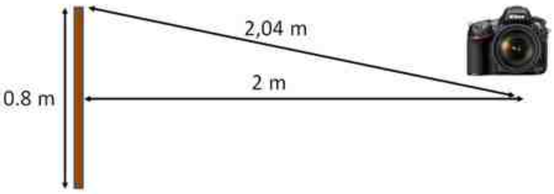
Figure 2. AIC PhD target photographed with Nikon D800 from 2m (minimum distance) with a Nikon Nikkor 200 mm lens. A resolution of 27 pixels/mm is delivered.

minimal or remarkable depending on the lens. Figure 3 shows a picture of a paper grid taken with the Nikon Nikkor 200 mm, which is renowned to have great mechanical and optical performance and, indeed, no distortion is observable. If a lens has geometrical distortion there are tools in Photoshop to correct it before attempting the stitching. Infrared hot spot is a bright circle in the center of the image that becomes more evident when increasing f-stop number. Hot spots are caused mostly by the coatings inside the lens barrel and on the lens elements or, rarely, by the interaction between the lens elements and the imaging sensor. The only solution is to use a different lens. Lists of lenses tested for hot spots are available for consultation online [6].

Set-up camera-painting

The camera should face the painting perpendicularly at its center. The actual distance from the painting depends on its dimension. The shorter the distance, the greater the magnification afforded. But, on the other hand, the depth of field decreases and the focus could become soft on the borders. It's necessary to compromise in order to get the highest resolution possible and keep the center and borders of the object into the depth of field near and far limits. There are a number of online sources that provide these values for a specified lens and a given distance and aperture [7]. In our case (lens 200 mm, distance 2 m, aperture f/7.1) the total depth of field was 4 cm. This is just enough to keep this painting, with a maximum dimension of 80 cm, on focus. Indeed, while the distance from the camera to the center of the painting is 2 m, the distance from the camera to the border of the painting is 2,04 m as can be immediately calculated with the Pythagorean theorem on the three sides of a right triangle (Figure 4). The picture of the AIC PhD target hold on the top





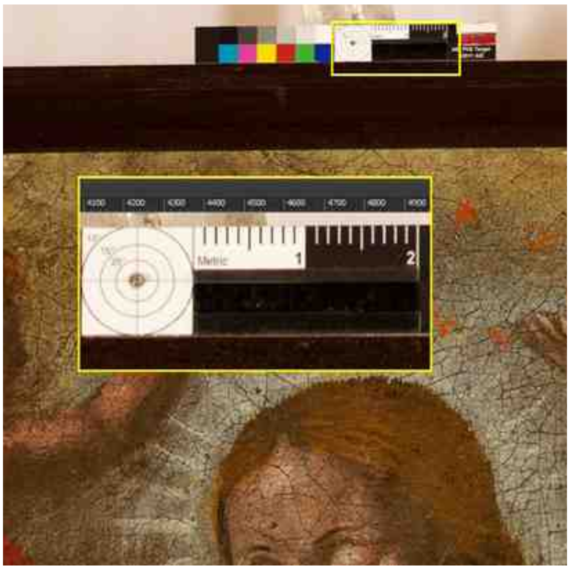


Figure 3 (upper). Overlapped images of a paper grid (1 cm) taken at 2 meters with the Nikon Nikkor 200 mm lens mounted on Nikon D800 and on InGaAs camera 320x256 pixels. There is no deformation pattern observable.in both cameras but InGaAs picture shows vignetting.

Figure 4 (middle). It is necessary to estimate the difference between the distance from the camera to the painting at the center and again at the higher border and be sure it falls within the lower and upper limits for the depth of field. This is immediately calculated with the Pythagorean Theorem using the right triangle shown above.

Figure 5 (lower). AIC PhD target photographed with Nikon D800 at distance camera-painting's center 2 meters and lens focused on the painting's center (200 mm lens, f/7.1).

border it's indeed still on focus (Figure 5) even if the lens was focused on the painting's center.

Pre-editing

It can be necessary to edit the set of panoramic images before attempting to stitch them, in order to correct for chromatic aberration, geometric distortion and vignetting. Photoshop scripts such as Actions and Droplets make this editing fast, even if there are a large number of images.

Stitching

Chosen from an array of available panorama stitching software, PTGui [8] allows a great deal of control onto the stitching process. Once the pictures are uploaded, PTGui attempts a total automatic stitching after being given the focal length of the lens, the crop factor of camera, and in the Align to Grid function, the number of rows and columns shot. The preliminary result could be refined, if necessary, with manual addition of control points. Some typical issues in panoramic photography are vignetting and panorama file size. Vignetting refers to a reduction in brightness near the corners of an image that depends on the lens. This effect is more evident with wide-angle lens, and less for telephoto lens. PTGui has automatic color and exposure adjustment for the correction of vignetting and flares that is performed by the analysis of the contents of overlapping images. Concerning the Panorama File Size, PTGui blends the panoramic images into a Photoshop file up to 300,000x300,000 pixels. For a painting 1x1 m, using the 200 mm lens at 2 m, image resolution is 25 pixels/mm and the total panorama pixel size will be around 25,000x25,000 pixels. To handle files this big, it is recommended to use a computer with at least 8 GB of RAM and a new

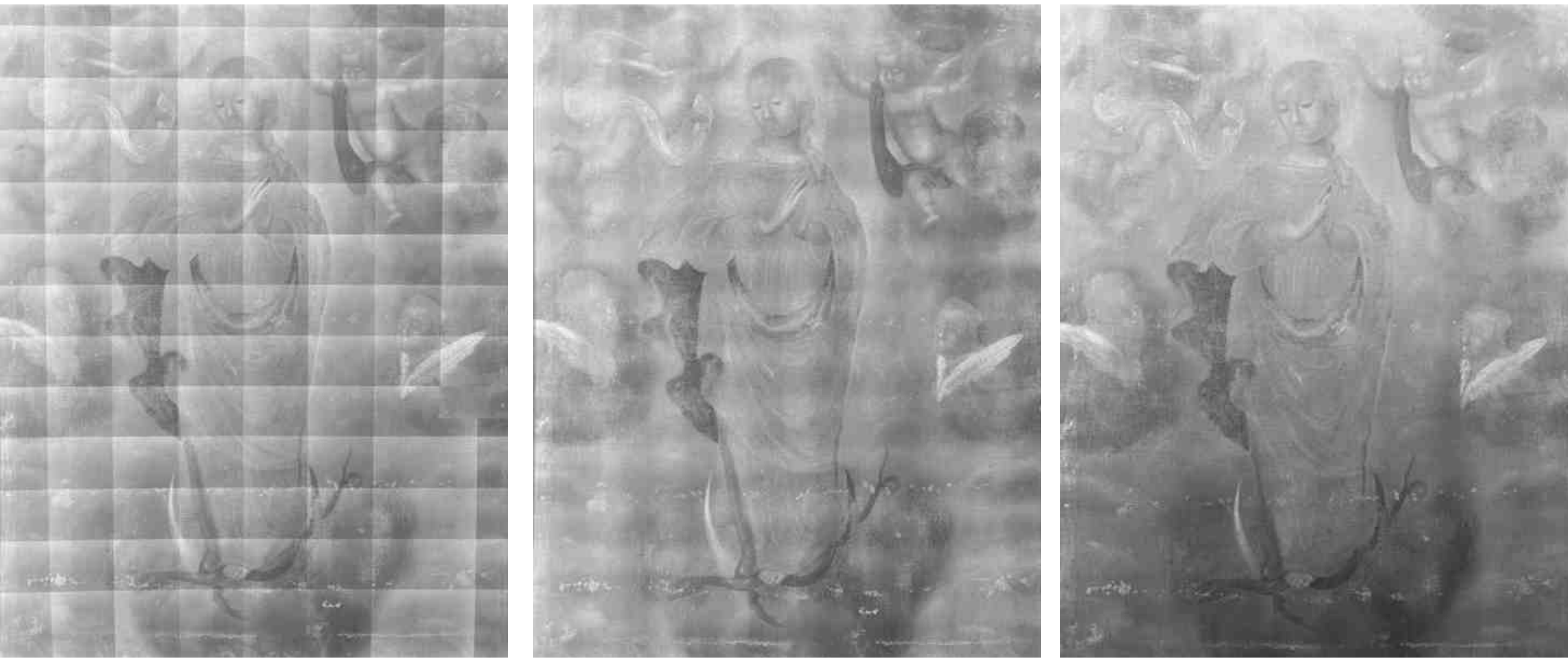


Figure 6. A. 104 images tiled (overlapped) without any blending. B. PTGui panorama without vignetting correction. C, PTGui panorama with PTGui vignetting correction.

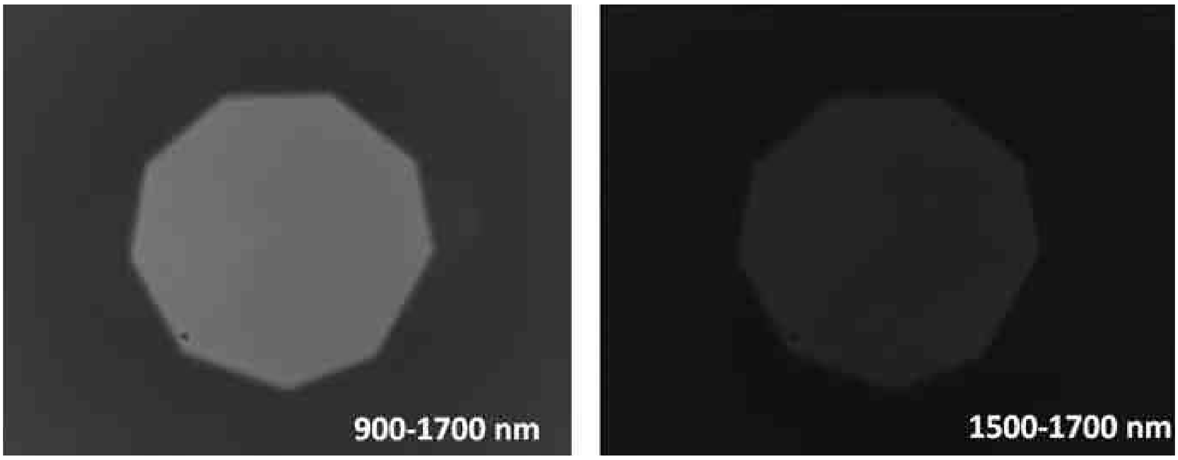


Figure 7. Left, InGaAs image of the bare halogen spot light. Right, the same spotlight pictured with the 1500 nm filter on. The lens transmits infrared in the 1500-1700 nm spectral range and permits to use the full capabilities of the InGaAs camera.

SSD (Solid State Disk) drive that is faster than the common Hard Disk Drive (HDD).

High Dynamic Range (HDR) photography

This photographic technique can be useful to document paintings with a dynamic range so high that a digital camera cannot reproduce it, such as ones including bright whites and pitch dark blacks. In these areas there is always a loss of detail and it's necessary to compromise between information lost in the brightest or darkest areas. HDR allows the user to capture all those details. PTGui provides extensive support for HDR imaging such as stitching bracketed exposures into an HDR panorama.

Infrared Reflectography with InGaAs camera

The Gigapan EPIC Pro motorized pan head allows the user to automatically take all the shots in sequence, since it can trigger a DSLR camera. Though, this head can be still used in automatic mode with any imaging device connected to a computer since a USB trigger adapter can be implemented. At the moment these USB adapters are not yet available commercially. In any case, pictures can still be shot manually while the Gigapan runs in a step-by-step mode. As an example, an InGaAs camera (320x256 pixels) Merlin NIR by Indigo Systems (Figure 8) was plugged to a Gigapan Pro head to produce the Infrared Reflectography [9] images in Figure 1 and Figure 6. A total of 104 images were shot with the same 200 mm lens (an adapter Nikon to C-mount was used for the lens). Infrared Reflectography between 900 and 1700 nm and Infrared photography with a modified DSLR are complementary methods [10] and Panoramic Infrared Reflectography is the budget alternative to high-resolution infrared scanners [11, 12]. The main issue with an InGaAs camera is its drastically lower pixel count. Currently these cameras are available at 640x512 pixels and there are even bigger detectors of 1024x1024 on the market, though they are much more expensive. At any rate, the pixel count of an InGaAs camera is much less than that of a digital camera. This means that particular care must be exercised to meet the minimum resolution needed to resolve the finest marks in the underdrawing, which is 5 pixel/mm [11, 13]. The InGaAs image of the grid paper shown in Figure 3 was acquired using the same set-up as the imaging with the Nikon D800, distance 2 m and lens 200 mm.

It’s now necessary to introduce the Crop Factor, which we define as the ratio of the diagonal in the 35 mm film format (24x36 mm, diagonal 43.4 mm) to the diagonal of the specific camera's imaging area. The Nikon D800 has an imaging area the same size of a 35 mm film so its crop factor is 1. The crop factor for a DSLR camera is indicated in the manual under technical specifications. The size of the imaging area of an InGaAs camera or any other imaging device used for panoramic photography is often not provided. In this case, Figure 3 is useful to estimate the crop factor of the InGaAs camera used in this article. Indeed, an immediate method is to calculate the diagonals of the pictures of the paper grid taken with the D800, which is a 35 mm equivalent sensor, and then repeat the same shot using the inGaAs camera. We recall that both images were taken at the same 2 m distance. These diagonals are about 31 cm and 9 cm, respectively, for the pictures taken with the Nikon D800 and the InGaAs camera. The ratio of the diagonals of the actual pictures the cameras take is the same as that of the diagonals of the imaging areas of their sensors. Therefore, the crop factor of the InGaAs camera is identifies as 31:9 =3.4. This is a simple method to figure out the crop factor for imaging devices when dimensions are not available.

Since the detector is smaller (crop factor 3.4), the lens works now as a 200x3.4= 680 mm. Indeed, multiplying the focal length of a lens by the crop factor gives the focal length of the lens that would yield the same field of view if used with the 35 mm reference camera format. In the conditions mentioned above, a minimum resolution of about 5 pixel/mm is achieved. The resolution could be greatly improved (roughly doubled) with a new 640x512 pixel model, thus becoming comparable with high-resolution scanners. The InGaAs image of the paper grid in Figure 3 shows that while there is no noticeable geometrical deformation, vignetting is much more evident and needs editing. Indeed, the 104 images of the painting stitched without any vignetting

Figure 8. Gigapan EPIC Pro Panoramic head with Nikon D800 (left) for multispectral imaging and with InGaAs camera Merlin Indigo Systems (right) for Infrared Reflectography, both mounted with a Nikon Nikkor 200mm lens.

correction show the characteristics tiled effect (Figure 6B). PTGui has a new function to automatically correct for the vignetting (Figure 6C).

Lens

As for the modified DSLR setup, it is necessary to verify the occurrence of hot spots for the specific lens and InGaAs camera. Another problem, which was overlooked while discussing modified DSLR is the lens transmittance in the infrared. Commercial photographic lenses show a decrease in transmittance moving from visible to infrared light [14]. While this is not noticeable before 1100 nm, from thereon to 1700 nm, the upper limit of InGaAs cameras, it could be significant. To quickly test if a lens does actually allow transmission of light in that range, a Thorlabs FEL1500 1” Long pass Filter with Cut-On Wavelength centered at 1500 nm can be used. The filter can be positioned over a spotlight halogen lamp which will provide a source of infrared light with wavelength higher than 1500 nm. Figure 7 shows an InGaAs image of the bare halogen spot light and of the same spotlight with the 1500 nm filter on.

Conclusions

Panoramic Multispectral Imaging is a valid alternative to more costly equipment for high resolution imaging. It can be implemented with consumer panoramic imaging tools and can deliver images with resolution up to 25 pixel/mm which is more than art examination and documentation requires. The stitching software is easy to use, the overall panoramic method does not require specialized personnel or intensive training and is, therefore, appealing to medium-small museums and private conservators who want to implement an affordable method to professionally document their collections.

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