

## PANORAMIC INFRARED REFLECTOGRAPHY. TECHNICAL RECOMMENDATIONS

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### **Abstract**

*This paper presents some practical recommendations on performing Infrared Reflectography by using an InGaAs camera and consumer-level panoramic photography tools. This method employs a panoramic head to precisely rotate the InGaAs camera and shoot a sequence of images around the entrance pupil of the lens. Then the images are automatically stitched by panoramic imaging software. Panoramic Infrared Reflectography has several advantages; it is fast and mobile; it can be implemented with low-budget equipment, already available commercially and no specific skill or expertise is required.*

**Keywords:** *Infrared Reflectography; InGaAs camera; Panoramic photography; Stitching software*

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### **Introduction**

This paper provides some technical insight into hardware and software tools for the implementation of a new panoramic infrared reflectography method, [1] which uses low budget equipment, already available commercially, for panoramic photography along with an InGaAs camera. This method is fast, mobile and economical. In particular, our study shows these distinct advantages by comparison to available infrared scanners [2 - 4]. The method consists of taking a series of images of a scene with a precision rotating head and then it uses special panoramic software to align and stitch the shots into a single, seamless panorama. This method can be applied by institutions or by private professionals that cannot invest in more costly, dedicated equipment, such as scanners, and/or who need a mobile (lightweight) setup. Furthermore, the self - assembled, modular equipment can be modified for specific tasks and upgraded with comparatively little funding, following technical and scientific developments in the consumer market, e.g. upgrading to an InGaAs camera with a higher pixel count. The same system can also be used for multispectral imaging if a digital camera, modified for UV-VIS-IR, is used instead of the InGaAs camera [1]. This paper provides recommendations for various different components of a Panoramic Infrared Reflectography system.

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### ***Panoramic Head***

Panoramic photography can be performed by using an automatic panoramic head, which can be programmed to rotate the camera around the entrance pupil of the lens. This piece of equipment boasts indisputable advantages: no risk to miss a shot, precise movements, speed and total automatization of the shooting process. Three affordable panoramic heads have been tested for this paper: Gigapan EPIC Pro [5], Gigapan EPIC 100 [5] and Kolor Panogear [6] (Fig. 1). All these heads provide precise movement and can be programmed to acquire images with sufficient accuracy and overlapping for the stitching process.



**Fig. 1.** From left to right: Kolor Panogear, Gigapan EPIC Pro, Gigapan Epic 100

*Gigapan EPIC.* This is the sturdiest model from Gigapan and comes with the largest number of accessories. This head is recommended if the intent is to also use it for applications other than infrared reflectography, especially in cases where the lenses and cameras required are heavy and bulky. Indeed, it boasts the sturdiest configuration with two arms holding the platform for the camera and plenty of room to accommodate larger camera and lens systems.

*Gigapan EPIC 100.* This model has fewer features than the EPIC Pro and accommodates a lighter equipment payload. Nevertheless, it can still be used successfully for Panoramic Infrared Reflectography with lightweight InGaAs cameras such as the Xenics Bobcat 640.

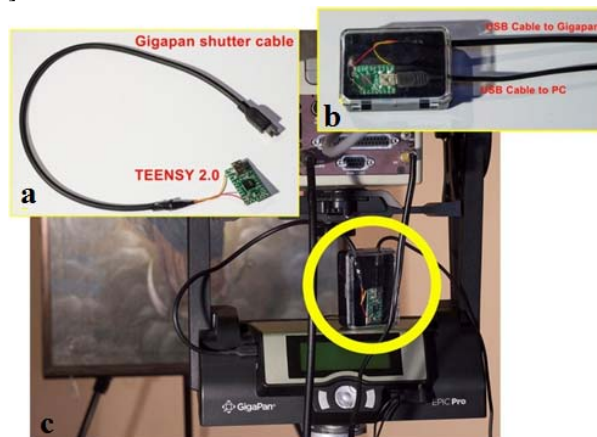
*Kolor Panogear.* This head differentiates itself from its corresponding model, the Gigapan EPIC Pro, due to its lateral arm mount. This setup has the advantage of being more lightweight, but it has decreased control over the position of the entrance pupil if a bulky camera and lens is used. For panoramas of distant objects, over 10 meters, the entrance pupil precision is not relevant, as it is designed for close objects, to avoid the occurrence of parallax errors. For painting documentation, it is not an issue since the surface of the object being imaged is mostly flat. Modern InGaAs cameras with an extremely small form factor, such as the Xenics Bobcat line of cameras, can be correctly accommodated. When imaging with a DSLR camera, a vertical set up of the camera itself can help achieve a more correct positioning of the lens pupil. While the Panogear and the Epic Pro would be equivalent in terms of panoramic infrared reflectography, the Panogear head features wireless communication with computers, smartphones and tablets, either over a wifi network or over the internet. This option would be particularly useful for applications where remote monitoring and control of the head is advisable.

### Triggering

Panoramic heads can automatically be set up to take shots with a DSLR camera but they are not equipped to trigger an InGaAs camera. Indeed, the application of a workaround for this feature is rather new; it was proposed by the author in the “Cultural Heritage Science Open Source” blog [7]. It is likely that at some point manufacturers will provide commercial solutions to trigger any kind of camera connected to a PC. However, in the meantime, the programmable Arduino circuit board provides a workaround [8]. Arduino is an open source electronic prototyping platform based on flexible, easy to use hardware and software. It is both hardware (a circuit board) and software (a simplified programming environment) and it allows the user to connect electronics and electrical devices together, as well as give them commands.

Without a programmed Arduino board we would have to manually trigger the acquisition of the InGaAs images on the computer while the panoramic head scans the artwork. Being able to automatically shoot the InGaAs images is of key importance, since the InGaAs detectors are much smaller than digital camera sensors, so a panoramic infrared reflectogram of a painting will require hundreds of images to be mosaicked. Automatic triggering will avoid the mistake of forgetting to take images and will save the operator from quite a painstaking task. New InGaAs cameras can stream their video directly to a connected PC through a LAN cable, while the older models stream the video signal to the PC by using a frame grabber. In both cases, the software on the PC will save a snapshot any time a combination of keys is pressed. Two suggestions are presented on how to set up an Arduino board for two panoramic heads with different triggering options.

*Gigapan Epic Pro and Kolor Panogear.* These panoramic heads have a shutter cable that triggers the DSLR camera. The camera side of this cable can be plugged to the pins of a TEENSY 2 board and this one can be programmed with the command – *keyboard print* (“your keyboard trigger”) where “your keyboard trigger” represents the particular key command for taking a snapshot [9].

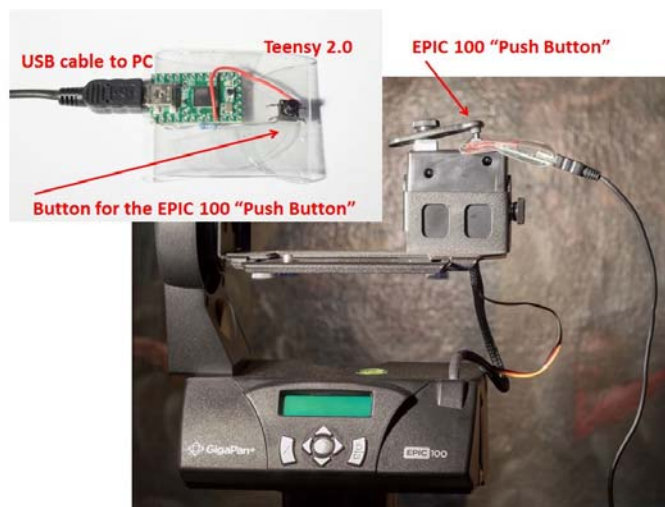


**Fig. 2.** Layout for connecting the Gigapan Epic Pro to an InGaAs camera: a - Wiring the Teensy 2 board to a Gigapan shutter cable; b - Connecting an USB cable to the PC and the Gigapan shutter cable to the Gigapan Epic Pro; c - The Teensy board is ready to automatically trigger the acquisition of the InGaAs images on the PC by sending the command for the required keyboard strokes

The workflow is as follows:

- a. The panoramic heads sends its shutter signal to the TEENSY.
- b. The TEENSY receives the shutter signal and outputs a keyboard sequence to the PC connected through the USB cable.
- c. The keyboard sequence triggers the acquisition of a snapshot on the InGaAs camera software.

*Gigapan Epic 100.* This panoramic head does not have a trigger cable but has a mechanical push button that is meant to be adjusted to fit the shutter button of a compact camera. In this case, the easiest solution is to use the push button of the head to press a switch connected to the Teensy board, which when programmed with the command *keyboard print* (“your keyboard trigger”) will send the desired keystrokes to the PC via the USB cable (Figure 3).



**Fig. 3.** Gigapan Epic 100 is an example of panoramic head which just uses a mechanical push button to trigger a compact digital camera. A Teensy board implemented with a push button can be programmed to deliver the necessary keystrokes to the PC through a USB cable

### *InGaAs Cameras*

InGaAs cameras are currently the most ideal infrared focal plane array imagers for panoramic infrared reflectography. Their image quality is superior [10] and other systems are too expensive, as in the case of HgCdTe or have too much vignetting, as with the vidicon tube. Two InGaAs cameras have been tested: An Indigo System Merlin camera (320x256pixels) and a Xenics Bobcat 640 (640x512pixels).



**Fig. 4.** Xenics Bobcat 640 is about 4 times smaller than the Indigo System Merlin camera

The Indigo System Merlin InGaAs camera represents an older and currently discontinued model, while the Xenics Bobcat 640 was just recently introduced to the market. The new camera not only performs better overall, but it is definitely better adapted for the specific needs of panoramic infrared reflectography:

a. The integration time (exposure) can be set up to 40 milliseconds, while for the Merlin it only went up to 16,5 milliseconds. Since telephoto lenses are slow, longer integration time is a valuable feature in order to perform the infrared reflectogram with as much as 3 times less lighting.

b. The Bobcat 640 is also 3 times lighter than the Merlin and that means more stability with a small panoramic head, such as the EPIC100. Moreover, the Xenics Bobcat is about 4 times smaller than the Indigo System camera allowing a more precise arrangement of the camera and the telephoto lens on the panoramic head (Fig. 4).

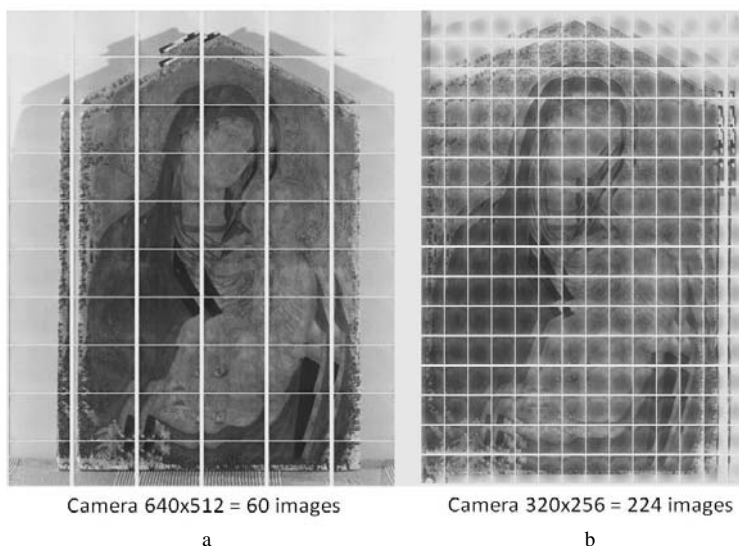
c. The Xenics camera delivers live-view streaming to the PC through a LAN cable and the images can be saved directly on the computer without the need for a frame grabber as in the case of earlier InGaAs cameras.

d. Xenics Bobcat 640 boasts a 640x512pixels array, and this means its images are more than 4 times bigger than those of the Merlin (320x256pixels) (Fig. 5). This higher pixel count translates into fewer images to stitch and therefore less possibility for the panoramic stitching software to make mistakes.



**Fig. 5.** The AIC Photo Documentation Target [11] seen by the Xenics Bobcat 640 (640x512pixels) and the Indigo System Merlin InGaAs camera (320x256pixels), in the insert, bottom right. The images are at their actual ratio. The cameras were at the same distance (2,2m) and had the same 200mm lens mounted

Indeed, the bigger images have much more details which make the stitching process even more precise. As an example, figure 6 shows the Madonna and Child, a panel painting owned by the Ingels Collection, Sweden, which is currently being studied and has been documented with multispectral imaging by the author. The painting seems to date back to the early 14<sup>th</sup> century Sienese school, as proposed by some scholars. An infrared reflectography image of this painting was previously acquired with the Indigo System Merlin InGaAs camera (320x256pixels) and subsequently with the Xenics Bobcat 640 (640x512pixels). The images were acquired with the same 200mm lens at the same distance from the painting.



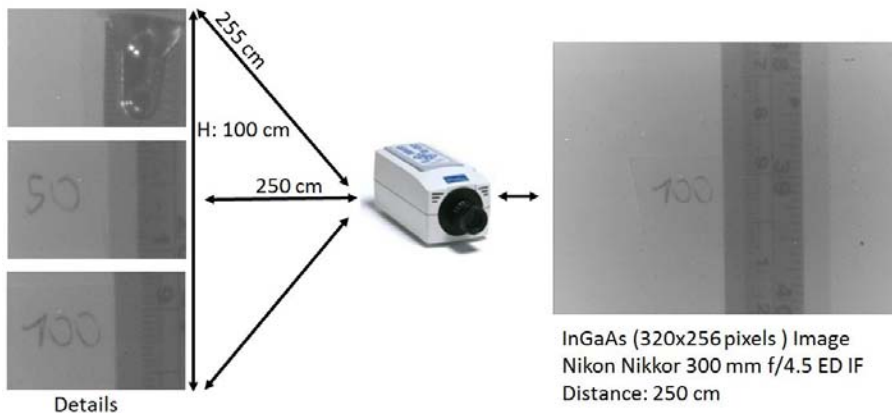
**Fig. 6.** Madonna and Child (56,5 x 35,5cm), Ingels Collection, Sweden:  
 a. Xenics Bobcat (640x520pixels) camera took 60 images;  
 b. Indigo Merlin (320x256pixels) camera took 224 images.  
 The cameras were at the same distance and used the same 200mm lens.  
 The amount of stitching is about 4 times higher with the smaller detector

### *Lenses*

The Panoramic method proposed in this paper is based on the fact that by stopping down the lens, the depth of field (DoF) can be large enough to cover the center of the painting as well as its borders [1], [300mm]. It is noted that fast lenses, such as those with a filter size greater than 52 mm are not necessary for panoramic infrared reflectography. Indeed, in order to have enough depth of field, the lens must be stopped down and therefore the higher aperture is not of any use. There is no standard minimal resolution for infrared reflectograms but 5 pixels / mm is considered acceptable [2, 12]. The actual resolution of reflectograms acquired with this panoramic method would depend on a number of factors, the distance from the painting to the lens, the lens specifications (magnification, focal length, minimum focal distance) and the dimension and pixel count of the sensor. The depth of field and the resolution of a specific setup (camera, lens, aperture and specific painting to lens distance) can be calculated, though, it is definitely more practical just to evaluate both of them by using a ruler fixed on a wall (Fig. 7).

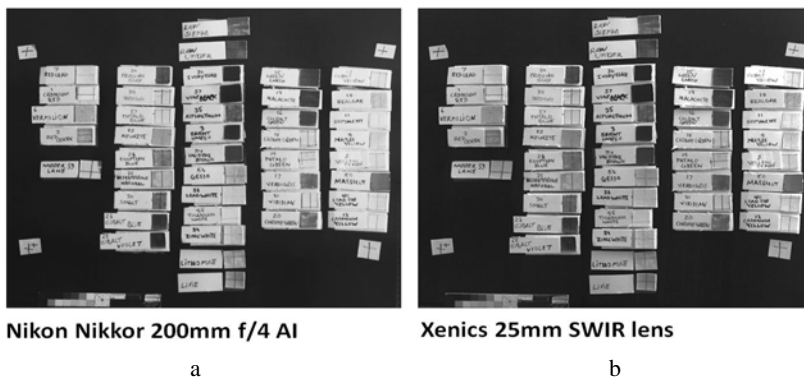
Three categories of lenses were tested, a normal photography lens (dioptric lens), a mirror lens and a SWIR lens. The author prefers photography lenses even for the InGaAs camera, since for his workflow the same lens is used for multispectral imaging on a DSLR camera [1]. It must be mentioned though, that InGaAs cameras feature the C-mount and lenses with this mount can be mounted directly with the need of any adaptor. The only difference is that C-mount lenses are smaller and lighter since they are engineered for the smaller detectors mounted in video cameras.

*Dioptric lens.* Nikon Nikkor 300mm f/4.5 ED IF is a good lens for panoramic photography and infrared reflectography. Its main feature is a close minimum focusing distance of just 2,5m which delivers enough magnification to meet the minimum resolution of 5pixels/mm. It does not show infrared hot spots [1].



**Fig. 7.** The InGaAs camera is focused on the middle of the 1m ruler hung vertically. The Camera has a Nikon Nikkor 300mm f/4.5 ED IF (f22) mounted and is set at 250 cm from the center of the ruler. **Left:** three details from the upper, the middle and the bottom of the ruler showing the ruler is in focus. **Right:** a snapshot of the ruler shows that the resolution is within the 5 pixels/mm minimum standard.

*SWIR lens.* In contrast to photography lenses, Short Wave Infrared (SWIR) lenses are much more expensive. They are optimized for the SWIR range (about 900-2000nm). The 25mm SWIR lens provided by Xenics with the InGaAs Bobcat 640 camera was tested on a collection of historical pigments. No notable features indicate any better performance of the SWIR lens over the photographic Nikon Nikkor 200mm f/4 AI, (Fig. 8). Indeed, the main advantage of SWIR lenses would be their improved IR transmittance, which would mean a faster telephoto lens for panoramic infrared reflectography [13].



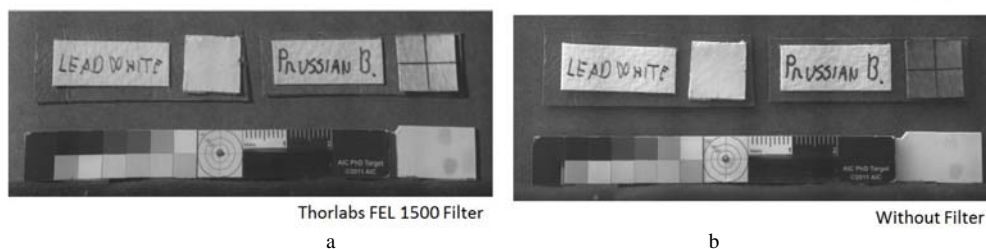
**Fig. 8.** Historical pigments swatches imaged with the Xenics Bobcat 640 with a Nikon Nikkor 200mm f/4 AI (a) and a 25mm SWIR lens (b)

*Mirror lens.* Common camera lenses are dioptic, which means they are made of a number of lenses which refract light through the barrel. In contrast, the Tamron 500mm f/8 SP BBAR MC lens is made mostly of mirrors. As for the specific needs of Panoramic Infrared Reflectography, it has some advantages: it is much more lightweight and since it has less glass, it has less IR absorption. For drawbacks, this lens has bad contrast and, most importantly, it has no variable aperture. Consequently, the depth of field is limited and that makes the lens unfit for panoramic photography.



### Filters

It is useful to mount a cut-off filter to block the near-IR. The InGaAs cameras do not actually need an infrared filter since they can only detect infrared light between 900 and 1700nm. However, a longpass filter, such as the Thorlabs FEL 1500, may be useful since it can cut off reflected light at shorter infrared wavelengths and avoid the appearance of overexposed areas, thus providing an enhanced contrast. Indeed, the near infrared is more likely to be reflected and to become overexposed, while the farthest infrared is the one that is more likely to provide the image of the underdrawing. Since the acquisition time (exposure) in panoramic imaging must be kept constant, the use of a filter is useful to equalize the overall image and reduce glare and, indeed, the filter increases the contrast in those pigments which become more transparent in the far infrared, such as the Prussian blue (Fig. 9).



**Fig. 9.** The image taken with Thorlabs FEL 1500 (a) - an infrared longpass filter which reduces the glare of infrared reflecting pigments, such as lead white and respectively without filter (b)

### Stitching software

Professor Helmut Dersch of the University of Applied Sciences Furtwangen was the creator of the Panorama Tools library (also known as PanoTools) that essentially re-projects and blends multiple images into panoramas. Most of the Panoramic stitching software, both freeware and commercial, uses the PanoTools library. The freeware software, such as Hugin [14] lacks some features which are essential for panoramic infrared reflectography but they are available for the commercial versions, such as the PTGUI [15] (acronym for PanoTools Graphic User Interface). This is the software recommended by the author. Stitching presents intrinsic difficulties due to the small size of the InGaAs images and the relatively low amount of detail and contrast. Therefore, features such as configuration in a grid pattern and management by using control points are mandatory and they are available only for the commercial versions of the panoramic software. Other companies have developed their own stitching software projects, such as Microsoft with the freeware Image Composite Editor (ICE) and Adobe Photoshop with Photomerge, but they cannot even be compared with the complete panoramic software PTGUI, which has advanced tools, such as vignetting and lens barrel correction. Vignetting refers to a reduction in brightness near the corners of an image that depends on the lens and its aperture. Differently than with the corresponding tools in photo editing software, vignetting correction in PTGUI is performed by the analysis of the contents of overlapping images, rather than one single image. PTGUI can see which pixel in one image corresponds to the same pixel in another image. This gives very reliable data both for vignetting and barrel correction. Once the pictures are uploaded, PTGUI attempts a total automatic stitching after being given the focal length of the lens, the crop factor of the camera and the number of rows and columns. The preliminary result could be refined, if necessary, with manual addition of control points.



## Conclusions

Panoramic Infrared Reflectography is a valid alternative to much more expensive scanners for high resolution imaging. It can be implemented with consumer panoramic imaging tools, which can be upgraded following technical developments, as opposed to IR scanners, which are products that cannot be modified. The stitching software is easy to use, the overall panoramic method does not require specialized personnel or intensive training and for these reasons the method is appealing to medium - small museums and private conservators who want to implement an affordable method to professionally document their collections. The savings of the infrared panoramic method are going to increase, since the cost of InGaAs cameras with higher pixel count and more transparent SWIR telephoto lenses will slowly become more affordable.

## Acknowledgements

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## Disclaimer

Reference to any companies or specific commercial products was not intended as an advertisement.

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