Multispectral Imaging in Reflectance and Photo-induced Luminescence modes: A User Manual

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**Foreword**

In recent times, multispectral imaging techniques have increasingly become a part of the range of examination and analytical methodologies that conservation professionals have at their disposal for the investigation of cultural heritage objects. These techniques, which include both luminescence (emitted light) imaging methods (ultraviolet-induced luminescence (UVL); visible-induced infrared luminescence (VIL) and visible-induced visible luminescence (VIVL)) and a range of related broadband reflectance imaging methods (visible reflectance (VIS), infrared reflectance (IRR) and ultraviolet reflectance (UVR)), are not only used by scientists but are also increasingly being adopted by a much wider range of users including conservators, archaeologists and curators, in more diverse and challenging settings. However, although attractive in offering qualitative, non-invasive and often relatively inexpensive and portable tools for spatial localisation of specific materials or material types, the equipment, capture and processing of images – particularly those used in luminescence imaging – have tended to be highly dependent on individual users and the set-up they employ, making cross-comparison between different institutions and researchers very difficult. It has thus become evident that there is a need to establish a clear set of widely-accessible methods and protocols from which to work.

As part of the CHARISMA project (Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/Restoration, [http://www.charismaproject.eu/](http://www.charismaproject.eu/)), research has been undertaken to develop new optimised methodologies for the acquisition and processing of images in order to investigate the 2D and 3D distribution of organic and inorganic materials on art objects. The CHARISMA project, funded by the European Union FP 7 Research Infrastructures programme (Grant Agreement no. 228330), is a unique consortium of 22 leading European institutions working together to develop and promote best scientific practice for the interdisciplinary study of cultural heritage and to disseminate this knowledge.

In developing new optimised multispectral imaging methodologies, emphasis has been placed on using equipment that is readily available and distilling the work carried out into a set of user-friendly practical materials and resources, which are aimed at a wide range of users and are as broadly accessible as possible. In this way it is hoped that these are not only widely adopted by the cultural heritage community but also address the needs of users beyond it.

The approach adopted in this work built on previous work undertaken at the British Museum by two of the authors and has centred on understanding the experimental factors and phenomena that can lead to those device-dependent issues experienced by users that may inhibit these comparisons. The optimisation and standardisation of experimental procedures and acquisition protocols was addressed as a first step towards reducing these issues and improving reproducibility and inter-comparison between the resulting images, both within and between institutions/users. Additionally, as a response to the limited guidance which is currently available on image post-processing methods, work was undertaken to develop robust image calibration and correction protocols and to create freely available (open-access), easily applicable post-processing software tools.
These tools enable the consistent application of the post-processing methods that have been developed and facilitate the comparison and interpretation of the resulting images, thus maximising the value of the information that can be obtained from such imaging methods. The tools are designed as ‘add-ins’ to nip2, the graphical interface of the free processing system VIPS (http://www.vips.ecs.soton.ac.uk/index.php?title=VIPS) developed previously by the third author. The optimised acquisition protocols and the post-processing methodology have been evaluated both on reference materials and on images acquired from real objects, which included museum artefacts.

The result is this User Manual, which not only outlines the theory of how to acquire and post-process the multispectral image sets that are the focus of this work, but also provides practical details concerning experimental set-ups, equipment recommendations and acquisition protocols. In addition, the Manual also describes the development of the post-processing software tools, instructions on their use (available for download from: http://www.britishmuseum.org/charisma) and explains how they incorporate the theory into workflows for the correction of the multispectral imaging data sets.

Finally, it should be noted that the current versions of both this User Manual and the post-processing software tools are the result of an iterative process of development, feedback and refinement that is likely to continue beyond the scope of the CHARISMA project, as both techniques and the technologies employed to produce images develop.

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In this version of *Multispectral Imaging in Reflectance and Photo-induced Luminescence modes: A User Manual (Version 1.0, October 2013)* the screen shots used to illustrate the operation of the post-processing software or “workspace” described in Chapter 3 were obtained by operation of this software (*bm-workspace.ws*) in nip2-7.34.0. This version of nip2, the post-processing workspace, the User Manual and other supporting materials are available from: [http://www.britishmuseum.org/charisma](http://www.britishmuseum.org/charisma)

It should be noted that as the graphical interface of a free image processing system (VIPS), nip2 is constantly evolving, with updated versions becoming available regularly. The post-processing workspace is designed to operate within these subsequent versions but some differences from the descriptions given in this version of the User Manual may be observed.

For the current supported version of the nip2 software for a number of operating systems go to: [http://www.vips.ecs.soton.ac.uk/supported/current/](http://www.vips.ecs.soton.ac.uk/supported/current/) and check the “What's New” page on [http://www.vips.ecs.soton.ac.uk/index.php?title=Supported](http://www.vips.ecs.soton.ac.uk/index.php?title=Supported) for an introduction to changes made to updated versions. Information about new features in nip2 can also be found at the nip2 blog: [http://libvips.blogspot.co.uk/](http://libvips.blogspot.co.uk/) and these links will also provide details about how to report any problems encountered with nip2.
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1. **Introduction to Multispectral Imaging**

This chapter describes the most commonly used multispectral imaging techniques that are currently available to the scientist, conservator, archaeologist and art historian, at a relatively low cost, for the non-invasive investigation of works of art. It will focus on the use of inexpensive and widely available equipment to provide qualitative, non-invasive, affordable and portable tools for the spatial localisation of specific materials or material types. In addition, it will aim to offer an understanding of the nature of the image sets produced from these techniques as well as the limitations which lead to the need for image correction procedures.

Multispectral imaging is the procedure used to observe an object using selected ranges of wavelengths in the electromagnetic spectrum\(^1\) that include and extend beyond the capabilities of the human eye. This study will concentrate on the wavelength range that can be observed using modified commercially available cameras, which typically employ silicon-based sensors sensitive from approximately 350 nm to 1100 nm. Cameras based on InGaAs sensors, which can record infrared radiation from approximately 700 nm to 1700 nm, are also used regularly in cultural heritage applications,\(^2\) but these shall not be addressed here as this specialized technology is often prohibitively expensive for the average user.

A generic setup for multispectral imaging is composed of three main components: 1) Incoming radiation, which is generated by a radiation source and travels towards the object; 2) The object, which interacts with the incoming radiation; 3) Outgoing radiation, which, following the interaction between the incoming radiation and the object, travels from the object to the recording device.

Both the incoming and outgoing radiation are typically in one of three ranges (Figure 1-1): ultraviolet radiation (UV 200-400nm), visible light (VIS 400-700nm) or infrared radiation (IR 760-1700nm).\(^3\)\(^4\)

![Figure 1-1. Wavelength ranges in the electromagnetic spectrum commonly used for multispectral imaging in cultural heritage applications.](image_url)
The extent to which this radiation will penetrate the object under investigation will be dependent on its wavelength and on the absorbance of the materials which compose the object, with longer wavelengths of radiation generally penetrating further into the piece. For example, when examining a painting, shorter wavelengths (such as UV) are often readily absorbed by the outer layers (usually varnishes), while longer wavelengths can pass through the varnish and interact with the pictorial film and the under drawing.\(^5\)

The radiation reaching any particular point in the object can be:

(i) absorbed;
(ii) reflected; and/or
(iii) absorbed and re-emitted as luminescence at longer wavelengths.\(^6\)

Each outcome produces an image set which yields information specific to that point. Thus by selecting particular combinations of illumination and detection ranges, it is possible to gain insight about the distribution of materials in the object under study.

\section*{a. Image sets}

The image sets possible under each of the illumination conditions discussed are summarised in Figure 1-2. Thus;

1) UV illumination can produce ultraviolet-reflected images (UVR) and ultraviolet-induced luminescence images (UVL)\(^7,8,9\), where the emitted radiation is in the ultraviolet, visible or infrared range.

2) Visible illumination can give rise to visible-reflected images (VIS) and visible-induced luminescence images, where the emitted radiation is in the visible range (VIVL)\(^10\) or in the infrared range (VIL).\(^11,12,13\)

3) Infrared illumination yields infrared-reflected images only,\(^5\) as so far there are few known cases of infrared-induced luminescence in cultural heritage applications.\(^14\) However, rules similar to those illustrated for UVL, VIVL and VIL would apply for materials that absorb and re-emit radiation in the infrared range.

The images produced therefore fall into two categories:

- Reflected radiation images
- Emitted radiation or photo-induced luminescence images (Figure 1-2).

These are discussed in more detail in the following sections.
i. Reflected images

For reflected images, the wavelength range of the incoming radiation and that of the outgoing radiation is the same.

The following types of images are the most commonly used reflected images, but other ranges can be explored.

Visible-reflected (VIS) images correspond to standard photography and record the reflected light in the visible region (400-700 nm) from a subject when this is illuminated with visible light.

This image is collected in the range in which the object is usually observed and can thus serve as the reference point to interpret the other image sets.
Infrared-reflected (IRR) images record the reflected radiation in the infrared region (700-1100 nm) from a subject when this is illuminated with infrared radiation.

This image can be valuable in revealing under drawings and concealed features. This is because infrared radiation is usually highly penetrative and many materials, such as organic binders and colorants, are generally transparent to infrared wavelengths.

Ultraviolet-reflected (UVR) images record the reflected radiation in the ultraviolet region (200-400 nm) from a subject when this is illuminated with ultraviolet radiation.

This image can be useful in characterising the superficial distribution of material, such as varnishes and coatings, as ultraviolet wavelengths are generally readily absorbed at the surface.

False-colour reflected images combine the infrared or ultraviolet-reflected image with components from the visible-reflected image of the subject, to form a tri-chromatic false-colour image. The combination can result in distinctive “false” colours that may aid the characterisation or differentiation of materials.

Ultraviolet-reflected false-colour (UVRFC) images are produced by splitting the visible image into its red, green and blue (RGB) components and shifting the blue and green components into the green and red channels respectively. The UVR image is inserted into the blue channel. The reflective properties of the object in the UV range are described by blue colour on the B channel.

Infrared-reflected false-colour (IRRFC) images are produced by splitting the visible image into its red, green and blue (RGB) components and shifting the red and green components into the green and blue channels respectively. The IRR image is inserted into the red channel. The reflective properties of the object in the IR range are described by red colour on the R channel. Note that Real infrared false-colour (RIRRFC) images can also be produced by recording three infrared images in the ranges: IRR1 (700-800 nm), IRR2 (800-900 nm) and IRR3 (900-1000 nm) and by placing those in the B, G and R channels of an RGB image, respectively. However, the generation of such images is not considered further in this work.
ii. **Photo-induced luminescence images**

For photo-induced luminescence images, the wavelength range of the incoming radiation and that of the outgoing radiation is different. According to the physical rules governing such phenomena, the outgoing radiation is less energetic than the incoming radiation. The incoming radiation is referred to as ‘excitation’, while the outgoing radiation is referred to as ‘emission’.

The following types of images are the most commonly used photo-induced luminescence images, but other ranges can be explored.

**Ultraviolet-induced luminescence (UVL) images** record the emission of light (luminescence) in the visible region (400-700 nm) from a subject when this is illuminated with UV radiation.

This image is used to investigate the distribution of luminescent materials, such as organic binders and colorants. Some inorganic materials also show luminescence properties, such as, for example, some inorganic pigments including zinc oxide with impurities. The absence of luminescence does not imply the absence of organic materials.

**Visible-induced infrared luminescence (VIL) images** record the emission of radiation (luminescence) in the infrared region (700-1100 nm) from a subject when this is illuminated with visible light.

This image characterizes the spatial distribution of pigments such as Egyptian blue, Han blue, Han purple and cadmium-containing pigments. This technique is very sensitive and can reveal even single particles of such pigments.

**Visible-induced visible luminescence (VIVL) images** record the emission of light in the visible region (500-700 nm) from a subject when this is illuminated with visible light (400-500 nm).

This image is useful in the characterisation of the spatial distribution of red and yellow lakes.
Figure 1-3 shows an example of the full suite of images that can be acquired using all the multispectral imaging techniques described above. Taken together, these methods are complementary, because each spectral range interrogates a different component of the object to form a multispectral image set, which can be compared and interpreted to yield a more holistic view of the piece.

The interpretation of multispectral image sets will not be addressed here as this will vary greatly depending on the types of objects investigated and the period they are from. Specialized publications and a variety of journal articles on the interpretation of multispectral image sets pertaining to specific classes of objects are available and the reader is referred to these (some examples of which, but by no means an exclusive list, are referenced here) for further information.  

1,3,13,18,20,21,22,23,24,25,26,27,28,29
1. **Reflected images:**

![Visible-Reflected VIS](image1.png)  
![UV-Reflected UVR](image2.png)  
![UV-Reflected False Colour UVRFC](image3.png)  
![IR-Reflected IRR](image4.png)  
![IR-Reflected False Colour IRRFC](image5.png)

2. **Photo-induced luminescence images:**

![UV-induced luminescence UVL](image6.png)  
![Visible-induced IR luminescence VIL](image7.png)  
![Visible-induced visible luminescence VIIVL](image8.png)

Figure 1-3. An example of the full suite of images that can be acquired using all the multispectral imaging techniques described above - Wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5).
b. Image Analysis

An important aspect in the interpretation of multispectral image sets relates to how these are acquired. Commercially available cameras are designed to provide aesthetically pleasing images and not the scientific analysis of artworks, and as a result can often introduce unwanted modifications to the multispectral images acquired. These include built-in adjustments to the contrast, brightness, sharpness, gain controls and white balance, among other factors, which modify the image taken by the camera into one closer to how the eye perceives it. However, these amendments may cause the erroneous interpretation of the information contained within multispectral images. This is particularly true for luminescence images, as described below. If uncontrolled, these changes can have a substantial impact on the reliability and reproducibility of images, making effective and meaningful comparisons between images taken at different times and with different set-ups challenging, if not impossible.

Figure 1-4 shows a detail from UV-luminescence images of a fresco by Agnolo Gaddi taken at the basilica di Santa Croce in Florence by two different institutions, the Opificio delle Pietre Dure (OPD) and the Getty Conservation Institute (GCI). The differences between these images, which depict the same subject are clear and underline the need to address the issues discussed.

Figure 1-4. UV-induced luminescence images of a detail from a fresco by Agnolo Gaddi taken at the basilica di Santa Croce in Florence by two different institutions, the Opificio delle Pietre Dure (© Annette Keller at the OPD, left) and the Getty Conservation Institute (© Organic Material in Wall Painting Project, Getty Conservation Institute, right).
An approach towards a methodology which produces device-independent images and allows better reproducibility and inter-comparisons between images, centres on three aspects:

1. Understanding the experimental factors (such as the limitations of commercially available equipment) and the physical phenomena which can lead to the observation of spurious effects or device-dependent issues in the images produced.
2. Using this understanding to optimise the experimental procedures employed in order to reduce these issues and standardise acquisition protocols as a first step towards reproducibility, both within and between institutions/users.
3. Developing freely available (open-access) image calibration and correction protocols for the different image types, based on the use of the standardised acquisition protocols and an understanding of the experimental factors and phenomena, facilitating their inter-comparison and interpretation.

![Diagram](image)

*Figure 1-5. Iterative approach towards a methodology which produces device-independent images and allows better reproducibility and inter-comparisons between images.*

The approach is summarised in Figure 1-5, which also emphasizes the synergistic and iterative nature of the methodology. The demands of the image correction protocols and the development of the post-processing system will determine the data required and the manner in which it needs to be collected. This in turn impinges on the experimental procedure.

In the following sections, the experimental factors and physical phenomena which may lead to spurious effects in the image sets are described, and experimental and post-processing methodologies towards their correction are proposed. The inherent difference in the properties of images capturing reflected radiation versus those that capture photo-induced luminescence also mean that the factors affecting reproducibility and device dependence of images are most easily considered separately.
i. **Reflected images**

The factors affecting reproducibility and device dependence of reflected images are discussed in the sections below. Three main effects are considered:

1) Spatial inhomogeneities of the radiation source;  
2) Spectral density of the radiation source and non-linear camera response;  
3) Camera response (colour calibration for visible-reflected images only).

In addition, the need for image registration of the various reflected images in order to produce false-colour images is discussed.

-- **Spatial inhomogeneities of the radiation source**

The spatial distribution of radiation reflected from objects and captured by a camera depends, among other factors, on the position of the radiation source(s) and the geometry of the object. Non-uniform illumination can lead to spatial inhomogeneities introduced by the illumination system.

Figure 1-6(a) and (c) show two images of a uniformly reflective board taken under different illumination conditions: Visible and UV illumination, respectively. Although these images look relatively uniform, it is clear from the enhanced contrast images (iso-grey level values) shown in Figure 1-6(b) and (d) that the distribution of incident radiation in each case is very uneven.

![Visible-IR illumination](image1.png) ![UV illumination](image2.png)

Figure 1-6. Images of a uniformly reflective board taken under different illumination conditions: (a) Visible and (c) UV illumination. Images (b) and (d) are enhanced contrast images showing the iso-grey levels corresponding to the distribution of incident visible light in (a) and UV radiation in (b) on the surface under investigation.

An example of the impact of non-uniform illumination on the resultant reflected image is shown in Figure 1-7(a), where the upper section of a visible-reflected image appears to be
darker than the lower section. Figure 1-7(b), an image of a uniformly reflective board taken under the same lighting conditions shows that there is an illumination gradient from dark (top of the image) to light (bottom of the image). A corrected image, where this gradient has been removed (see later for details), produces an image which appears more evenly illuminated, Figure 1-7(c).

Optimisation of experimental procedures can minimise the spatial inhomogeneities in illumination which cause these effects. Symmetrical positioning of the radiation sources, avoiding specular reflections and shadows and checking the intensity of the incident radiation around the object with a light meter, are some of the most important factors in achieving these optimal conditions. Further recommendations and solutions for the illumination of objects can be found in the numerous manuals available on the photography of works of art. However, site or object constraints may sometimes impede appropriate positioning of the radiation sources or accurate light intensity measurements, in these cases the inhomogeneities encountered may be addressed via post-processing methodologies.

Figure 1-7. (a) Visible-reflected image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) showing inhomogeneous illumination. (b) Image of a uniformly reflective board taken under the same lighting conditions showing an illumination gradient, from dark (top of the image) to light (bottom of the image). (c) The corrected image appears more evenly illuminated.

The mathematical operation of compensating visible, UV- and IR-reflected images for the spatial inhomogeneities of the radiation source and establishing uniform illumination conditions is known as “flat-fielding” (see Appendix 1 for more explanation). Experimentally this involves recording the distribution of the source on a uniformly reflective board (as seen in the above examples) and dividing the reflected image by the distribution of the radiation in post-processing. This procedure also removes spurious effects caused by variations in the pixel-to-pixel sensitivity of the detector and/or by distortions in the optical path.
The uniformly reflective board is ideally a grey Lambertian reflector (a surface showing the same radiance when viewed from any angle - see Chapter 2 for examples). An image of the board represents an RGB map of the distribution of the radiation source which is incident on the surface under investigation. The board is placed parallel to the object and as close to the plane of the object as possible. An image of the board, which must cover the entire capture area, is taken. If the illumination is uniform, the image of the board should also have consistent RGB values throughout.

The reflected image of the object is divided, channel by channel and pixel by pixel, by the image of the uniformly reflective board. Subsequently, the reflected image is normalised back to the original maximum value of image, calculated as the average grey value on a 99% reflectance standard (for a description of the 99% Spectralon diffuse reflectance standard see Chapter 2). This procedure avoids the normalisation to hot pixels. The result of the division theoretically corresponds to the image of the object uniformly illuminated.

Figure 1-8. Compensation of spatial inhomogeneities of the radiation source for VIS, IRR and UVR images of a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5). Each image is divided by its corresponding image of the uniformly reflective board. The latter represents the distribution of the incident radiation. The result of the division theoretically corresponds to the image of the object uniformly illuminated.

Figure 1-8 shows some examples of images which have been corrected for the spatial inhomogeneity of the radiation source using this approach. The integration of this method into a workflow for the development of the post-processing software addressing the correction of reflected images is discussed in Chapter 3. The optimisation of experimental procedures to minimise the spatial inhomogeneities in illumination as well as the data acquisition requirements for post-processing are discussed in Chapter 2.
Two crucial factors in achieving reproducible and comparable brightness distribution or luminance in reflected images are the spectral density of the radiation source used to illuminate the object and the linearity of the camera used to record the image.

The spectral density of a radiation source describes how the intensity of the radiation emitted varies with wavelength. It is an intrinsic property of any source, described by its spectral power distribution (SPD). An ideal illuminant (e.g. the CIE standard illuminant E, Figure 1-9) would have an equal distribution of intensity (an equal energy spectrum) across all the wavelengths produced.

![Figure 1-9. Spectral power distribution of the CIE standard illuminant E.](image)

The intensity of the reflected wavelengths would then only be dependent on the properties of the surface. In reality however, the intensity of most radiation sources is not homogeneous across the wavelengths produced (the CIE standard illuminant E is a hypothetical radiation source). Figure 1-10 shows the difference in luminance observed for visible-reflected images as a result of capturing these with illuminants which have very different spectral power distributions: Figure 1-10(a) was captured with tungsten lamps (as represented by the CIE standard illuminant A, shown), whilst Figure 1-10(b) was captured with flashes (as represented by the CIE standard illuminants D50 or D55). As may be observed the very different distribution of intensity across the wavelengths produced by these radiation sources, has direct repercussions on the luminance of reflected images, and for visible-reflected images, also seriously impacts the colour-rendering of images. The warmer wavelengths prominent in incandescent sources (such as tungsten lamps) give rise to images with a redder colour cast, whereas the more even distribution of wavelengths in the source representative of daylight (such as D55 flashes) yield more balanced colour rendering of the image.
Figure 1-10. Visible-reflected image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) captured with (a) tungsten lamps (represented by the CIE standard illuminant A) and (b) flashes (represented by the CIE standard illuminants D50 or D55).

The manner in which cameras process images (see Chapter 3, section a) will also have an effect on the reproducibility of luminance in reflected images. The sensors used in DSLR cameras are linear, i.e. the number they generate for each pixel is proportional to the amount of light at that point. However, because the sensitivity of the human eye to light is different to that of a camera (Figure 1-11(a)), a function, or "gamma" is often applied to the captured image when this is converted into a standard JPEG or TIFF file by the camera or
the RAW image conversion software. An encoding gamma of 1/2.2 (such as those using sRGB and Adobe RGB 1998 colour) is commonly used (Figure 1-11(b)). In addition, S-shaped (tonal) curves may also be applied to the image if care is not taken to uncheck these options (see Chapter 3). These processes redistribute native camera tonal levels into ones closer to how the eye perceives them and add artistic enhancements, such as contrast and saturation, to the images. In order to produce comparable images, the linear data describing the tonal levels observed by the camera must be retrieved.

**Figure 1-11.** (a) Comparison of the sensitivity of the human eye to light with that of a camera (b) Schematic of gamma function applied to an image by manufacturers. This depicts an image in the sRGB colour space (which encodes using a gamma of approx. 1/2.2).

In the past, methods to compensate for both camera-applied gamma and the spectral density of the radiation source have employed a set of Lambertian grey references such as the Spectralon references (Figure 1-12, for a description of Spectralon diffuse reflectance standards, see Chapter 2) inserted in the frame as shown in Figure 1-13. Spectralon references have certified reflectance properties with associated RGB values in the UV-VIS-IR spectral range under investigation. Capturing these in the image allows a calibration curve to be calculated to convert the original RGB values of the greyscale read on the image to the RGB values assigned to these internal standards. Figure 1-13 shows an example of a visible-reflected image which has been compensated for the distribution of the incoming radiation by applying such a calibration curve. The greyscale of the balanced image (right) shows the RGB values reported in the table in Figure 1-12.

However, with this procedure the gamma function, which is a power function, is not truly removed but merely ‘compensated’ for. As a result, even simple mathematical operations undertaken with images corrected in this fashion will not provide the same results as with linear images, e.g. \((A + B)'^{\gamma} \neq A'^{\gamma} + B'^{\gamma}\). Even in the case of linear images, it should be mentioned that a gamma function is always finally applied to visualise them on a screen, which is intended to work with a gamma function to emulate what is observed by the eye.
Figure 1-12. The reference grey scale (Spectralon) and their reflectance spectra. The grey scale shows constant reflectance in the UV-VIS-IR sensitivity range of solid state CCD. Table of assigned RGB value.

<table>
<thead>
<tr>
<th>Reflectance values</th>
<th>Assigned RGB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>42</td>
</tr>
<tr>
<td>5%</td>
<td>66</td>
</tr>
<tr>
<td>10%</td>
<td>95</td>
</tr>
<tr>
<td>20%</td>
<td>116</td>
</tr>
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<td>50%</td>
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<td>60%</td>
<td>198</td>
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<tr>
<td>75%</td>
<td>216</td>
</tr>
<tr>
<td>80%</td>
<td>223</td>
</tr>
<tr>
<td>99%</td>
<td>249</td>
</tr>
</tbody>
</table>

Figure 1-13. Visible-reflected image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883.0505.5) (a) as shot and (b) after compensation for the distribution of the incoming radiation and the non-linear response of the camera by a calibration curve (c).

A more rigorous approach is to use the embedded colour or ICC profile automatically produced by the external RAW conversion software, on converting the RAW data into a TIFF
file (see Chapter 3), as it contains the exact information required to reverse any processing carried out on the image, including the gamma correction applied. Note that although camera profiles can also theoretically be approximated for JPEG images straight from the camera, this process has traditionally been difficult, as it involves an image that has already been "profiled" once to a particular colour space but may also include additional hue/saturation settings which distort the raw data.

The luminance of the linear image produced using this embedded ICC profile can then be calibrated according to a grey reference scale. For visible-reflected images, existing methods used for colour calibration based on use of a Macbeth target (for a description of colour calibration targets see Chapter 2) and an existing nip2 tool,⁴⁰ can be employed for this purpose. The luminance is set by analysing the Macbeth greyscale and carrying out a linear regression to find a scale factor on the linear image which minimises the average error. The procedure then finds the average brightness of all Macbeth chart patches and generates a matrix. Least-mean-square optimisation against patches with known values produces a 3x3 matrix from camera RGB to XYZ. Provided that the linearization is carried out correctly, this should give safer and more reproducible results than manual adjustment of the tone curve. Figure 1-14 shows an example of an image which has been corrected for both camera-applied gamma and the spectral density of the light source using this method. The muted appearance is typical of a corrected linear image, as all in-camera aesthetic enhancements have been removed.

Figure 1-14. Visible-reflected image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) (a) as shot and (b) after compensation for the distribution of the incoming radiation and the non-linear response of the camera using the embedded ICC profile and calibration according to a grey reference scale.

¹ Nip2 is the graphical user-interface of VIPS (http://www.vips.ecs.soton.ac.uk/index.php?title=VIPS), a free image processing system which will be used in the development of the post-processing software addressing the correction of images (see Chapter 3).
The luminance matching between the calibrated visible-reflected images (such as that shown in Figure 1-14(b)) and the corresponding linearized UV- and IR-reflected images is carried out by comparison of the Spectralon diffuse reflectance standards included in these images. A matrix of the average X, Y and Z values for each of the standards is generated in both the visible-reflected and UV- and/or IR-reflected images and these are then matched by linear regression (see Chapter 3). Finally, the UVR and IRR images in XYZ space are made into monochrome images (“mono-ized”) with just the data from the X or Z channel, respectively. This is equivalent to taking the data from the B or R channels in RGB space, as described by Aldrovandi et al.\textsuperscript{15} However, as a tri-band image is still required, and the X Y and Z have different maximum values (X=95.047, Y=100.00, Z=108.883), the X or Z channels cannot simply be copied into the other two channels. Instead X or Z are scaled down to 0 - 1, and then scaled up again by the maximum of the channel it is being copying into.

This process not only corrects for the camera-applied gamma and the spectral density of the radiation source but is a crucial step for creation of false-colour images, where the luminance of the images fed into the various channels must be well-matched. The integration of this approach into a workflow for the development of the post-processing software addressing the correction of reflected images is discussed in Chapter 3. The optimisation of experimental procedures, as well as the data acquisition requirements for post-processing, are discussed in Chapter 2.

– Camera response (colour calibration for Visible-reflected images only)

The colour signal captured by an imaging system, is the product of the incident light, the reflective properties of imaged surface and the spectral sensitivity of the recording device. The impact of spectral density on reflected images and the correction methods applied to address spectral inhomogeneity and camera applied gammas were discussed in the previous section. This section will discuss approaches towards the correction of the spectral sensitivity of the camera, commonly known as colour calibration.

In DSLR cameras the RGB values recorded for an image are dependent on the spectral sensitivity of the camera, (as a result of its sensor and the characteristic response of the embedded R, G, B, IR cut-off filters), i.e. different sensors can yield different RGB outputs for the same scene. Figure 1-15 shows two visible-reflected images of a detail from a wall painting fragment as shot with two different cameras with different sensor types: a Canon 40D (CMOS sensor) and a Fuji S3 Pro (CCD-based sensor). Although subtle, a slight difference in colour can be observed between the two images, resulting from the differences between the spectral sensitivity of these sensors and other optical characteristics. Estimation of camera spectral sensitivity or response is necessary to colour calibrate visible-reflected images so that these may be reproducible and comparable.

A standard technique for determining the spectral sensitivity of a camera establishes a relationship between incident narrow-band light with different wavelengths across the visible wavelength range and the camera output. The procedure used to achieve this is summarised in Figure 1-16. A monochromator or narrow-band filters are used to generate a series of monochromatic wavelengths of light. Each of these is cast on a standard white
board, and the reflected light observed by the target camera. At the same time, the spectral distributions of the monochromatic light are measured by a spectrometer. The camera spectral sensitivity can then be calculated using the captured images and measured spectra.\textsuperscript{41} This method is accurate as the measurements are independent of each other. However, it requires expensive optical equipment and a dark room. Moreover, capturing dozens of images and spectral distributions makes the whole procedure time-consuming, restricting its use to well-equipped laboratories.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1-15.jpg}
\caption{Visible-reflected image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) as shot with; (a) a Canon 40D and (b) a Fuji S3 Pro.}
\end{figure}

To simplify the procedure, methods which include calibration targets, in the captured image such as the Macbeth colour chart discussed in the previous section have been proposed. Various software solutions are available for calculating the 3x3 matrix coefficients, evaluating the colour error and colour calibrating visible-reflected images using calibration targets. One of these is an existing and already widely used workspace in nip2, as discussed above.\textsuperscript{40} This module will thus be integrated into the workflow for the correction of reflected images, as discussed in Chapter 3. The optimisation of experimental procedures, as well as the data acquisition requirements for post-processing will be discussed in Chapter 2.
Figure 1-16. Scheme showing the procedure for measuring the spectral sensitivity of the camera sensor, characterized by means of a calibrated Czerny-Turner monochromator and a calibrated light source (Oriel-QTH).

**– Image registration**

The dimensions of the UV- and IR-reflected images are different from those of the visible image, as UV, IR and Visible light are not all focused at the same distance inside the camera. The adjustment in focal point in capturing each of these images results in the difference in size observed. As a result, overlaying these images for comparisons or processing them to produce false-colour images can be challenging, as it often requires manual adjustment and resizing of the images. A tool in nip2 was previously developed for this purpose. Although this tool does not fully automate the procedure, it facilitates it by enabling the user to pick similar points in the images of interest which it uses as reference. It also enables the batch-processing of image sets. This module will thus be integrated into the workflow for the correction of reflected images for particular application to the creation of false-colour images, as discussed in Chapter 3.

**– Summary**

Figure 1-17 and Figure 1-18 summarise the workflows which will be used in the development of the post-processing software, based on the correction requirements discussed in this section. They highlight the transformations which must be carried out for each image set and also record the requirements in terms of images or files which will be necessary for the post-processing software to carry out the image correction procedure. Development and operation of the software will be discussed further in Chapter 3.
Visible-reflected images

- Camera output file – visible-reflected image
- ICC profile for conversion from RAW (contained within the image file)
- Image of uniform reflective board under experimental conditions for flat fielding
- Image of Macbeth chart for spectral density and colour calibration (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions)
- Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions)

All must be taken under identical illumination conditions and geometry

Figure 1-17. Workflow and post-processing requirements for visible-reflected images - Wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5).
**IR and UV-reflected images**

- Camera output file – IR or UV-reflected image
- ICC profile for conversion from RAW (contained within the image file)
- Image of uniform reflective board under experimental conditions for flat fielding
- Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions)

**Additional requirements from other workflows:**
- Calibrated visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available)

*All must be taken under identical illumination conditions and geometry*

Figure 1-18. Workflow and post-processing requirements for IR and UV-reflected images - Wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5).
ii. Photo-induced luminescence images

The factors affecting reproducibility and device dependence of photo-induced emitted radiation or luminescence images are discussed in the sections below. Four main effects are considered:

1) Spatial inhomogeneities of the radiation source;
2) Ambient stray radiation;
3) Camera response (luminescence calibration);
4) Pigment-binder effects.

Some of these factors are common to both reflected and photo-induced luminescence images and are discussed only briefly. In addition, correction for some of the above effects will not be necessary for the three types of luminescence image discussed, e.g. the effect of colour calibrating the camera response for luminescence is irrelevant to the correction of visible-induced infrared luminescence images, as these are monochrome. In addition, although some of the methods discussed could possibly be applied to visible-induced visible images, the post-processing of this image type is outside the scope of this work.

– Spatial inhomogeneities of the radiation source

In common with reflected images (see above), photo-induced luminescence images must also be flat-fielded to correct for the spatial inhomogeneities of the radiation source. As described previously, experimentally this involves recording the distribution of the incoming radiation on a uniformly reflective board and dividing the reflected image by the distribution of the radiation in post-processing.

Figure 1-19. (a) UV-induced luminescence image of a detail from a fresco by Agnolo Gaddi taken at the basilica di Santa Croce in Florence showing inhomogeneous illumination. (b) Image of a uniformly reflective board taken under the same lighting conditions showing an inhomogeneous distribution of radiation present at the top and bottom edges of the image. (c) Flat-fielded image appears more even (© Organic Material in Wall Painting Project, Getty Conservation Institute).
Figure 1-19 shows an example of a UV-induced luminescence image which has been flat-fielded. The top and bottom edges of the image shown in Figure 1-19(a) appear darker than the central section. An image of a uniformly reflective board taken under the same lighting conditions, Figure 1-19(b), shows the inhomogeneous illumination. A flat-fielded image, which removes this inhomogeneity using the procedures described in section i, produces an image which appears more evenly and brightly illuminated, Figure 1-19(c).

The above method can also be applied to visible-induced infrared and visible-induced visible images (although the post-processing of this image type is outside the scope of this work) and will be integrated into a workflow for the development of the post-processing software addressing the correction of luminescence images (see Chapter 3). The optimisation of experimental procedures to minimise the spatial inhomogeneities in illumination as well as the data acquisition requirements for post-processing are discussed in Chapter 2.

– Ambient stray radiation

Under ideal experimental conditions the radiation captured by an image should be due to reflected or emitted wavelengths. In practice, working conditions can often be far from optimal and it is not always possible to exclude ambient or parasitic sources of radiation fully.

Parasitic radiation is associated with the inefficient filtration of unwanted radiation from a source. Sources of UV for example, also often emit a considerable amount of violet, blue and IR radiation and while single-colour LED radiation sources do not usually emit IR radiation, commercially available fluorescent radiation sources in the visible range are very likely to emit some IR radiation.

Figure 1-20 shows visible-induced infrared luminescence images, acquired with a mixture of radiation from LEDs (R, G and B) and tungsten lamps (Figure 1-20(a)), and with radiation from LEDs only (Figure 1-20(b)).

The IR radiation emitted by the incandescent source used in Figure 1-20(a) is visible as parasitic radiation in the image. However, as Egyptian blue is strongly luminescent and the amount of parasitic IR radiation is low, the effect is acceptable and can even be useful, as it can aid the location of luminescent areas on the object under investigation. However, in large amounts or cases with limited luminescence, these parasitic components can easily mask the luminescence of weak or poorly concentrated emitters. Strategies towards the elimination of parasitic radiation arising from these sources by means of filters are discussed in Chapter 2.
Figure 1-20. Visible induced luminescence images of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) acquired (a) with a mixture of radiation from LEDs (R, G and B) and tungsten lamps, and (b) with radiation from LEDs only.

Ambient stray radiation can arise from non-ideal working conditions such as a room where it is not possible to exclude external radiation or in which there are luminescent objects. Whilst some of these concerns can be addressed under controlled conditions or with nocturnal image capture, it is often not possible to completely exclude ambient stray radiation in a museum or gallery environment.

Figure 1-21. UV-induced luminescence images image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) (a) with ambient stray radiation and (b) in the absence of ambient stray radiation. The images are as shot.
Figure 1-21 shows an example of how the presence of ambient stray radiation can interfere with the interpretation of luminescence phenomena. The UV-induced luminescence image on the left Figure 1-21(a), was taken in the presence of some red ambient stray radiation. Figure 1-21(b) shows the UV-induced luminescence of the same subject where the source of this ambient stray radiation has been removed. Comparing these, it is clear that in Figure 1-21(a) the ambient stray radiation caused the dark areas in the image to appear lighter, the areas of ‘blue’ luminescence around the figure appears purple and the ‘yellow’ luminescence of the figure appears more orange.

The ambient stray radiation observed in images such as Figure 1-21(a), can be considered as ‘background noise’ and, although this cannot be measured directly, it can be mathematically reconstructed and removed from luminescence images by post-processing methods, represented schematically in Figure 1-22 using a UV-induced luminescence image as an example.

![Figure 1-22](image_url)

*Figure 1-22. Schematic showing the correction of luminescence images for ambient stray radiation using a UV-induced luminescence images image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) as an example.*
Photo-induced luminescence images produced in the presence of ambient stray radiation will contain information on both the luminescence properties of the object and the stray radiation reflected from its surface. In order to decouple these contributions, a measurement of the reflective properties of the surface under investigation must be made by inserting a reflectance standard in the photo-induced luminescence image, Figure 1-22(a). These reflectance standards (e.g. the 99% Spectralon diffuse reflectance standard, as described in Chapter 2) are non-luminescent and thus appear dark in the absence of stray radiation but allow the evaluation of any ambient (and parasitic) stray radiation as RGB (or XYZ) values, Figure 1-22(b).

These average values are multiplied pixel by pixel and channel by channel by a corrected reflected image in the same spectral region as the luminescence image, in this case a visible-reflected image Figure 1-22(c), which has been transformed into a reflectance map of the object by rescaling the image from 0 to 1 (dividing each pixel in the reflected image by the average grey level value on the 99% reflectance standard). The result is an image which mathematically reconstructs the ambient stray radiation, Figure 1-22(d). This can then be subtracted pixel by pixel from the photo-induced luminescence image to produce the corrected image, Figure 1-22(e).

The above method can also be applied to visible-induced infrared and visible-induced visible images (although the post-processing of this image type is outside the scope of this work) and will be integrated into a workflow for the development of the post-processing software addressing the correction of luminescence images (see Chapter 3). The optimisation of experimental procedures to minimise the presence of parasitic and ambient stray radiation as well as the data acquisition requirements for post-processing are discussed in Chapter 2.
– **Camera response (luminescence calibration)**

As discussed in the previous section on reflected images, the issue of varying camera responses and therefore how to calibrate the camera, or apply corrections to address these variations, is a particular challenge. Approaches for the colour calibration of reflected visible light images have been addressed (see section above) but the calibration of camera response with respect to luminescence is much more problematic, as this corresponds to the direct capture of a light source. As a result, standard colour charts and greyscales used for reflection cannot be used to solve issues related to exposure and colour correction.

Absolute calibration methods as discussed above, although accurate, are time-consuming and restricted to well-equipped laboratories. These factors make absolute calibration methods impractical for most users. However, such methods may not strictly be necessary in order to produce comparable device independent images.

In this work the focus has been on the use of an ‘indirect’ method to standardise luminescence images to allow their inter-comparison. The method described below achieves a solution which will make use of accessible resources and are a viable alternative for more advanced technological approaches. This new approach considers existing methods used for the colour calibration of reflected visible light images based on use of a Macbeth target\(^{42}\) and an existing nip2 tool,\(^{40}\) as discussed earlier, and extends these to the calibration of luminescence images by considering that:

The colour calibration matrix for reflected visible light images \( M \) calculated by this tool, takes a Macbeth target illuminated with a source of colour temperature \( T \) and imaged with the camera in the camera’s RGB colour space and converts this output into the equivalent CIE XYZ colour space under a D65 illuminant i.e. D65 CIE XYZ (Figure 1-23).\(^3\) The colour calibration matrix, \( M \), can then be applied to calibrate the VIS image acquired under the same conditions.

![Diagram of camera response (luminescence calibration)](image)

A UV-induced luminescence image acquired with a white balance set to D65 and imaged with the camera RGB would require a calibration matrix \( M' \), to take this target to D65 CIE XYZ (Figure 1-23).

![Diagram of camera response (luminescence calibration)](image)

This cannot be determined directly but we can think of \( M' \) as a product of a colour temperature transform \( MT' \), which takes camera RGB D65 to camera RGB T, and a matrix \( M \) (the colour calibration matrix for VIS images, which is known), which then takes this image to D65 CIE XYZ (Figure 1-23).
However, once more, the temperature transform $MT'$ to take us from D65 RGB to T RGB is not easy to find directly, and as strictly speaking, matrix multiplication is non-commutative, we cannot simply invert this as $M' \neq M \times MT'$. However, if $M$ is not too far from an identity matrix and $T$ is not far from D65 then: $M' \approx M \times MT$, where $MT \rightarrow MT'$ and yields an approximate $M'$.

Figure 1-23. Schematic showing the colour correction of visible images (left) and the application of the calibration matrix $M$ together with a colour temperature transform, $MT$ (to compensate for the difference in colour temperature between D65 and T) for the correction of UV-induced visible luminescence images (right).
This procedure has been incorporated into a post-processing workspace for UV-induced luminescence images using nip2. It applies the colour calibration matrix $M$ (determined for the calibration of VIS images, captured with an illuminant of colour temperature $T$), to the UVL image acquired with a white balance set to D65 and imaged with the camera in RGB colour space. This creates an image in ‘D65’, which requires a colour temperature transform, $MT$, to compensate for the difference in colour temperature between D65 and $T$, and move the result back to the equivalent CIE XYZ colour space under a D65 illuminant.

In the post-processing workspace this approach to the white-point adjustment has been developed into a slider, so that the user can select the calibration illuminant colour temperature $T$ (used to acquire the VIS image and to determine $M$), from a source with known colour temperature e.g. a D50 flash, or as measured with a colour temperature meter (see Chapter 3). However, the approximation assumes that the changes in colour temperature between $T$ and D65 will not be very large. This is likely to be the case, since the overwhelming choice of illuminant used in the acquisition of VIS images are flash lights which are approximately D50, and hence close to D65. Trials have shown that for other illuminants such as tungsten lamps (D32), the change in colour temperature is too great and the approximation breaks down.\textsuperscript{43}

Currently the above method has only been applied to UV-induced luminescence images but not to visible-induced infrared luminescence images as these are monochrome. The method could possibly be applied to visible-induced visible images but the post-processing of this image type is outside the scope of this work. The approach will be integrated into a workflow for the development of the post-processing software addressing the correction of luminescence images (see Chapter 3). The optimisation of experimental procedures, as well as the data acquisition requirements for post-processing, are discussed in Chapter 2.
– **Pigment-binder effects**

It has been established that the luminescence of materials, such as organic binders or colorants found in painted surfaces are generally severely affected by the presence of absorbing non-fluorescing materials, such as inorganic pigments.\(^44\text{-}45\)

The effect, also known as the “pigment-binder interaction”, is represented schematically in Figure 1-24, which shows pigment particles (black ovals) homogeneously dispersed in a binding medium (light and dark grey circles). The luminescence produced by the organic binding medium by radiation entering the painted surface, can be:

(a) Emitted without further modification;
(b) Absorbed and re-emitted by binder particles;
(c) Interact with the surrounding pigmented particles and undergo scattering and absorption phenomena.

![Figure 1-24. Schematic model for the propagation of luminescence from the organic binding medium in a paint layer. Luminescence can: (a) be emitted without further modification; (b) be absorbed and re-emitted by binder particles; or (c) interact with the surrounding pigmented particles and undergo scattering and absorption phenomena.\(^45\)](image)

As a result the true emissions, corresponding to the presence of materials which exhibit luminescent properties as in Figure 1-24(a), will be compromised by emissions arising from the interactions among luminescent materials and surrounding non-fluorescent materials, as in Figure 1-24 (b-c). The luminescence captured in the image will be a superposition of all these emissions, leading to an inaccurate record of the luminescence properties of the surface.

Post-processing methodologies can be applied in order to decouple the various contributions to the luminescence recorded in the image. The correction uses a mathematical model based on the Kulbelka-Munk theory\(^46\text{-}47\text{-}48\) and essentially consists of dividing the luminescence image by a function \((\gamma)\), which expresses the extent to which the pigment particles absorb the radiation emitted by the luminescent materials (see Appendix 1 and references therein for more detail).
Experimentally, the correction of a luminescence image for the pigment-binder interaction involves the acquisition of:

(a) a luminescence image (e.g. a UV-induced visible luminescence image)
(b) a reflected image in the spectral range in which the luminescence of interest was induced (e.g. a UV-reflected image if correcting a UV-induced luminescence image). Corrected as described.
(c) a reflected image in the same spectral range in which the luminescence of interest was collected (e.g. a visible-reflected image if correcting a UV-induced visible luminescence image). Corrected as described.

The corrected images are then subjected to the mathematical operations discussed in more detail in the Appendix 1 and shown schematically in Figure 1-25 for a UV-induced visible luminescence image. Summarizing, the three processes are:

1. Calculation of the remission functions for the visible and UV-reflected images, Rem(VIS) and Rem(UV);
2. Calculation of the $\gamma$ function;
3. Calculation of the corrected luminescence image.

Figure 1-25. Schematic showing the 'pigment-binder' correction of luminescence images using a UV-induced luminescence images image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5) as an example.
Figure 1-26 shows the images shown in Figure 1-25, in more detail.

![UV-induced luminescence images](image)

**Figure 1-26.** UV-induced luminescence images image of a detail from a wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883.0505.5) (a) uncorrected for the pigment-binder effect and (b) following correction. (c) Visible-reflected image and (d) UV-reflected image of the same wall painting fragment.\(^3\)

The uncorrected image (Figure 1-26 (a)) generally shows a strong blue luminescence (with the exception of the dark areas which have undergone conservation). However, the figure can still be distinguished, as its luminescence is different from the background. The corrected image (Figure 1-26 (b)) shows a uniform distribution of luminescence and the anatomical details of the figure are less distinguishable. By contrast, the correction does not have an effect on the white background, which reflects radiation uniformly. This result is indicative of the presence of a layer of varnish which absorbs all the UV radiation, as
suggested by the UV-reflected image Figure 1-26 (d)), which shows the UV radiation fully absorbed by this varnish layer, particularly over the figure. The information on luminescence therefore relates strictly to the varnish layer and the colours present on the figure are due to apparent emissions, which have been removed on correction.

Although the above method has been proposed and tested for UV-induced visible luminescence images, it is envisaged that it can also be applied to visible-induced infrared luminescence and visible-induced visible luminescence images, although post-processing methods for the latter are outside the scope of this work. The procedure will be integrated into a workflow for the development of the post-processing software addressing the correction of luminescence images (see Chapter 3).

– **Summary**

Figure 1-27 and Figure 1-28 summarise the workflows which will be used in the development of the post-processing software, based on the correction requirements discussed in this section. They highlight the transformations which must be carried out for each image set and also record the requirements in terms of images or files which will be necessary for the post-processing software to carry out the image correction procedure. They address the correction of UV-induced visible luminescence images and visible-induced infrared luminescence images, respectively. It is envisaged that a workflow based on that for UV-induced visible luminescence images could be adapted for use for the correction of visible-induced visible luminescence images but this is beyond the scope of this work. The development and operation of the software will be discussed further in Chapter 3.
UV-induced visible luminescence images

- Camera output file – UV-induced visible luminescence image
- ICC profile for conversion from RAW (contained within the image file)
- Image of uniform reflective board under experimental conditions for flat fielding
- Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions)

**Additional requirements from other workflows:**
- Calibrated visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available)
- Corrected UV-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available)

All must be taken under identical illumination conditions and geometry

Figure 1-27. Workflow and post-processing requirements for UV-induced visible luminescence images - Wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5).
Visible-induced infrared luminescence images

- Camera output file – Visible-induced IR luminescence image
- ICC profile for conversion from RAW (contained within the image file)
- Image of uniform reflective board under experimental conditions for flat fielding
- Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions)

**Additional requirements from other workflows:**
- Calibrated visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available)
- Corrected IR-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available)

All must be taken under identical illumination conditions and geometry

Figure 1-28. Workflow and post-processing requirements for visible-induced infrared luminescence images - Wall painting fragment from the British Museum (Winged youth from the Tomb of the Nasonii, 1883,0505.5).
Appendix 1

i. Flat-field correction

A flat-field or uniform photometric response is achieved by calculating reflectance factors (RF), which are the ratios of the reflected radiation from a sample (RS) to those of a known reference material (RR). An RF value for an individual pixel (i) at a given wavelength (λ) can be calculated using following equation:

\[ RF_{\lambda} = \frac{RS_{\lambda} - RD_{\lambda}}{RR_{\lambda} - RD_{\lambda}} \times RC \]

where, RS = sample image
RD = dark current image
RR = reference image
RC = correction factor for the reference panel

This considers that the signal from each pixel will consist of a gain (a signal given by the detector which varies as a function of the amount of radiation, RS or RR) and a dark current (a signal given out by the detector when there is no incident radiation, RD). To eliminate the impact of the dark current signal, the dark current image is subtracted from the gain. The ratio of the signals for the sample and reference image is then multiplied by a correction factor RC. An RC of 1.0 was used in our applications so as not to change the overall brightness of the image.

Flat-field corrections often make use of an image captured with the sensor in the dark by leaving the lens cap on the camera (a “lens-cap black”) to access the impact of the dark current signal. Experiments allowing for a lens-cap black were conducted during our investigations, but the improvement was very marginal with the cameras tested. As a result, a dark current image subtraction was not included in the approach adopted. However, to check if this assumption is pertinent to the camera employed, simply take an image with the lens-cap on and look at the values for the image. If the image is below the noise level then the dark current signal will not have a significant effect on the flat-field correction.

Sensor size and impact on flat-field corrections

Flat-field correction is particularly important in images taken with cameras having full-frame sensors, where effects such as lens vignetting (a reduction in the brightness or saturation of an image at the periphery compared to the image centre) are more prevalent. In general, the cameras tested did not have full-frame sensors and only use the centre 50% of the lens. In such cases, although still recommended, flat-field correction may be omitted in circumstances where taking an image of a uniform reflective card may not be possible. Provision in the software design will be made to accommodate such situations.

If using cameras with full-frame sensors this correction may be particularly important. Preliminary tests may need to be done on cameras with such sensors in order to quantify the impact of such effects.
ii. **Pigment-binder interaction - Kulbelka-Munk correction**

The correction methodology employed\(^{44,45}\) is based on the Kubelka–Munk theory\(^{46,47,48}\) and was developed by Ramos and Lagorio for the correction of fluorescence spectra of chlorophyll in plant leaves. It assumes that:

(a) the painted surface is an ideal, homogeneous scattering and absorbing material, characterized by a scattering coefficient \(s(\lambda)\) and an absorption coefficient \(k(\lambda)\). Although this is a broad, and in most cases unrealistic, approximation it will be accepted here because no quantitative information or identification is sought for image correction;

(b) the incoming radiation is a collimated beam illuminating normally the painted surface and that no radiation is transmitted through the paint layer. In other words, it is considered to be optically opaque and no radiation is transmitted to any underlying layers.

Under these hypotheses, the well-known result of the Kubelka–Munk theory can be obtained:

\[
\frac{k(\lambda)}{s(\lambda)} = \frac{[1 - R(\lambda)]^2}{2R(\lambda)} = Rem[R(\lambda)]
\]

where \(\lambda\) represents the wavelength, \(R(\lambda)\) is the diffuse reflectance factor (i.e., the ratio between the reflected radiation at the front surface and the incident radiation), and \(Rem[R(\lambda)]\) is the remission function.

When a luminescent material is present in the scattering media, the Kubelka–Munk theory can be modified by considering that the radiation emitted can be decomposed into two photon flows traveling in the direction of the incoming (\(\lambda\)) and reflected radiation (\(\lambda_0\)), respectively.\(^{47}\) A correction factor \(\gamma(\lambda, \lambda_0)\) is introduced to account for this given by:

\[
\gamma(\lambda, \lambda_0) = \begin{vmatrix}
1 + \frac{1}{Rem[R(\lambda)] + 2} \\
1 + \frac{1}{Rem[R(\lambda)](Rem[R(\lambda)] + 2)} \\
1 + \frac{1}{Rem[R(\lambda_0)](Rem[R(\lambda_0)] + 2)}
\end{vmatrix}
\]

Dividing the observed luminescence image by this correction factor yields the true luminescence.
References


24 Proceedings IS&T/SPIE Electronic Imaging 7531, Computer vision and image analysis of art, eds. Stork, D. G., Coddington, J., Benktowska-Kafel, A., (2010), San Jose, California, United States.

25 Proceedings IS&T/SPIE Electronic Imaging 6801, Computer image analysis in the study of art, eds. Stork, D. G., Coddington, J., (2008), San Jose, California, United States.


35 ISO/CIE 10526:1999, CIE standard illuminants for colorimetry


38 http://www.cambridgeincolour.com/tutorials/gamma-correction.htm


2. Experimental Set-up

The experimental factors and physical phenomena leading to the observation of spurious effects or device-dependent issues in multispectral images were discussed in Chapter 1. A number of workflows were proposed for both reflected and photo-induced luminescence images, which detailed the corrections required and the general transformations to be carried out by the post-processing software (see Chapter 1, Figures 17-18 and 27-28). The development and operation of this software will be discussed in more detail in Chapter 3, but the requirements of the software in order to carry out the image correction procedure are central to the development of the acquisition protocols. As a result, work to develop optimised and standardised acquisition protocols which permitted the raw image data to be collected in the manner required, was undertaken in parallel with work on the development of post-processing methods. The optimised and standardised acquisition protocols for the capture of reflected and photo-induced luminescence images resulting from this iterative process are detailed in this Chapter.

The development of these protocols began with an understanding of the function that each equipment component must carry out within the experimental set-up. The following sections discuss each of these components in more detail and the particular properties required in order to carry out these functions and acquire each of the multispectral imaging sets considered. A discussion of the set-up of this equipment in order to minimise experimental sources of error and the effect of physical phenomena follows. Finally, the five workflows for the optimised and standardised acquisition of the multispectral image sets discussed are described. A checklist of the requirements for the image correction procedure is included at the end of each workflow. A workflow for the optimised and standardised acquisition of visible-induced visible luminescence images is also included, although the post-processing of this image type is outside the scope of this work.

a. Equipment selection

The experimental set-up for the acquisition of multispectral images can be considered as being made up of a number of equipment components as shown in Figure 2-1:

1) A pair of radiation sources which provide the incident radiation to the object being studied and in the case of luminescence techniques also provide the means to induce the luminescence (the excitation source) in the materials under study;
2) A filter or set of filters in order to allow the transmittance of radiation in the wavelength range under study and exclude unwanted radiation from being recorded;
3) A detector or recording device which in this work is a commercially available digital camera with a silicon-based sensor, modified by removal of the IR-blocking filter to provide sensitivity from approximately 350 nm to 1100 nm;
4) A set of standards to enable the post-processing methods discussed in Chapter 1 and detailed in Chapter 3.
Figure 2.1. Schematic representation of a generic set-up for the collection of multispectral images showing the main components required.

The following sections offer a series of general recommendations on the selection of these components for each of the multispectral imaging techniques discussed. A list of typical (but by no means exclusive) suppliers used currently for such equipment has been included in Appendix 2 for reference. However, the aim is to provide guidance on the properties that the equipment selected should possess rather than to recommend particular items, models and/or brands. This should make the guidelines more widely applicable and less susceptible to become obsolete should production or availability of certain items/models cease.

Table 2.1 summarises the equipment required by each imaging technique. As may be observed, the recording device and standards remain almost constant throughout, whilst the combination of radiation source and filter (or sets of filters) is altered to allow the study of the spectral windows of interest. Recommendations for the properties of the camera and standards are thus made in more general terms for all the techniques concerned, whereas the radiation sources and filters are discussed more specifically within the requirements of each particular technique.
Table 2-1. Summary of the equipment required by each of the multispectral imaging techniques considered.

<table>
<thead>
<tr>
<th>Imaging Technique</th>
<th>Radiation Sources</th>
<th>Filter(s) in front of radiation source</th>
<th>Detector</th>
<th>Filter(s) in front of detector</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible-reflected (VIS) Images</td>
<td>Visible/IR light sources (e.g. tungsten-halogen, white LEDs or Xenon flashes)</td>
<td>None</td>
<td>Commercially available digital camera</td>
<td>Visible bandpass filter (e.g. IDAS_UIBAR)</td>
<td>Macbeth colour chart, Spectralon diffuse reflectance standards as available.</td>
</tr>
<tr>
<td>Infrared-reflected (IRR) Images</td>
<td>Visible/IR radiation sources (e.g. tungsten-halogen, white LEDs or Xenon flashes)</td>
<td>None</td>
<td>Commercially available digital camera</td>
<td>UV/Visible-blocking filter (e.g. Schott RG830)</td>
<td>Spectralon diffuse reflectance standards as available.</td>
</tr>
<tr>
<td>UV-reflected (UVR) Images</td>
<td>UV radiation sources (e.g. wood lamps, UV LEDs)</td>
<td>IR- and VIS-blocking filter (e.g. DUG11x)</td>
<td>Commercially available digital camera</td>
<td>UV bandpass filter (e.g. DUG 11X)</td>
<td>Spectralon diffuse reflectance standards as available.</td>
</tr>
<tr>
<td>UV-induced visible luminescence (UVL) Images</td>
<td>UV radiation sources (e.g. wood lamps, UV LEDs)</td>
<td>IR- and VIS-blocking filter (e.g. DUG11x)</td>
<td>Commercially available digital camera</td>
<td>UV-blocking filter (e.g. Schott KV418 + IDAS_UIBAR)</td>
<td>Macbeth colour chart, Spectralon diffuse reflectance standards as available.</td>
</tr>
<tr>
<td>Visible-induced infrared luminescence (VIL) Images</td>
<td>Visible light sources (e.g. LED light sources)</td>
<td>None</td>
<td>Commercially available digital camera</td>
<td>UV/Visible-blocking filter (e.g. Schott RG830)</td>
<td>Spectralon diffuse reflectance standards as available.</td>
</tr>
<tr>
<td>Visible-induced visible luminescence (VIVL) Images</td>
<td>Visible light sources (e.g. Blue LED light sources)</td>
<td>None</td>
<td>Commercially available digital camera</td>
<td>Blue-blocking filter (e.g. Lee No.16 or Lee No.21) Visible bandpass filter(e.g.IDAS_UIBAR)</td>
<td>Macbeth colour chart, Spectralon diffuse reflectance standards as available.</td>
</tr>
</tbody>
</table>
i. **Camera (detector)**

For a general discussion and recommendations on the selection of cameras and lenses for the capture of high-quality photographic documentation in art historical and conservation contexts, the reader is referred to the *AIC Guide to Digital Photography and Conservation Documentation* and references contained therein.

In addition, the following recommendations are made for the purposes of the multispectral imaging techniques described in this work, which as discussed, employ commercially available digital cameras with a silicon-based sensor modified by removal of the IR-blocking hot mirror to provide sensitivity from approximately 350 nm to 1100 nm:

1) A high native sensor pixel count in order to produce high resolution images;
2) Ability to shoot RAW formats;
3) Live view capability.

Note that the sensitivity of the camera sensors is typically 200 – 1100 nm and that the range is attenuated to the quoted 350 – 1100nm (in the modified cameras described in this work) because of the widespread use of glass lenses. The use of quartz lenses would make this range approximately 225 – 1100 nm, although it should be noted that the sensitivity of the sensor drops off significantly at the extremes of its wavelength range (see spectral response curves for a typical silicon-based sensor shown in Figure 2-2).

![Figure 2-2](image)

*Figure 2-2. Schematic representation of the spectral response of a typical silicon-based (CCD/CMOS) sensor with and without an IR-cut off filter (as in the modified cameras described in this work).*

ii. **Radiation sources and filters**

The appropriate choice of radiation sources in order to produce sufficient incident radiation of the desired wavelength range, together with the efficient filtration of this radiation from the detector/camera, is paramount to the optimisation of the experimental set-up. In this section the output of typical sources for each of the imaging techniques is considered, in combination with the properties required by a filter (or filter set) to block this from entering the camera, whilst allowing the transmittance of radiation in the wavelength range under study.
Visible-reflected (VIS) Images

Radiation source:
The three most commonly used radiation sources for visible light photography in cultural heritage applications are: fluorescent light banks, incandescent light sources (such as tungsten or tungsten-halogen lamps) and strobe or flash sources. Each has associated advantages and disadvantages and these are discussed in some length in the numerous manuals available on the photography of works of art.\(^3\)

For the purposes of this work, the most important consideration is the spectral output distribution (SPD) of the chosen source. A well-characterised SPD will allow the appropriate selection of filters to eliminate the unwanted wavelengths of radiation, e.g. many sources of visible radiation may include some UV and/or IR radiation in the form of heat (see the SPDs of a typical tungsten lamp and a xenon flash tube shown in Figure 2-3).

![Schematic representation of the spectral output distribution (SPD) of a typical tungsten lamp and xenon flash tube compared to the wavelength range of a CCD/CMOS sensor. Shading shows wavelengths to be excluded (filtered) in the acquisition of visible-reflected images.](image)

In addition, knowledge of the SPD of the source, its associated colour temperature (or correlated colour temperature for non-incandescent sources) and colour-rendering index is valuable in the evaluation of its colour rendering capabilities and in the subsequent colour
calibration of the images produced. Sources with colour temperatures close to D65 will give best results for the UVL calibration procedure using the VIS image described in Chapter 1.

**Filter(s) in front of radiation source:**
None

**Filter(s) in front of camera:**
For visible-reflected images a filter is required which will allow only light in the visible region (400-700 nm) through and block any UV or IR radiation. A bandpass filter which eliminates these wavelengths must be selected. Visible bandpass filters are available in a variety of bandwidths to allow selection of broad bands within the visible or narrower bands focussing on a specific spectral range or colour (monochromatic bandpass filters).

In this instance, the entire visible region is of interest and as such an interference UV-IR blocking filter, similar to the IDAS-UIBAR filter (bandpass, c.380–700 nm, see Figure 2-4 for transmittance curve), is recommended. Note that the sensitivity of the camera sensor will not be constant throughout its wavelength range (see spectral response curves for a typical silicon-based sensor shown in Figure 2-2).

![Transmittance curve of a visible bandpass filter (IDAS-UIBAR).](image)

It should be noted that for the purposes of UVL calibration using the VIS image (as described in Chapter 1), it may be advisable to capture a VIS image in the same wavelength as that used to acquire the UVL image, as a large difference in the acquisition window for these images may impact on the accuracy of the colour calibration of the UVL images. The decision will be dependent on the particular equipment used and would have to be made by each user, after testing the differences incurred by their particular experimental set-up.

– *Infrared-reflected (IRR) Images*

**Radiation source:**
Some of the radiation sources discussed above emit IR radiation (e.g. incandescent sources) and can therefore be used for the acquisition of IRR images. Fluorescent sources however
are not appropriate. Glare-free and uniform illumination across the entire surface is essential as shadows, reflections or uneven illumination could be misconstrued as variations in infrared absorbency, although some of these issues can be dealt with in post-processing as discussed in Chapter 1.

**Filter in front of radiation source:**
None

**Filter in front of camera:**
For infrared-reflected images, a filter is required which will block radiation in the UV and visible region (200 - 700 nm). The filter selected should allow IR radiation to be collected between 700 and 1100 nm, the end of the sensitivity of most DSLR camera sensors (Figure 2-5). However, the choice of the filter depends on the type of investigation which is undertaken, as different materials have different reflective properties in the IR range. The most commonly used range is approximately between 800 and 1100 nm, requiring a filter with properties similar to the Schott glass RG830 filter which cuts-on at 830 nm (see Figure 2-6 for transmittance curve). Note that the sensitivity of the sensor drops off significantly at the extremes of its wavelength range (see Figure 2-2).

*Figure 2-5. Schematic representation of the spectral output distribution (SPD) of a typical tungsten lamp and xenon flash tube compared to the wavelength range of a CCD/CMOS sensor. Shading shows wavelengths to be excluded (filtered) in the acquisition of infrared-reflected images.*
UV-reflected (UVR) Images

Radiation source:
The most commonly used excitation sources for imaging methodologies requiring UV radiation are UV-A glass mercury vapour lights ($\lambda_{\text{exc}} = 365$ nm), also known as Wood’s lamps (named after Robert W. Wood who in the 1920s, created a glass with nickel oxides which has the property of transmitting UV and IR radiation and blocking most of the visible radiation) or black-light-blue (BLB) lights. The spectral output distribution of a typical Wood’s lamp (Philips PL-S 9W double BLB) is shown in Figure 2-7. It should be noted that, although the source has a principal peak at 365 nm, the emission has a tail which extends well down into the visible and IR range. Mercury lights also have a peak at 405 nm. Therefore, a considerable amount of violet, blue and IR radiation is emitted. This parasitic component can easily mask the luminescence of weak or poorly concentrated emitters in this region.

Filter in front of radiation source:
In general terms, silicon-based camera sensors have low sensitivity to UV radiation, but are very sensitive to visible and IR radiation. Therefore, it may be beneficial to block off the parasitic visible and IR radiation described above. The use of an interferential excitation filter (vapour-deposited heavy metal oxides on both sides), such as the Schott DUG11X filter (see transmittance curve in Figure 2-8) in front of the radiation source has been proposed in order to minimise the transmittance of both violet-blue and IR radiation. It should be noted that, although the DUG11X filter is still available at present, it will soon be out of production. It is important that alternatives to this filter (whether one or a combination of filters) retain the properties exhibited in Figure 2-8, and effectively completely cuts-off IR radiation, as well as visible wavelengths.

Note that, in addition to the parasitic light due to the excitation source, sources of ambient stray radiation (such as apertures or fluorescent specimens present in the studio or

Figure 2-6. Transmittance curve of a UV/visible-blocking filter (e.g. Schott RG830, which cuts-on at 830 nm).
examination location) should also be carefully controlled, as they can significantly interfere with the interpretation of the luminescence.

**Filter in front of the camera:**
For UV-reflected images a filter is required which will block radiation in the visible and IR regions (400 - 1100 nm). This would require a filter with properties similar to the Schott glass DUG11X filter (see Figure 2-8 for transmittance curve and recommendations for alternatives above).

![Image](image_url)

*Figure 2-7. Schematic representation of the spectral output distribution (SPD) of a BLB ultraviolet light compared to the wavelength range of a CCD/CMOS sensor. Shading shows wavelengths to be excluded (filtered) in the acquisition of UV-reflected images.*

Note that although the sensitivity of camera sensors is typically 200 – 1100 nm, the range will be attenuated to the quoted 350 – 1100nm (in the modified cameras described in this work) because of the widespread use of glass lenses. This would yield “UV-reflected” images in the range 350 – 400 nm, with the filters recommended above. In order to collect images that can truly be referred to as UV-reflected, quartz lenses would need to be used, which would make the range of acquisition of these images) approximately 225 – 400 nm with the filters recommended above. However, it should be noted that the sensitivity of camera sensors drops off significantly at the extremes of its wavelength range (see Figure 2-2).
– *UV-induced visible luminescence (UVL) Images*

**Radiation source:**
See UV radiation sources equipped with visible and IR-blocking filters, as described above.

**Filter in front of the camera:**
Collection of UVL images requires a filter with properties similar to the IDAS-UIBAR filter (bandpass, c.380–700 nm, see Figure 2-4 for transmittance curve). However, a narrower bandpass which would also eliminate the parasitic light at c. 420 nm would be preferable. If unavailable, an additional filter with properties similar to the Schott KV418, which cuts-on at 418 nm (see Figure 2-10 for transmittance curve) could be added to the bandpass to remove these additional wavelengths.

Kodak WRATTEN 2 Optical Filters (particularly the 2E filter) are also very commonly used as UV-blocking filters in the capture of UVL images. Kodak WRATTEN 2E is a pale yellow filter which cuts-on at c.430 nm. Although this would eliminate the parasitic light, its use is not ideal, as the longer cut-on gives images a yellow cast which must be considered when carrying out image calibration. In addition, some studies have suggested that this class of filters fade with exposure to UV (Figure 2-11) and luminesce slightly when illuminated by short-wave UV radiation and should be replaced regularly if used.
Figure 2-9. Schematic representation of the spectral output distribution (SPD) of a BLB ultraviolet light compared to the wavelength range of a CCD/CMOS sensor. Excitation: the same lamps and filters as for UVR can be used. Emission: a filter is required which will allow only light in the visible region (400-700 nm) through and block any UV or IR radiation. Shading shows wavelengths to be excluded (filtered) from the camera.

Figure 2-10. Transmittance curve of a UV-blocking filter (e.g. Schott KV418, which cuts-on at 418 nm).
Visible-induced infrared luminescence (VIL) Images

Radiation source:
The choice of the radiation source depends on the luminescence properties of the pigment under investigation. Incandescent radiation sources have been used in the investigation of cadmium-containing pigments. It should be noted that such radiation sources are very likely to emit some parasitic IR radiation and as such will require filtering.

Light emitting diodes (LEDs) have been used in the case of Egyptian blue, Han blue and Han purple. LEDs are good visible light sources that generally emit minimal amounts of infrared radiation, however the spectral distribution of LEDs should always be checked to evaluate how much, if any, infrared radiation is emitted.

Filter in front of the radiation source:
None if LEDs with spectral distributions in the visible are used.

Filter in front of the camera:
For VIL images a filter is required which will block light in the visible region (400-700 nm).

The filter selected should allow IR radiation to be collected between 700 and 1100 nm, the end of the sensitivity of most DSLR cameras but the choice of the filter depends on the type of investigation which is undertaken, as different materials have different reflective properties in the IR range. The most commonly used range is approximately between 800 and 1100 nm, which requires a filter with properties similar to the Schott glass RG830 filter (see Figure 2-6 for transmittance curve). Note that the sensitivity of the sensor drops off significantly at the extremes of its wavelength range (see Figure 2-2).

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Figure 2-11. Transmittance curve of a new (right) and well used (left) Kodak Wratten 2E filter demonstrate that these ultraviolet absorbing filters gradually lose their effectiveness and should be replaced regularly.
Figure 2-12. Schematic representation of the spectral output distribution (SPD) of a wide spectrum LED compared to the wavelength range of a CCD/CMOS sensor. Shading shows wavelengths to be excluded (filtered) in the acquisition of visible-induced infrared luminescence images.

Visible-induced visible luminescence (VIVL) Images

Radiation source:
Blue LEDs

Filter in front of radiation source:
None

Filter in front of camera:
For VIVL images a filter is required which will block blue light in the visible region as emitted by the blue LED (e.g. 400-500 nm). The filter selected should allow visible light to be collected between 500 and 700 nm, but the choice of the filter depends on the type of investigation undertaken.

Commonly used ranges in the investigations carried out to date are approximately between 520-700 nm and 475-700 nm, which requires filters with properties similar to the Lee No. 21 and Lee No. 16 filters (see Figure 2-14 and Figure 2-15 for transmittance curves). Note that an additional filter is required which will allow only light in the visible region (400-700 nm) through and block any UV or IR radiation, e.g. IDAS_UIBAR.
In addition, according to the discussion on post-processing requirements below, a visible-reflected image collected between 400-500 nm would also need to be collected. This would require a filter with properties similar to the Lee No. 47B filter (Figure 2-16), which would allow visible light to be collected between 400 and 500 nm.

Figure 2-13. Schematic representation of the spectral output distribution (SPD) of a blue LED compared to the wavelength range of a CCD/CMOS sensor. Shading shows wavelengths to be excluded (filtered) in the acquisition of visible-induced visible luminescence images.

Figure 2-14. Transmittance curve of a blue-blocking filter (e.g. Lee No. 21, which cuts-on at 560 nm). Provided by Lee Filters.
Figure 2-15. Transmittance curve of a blue-blocking filter (e.g. Lee No. 16, which cuts-on at c.545 nm). Provided by Lee Filters.

Figure 2-16. Transmittance curve of a blue bandpass filter (e.g. Lee No. 47B). Provided by Lee Filters.
iii. Standards and Calibration targets

The correction methods detailed in Chapter 1 and the workflows proposed for the development of the post-processing software, make use of a number of calibration tools in order to apply these correction procedures. These are discussed in some detail below.

– Uniform reflective board

Flat-fielding, the mathematical operation of compensating multispectral images for the spatial inhomogeneities of the radiation source and establishing uniform illumination conditions described in Chapter 1, uses an image of a uniformly reflective board to record the distribution of the radiation incident on the surface under investigation.

Ideally, such a board should be a grey Lambertian reflector: a surface showing the same radiance when viewed from any angle. However, Lambertian reflectance targets made from materials such as Spectralon which have near-perfect Lambertian diffuse reflectance can be prohibitively expensive, especially when considering that a large board is often required since:

1) The image of the board must cover the entire capture area; and
2) The board must be placed parallel to and as close to the plane of the object as possible.

Commercially available white foam board, such as Plastazote LD45 (a closed cell cross-linked polyethylene nitrogen expanded foam), which is commonly used in the storage of museum objects, can provide affordable alternatives to such products. The flexible foam board can be affixed to a rigid support of any dimensions. The foam is non-luminescent in the wavelength range investigated and any means of affixing it to a rigid support should also be tested for it luminescence properties in this region.

– Macbeth (X-Rite) ColorChecker

The colour calibration procedures for both visible-reflected and UV-induced visible luminescence images and the methods proposed for correcting reflected images for the spectral density of a radiation source, both employ existing methods based on use of a Macbeth target and an existing nip2 tool.

The X-rite ColorChecker Color Rendition Chart (often referred to by its original name, the Macbeth ColorChecker, as it was formally produced by Gretag Macbeth) is a colour calibration target consisting of a cardboard-framed arrangement of 24 squares of painted samples in a 4 × 6 grid. Six of the patches form a uniform greyscale, and another six are primary colors typical of chemical photographic processes – red, green, blue, cyan, magenta, and yellow. The remaining colors include approximations of medium light and medium dark human skin, blue sky, the front of a typical leaf, and a blue chicory flower. The rest were chosen arbitrarily to represent a gamut “of general interest and utility for test purposes”, though the orange and yellow patches are similarly colored to typical oranges and lemons.

Other such targets are available but this work is based on the use of the X-rite ColorChecker, as the nip2 software referred to above has built into it the Lab values for these patches under D50 and D65 illuminants, which it uses in carrying out the least-mean-square optimisation to produce a 3x3 matrix from camera RGB to XYZ.
The targets themselves come in a range of sizes and formats, from the full-size ColorChecker Classic (20.9 x 27.9 cm), preferable for large works, to the now discontinued ColorChecker Mini (5.7 x 8.2 cm), which has been integrated into the ColorChecker Passport\textsuperscript{24} (Figure 2-17) and is used for close-up shots or smaller works. Note that the frame of this new version exhibits luminescence, and should be masked off for use in the acquisition of luminescence images.

The manufacturer suggests that the typical lifespan of a ColorChecker target is two years. However, it is important to note that prolonged exposure of these targets to radiation, particularly UV radiation, will fade the ColorChecker patches and alter the Lab values, thus affecting the colour calibration procedure.

– Spectralon diffuse reflectance standards
The Spectralon diffuse reflectance standards referred to in Chapter 1 carry out several functions, including luminance calibration of reflected images, and detection of the presence of ambient stray radiation in luminescence images. These standards are recommended due to their durability, chemically inertness and their certified spectral flatness over the UV-VIS-NIR spectrum (Figure 2-18).
Figure 2-18. The reference grey scale (Spectralon) and their reflectance spectra. The grey scale shows constant reflectance in the UV-VIS-IR sensitivity range of a silicon-based CCD/CMOS sensor.

Spectralon diffuse reflectance standards are manufactured by Labsphere and are available individually, with typical reflectance values ranging from 2% to 99%, and are also available in sets. Although the inclusion in the frame of a number of these standards within this range is considered beneficial and would be recommended, it is realized that these are not inexpensive items. The minimum requirement in order to carry out the post-processing methods proposed is thus the 99% Spectralon diffuse reflectance standard (Figure 2-19).

Figure 2-19. The 99% Spectralon diffuse reflectance standard.

The Spectralon diffuse reflectance grey scale is not commercially available at present and is custom-made, from patches of Spectralon material from the following reflectance values (white to black); 99%, 75%, 60%, 50% 20%, 10% (two of these) and 2%.
b. Setting up equipment

Below are some very general guidelines to the setting up of equipment for multispectral imaging. Reference is made to existing manuals on the photography of works of art, in which these topics have already been dealt with in some detail.

i. Location
A designated space, preferably a studio, which can be darkened when required, is advised. Where a designated space is not available or when capturing images in the field or museum gallery, care should be taken to follow the optimised acquisition protocols as closely as possible and to accurately record the conditions under which images are captured.

ii. Positioning the object
For a general discussion and recommendations on the safe handling and positioning of objects for imaging in art historical and conservation contexts, the reader is referred to the AIC Guide to Digital Photography and Conservation Documentation and other such manuals on the photography of works of art as referenced therein.

iii. Positioning the camera and illumination sources
For guidelines on the illumination of both two- and three-dimensional objects refer to the AIC Guide to Digital Photography and Conservation Documentation and other such manuals on the photography of works of art and scientific subjects as referenced therein. In addition, the reader is referred to Lighting Methods for Photographing Museum Objects.

iv. Positioning the calibration targets
The following guidelines are offered for the positioning of the Macbeth chart or X-Rite ColorChecker and the Spectralon diffuse reflectance standards (as available):

1) These should be positioned as centrally as possible within the frame and in line with the plane of the object (in as much as is possible). The post-processing workspace includes a function, to allow for some flexibility in the choice and number of Spectralon diffuse reflectance standards (see Chapter 3). This function allows the selection of the area sampled and enables the visualisation of these areas, which gives the user greater control of what is being sampled by the program, but in order for this to be effective, the available Spectralons need to be placed in a line and equidistant from each other, as shown in Figure 2-20(b).

2) Homogeneous illumination of the ColorChecker and Spectralon diffuse reflectance standards with no shadows should be ensured.

3) If images cannot easily be placed directly in the frame, “twin images” can be acquired by taking two images under exactly the same conditions. In one of these images, the ColorChecker and Spectralon diffuse reflectance standards are held in front of the object, as shown in Figure 2-20(b), where the targets are affixed to a rigid support with Velcro. Its “twin image” is recorded without the targets (Figure 2-20(a)). This is a particularly useful approach for field work.

4) A scale can also be inserted in the image if required.
Figure 2-20. Two visible-reflected images taken under identical conditions, known as “twin images” in (a) the image is recorded without the targets and in (b) the image is recorded with an X-Rite ColorChecker and Spectralon diffuse reflectance standards are held in front of the object.

v. General camera settings
The following are meant as general guidelines, for detailed camera settings refer to the instruction manual for the camera used.

Image-recording quality and format
The images should be acquired in native digital camera RAW formats, e.g. CR2 (Canon), ERF (Epson), DCR, K25, KDC (Kodak), NEF (Nikon), ORF (Olympus), PEF (Pentax), RAF (Fuji), RW2 (Panasonic) and ARW, SRF, SR2 (Sony).

If the option to export both RAW + JPEG files is available this may also be used, but ensuring that the camera is set to save and export the RAW file is the priority.

Colour space
sRGB

White balance
By far the best white balance solution is to photograph using the RAW file format (if the camera supports this), as this allows the most flexibility in post-processing (see Chapter 3).

Camera mode
Manual mode (M)

Picture style
Turn off all default image improvements, such as sharpness, contrast, saturation, etc. If available, select Picture style ‘Neutral’.

Self-timer mode
Set the camera to timer (2 s or 10 s), to avoid camera shake during long captures. Or use the camera remote control, if available to capture the shot.
**Display mode**
Select the option to show the RGB Histogram, if this is available.

The histogram is a useful guideline to assess the exposure of an image. It is a simple graphical representation of data collected. Digital images are made up of millions of tiny square pixels. In every 8 bit digital image each pixel is assigned a brightness value between 0 and 255. The camera scans each pixel and adds up how many pixels there are at each brightness level. Then it translates that into a frequency graph called a histogram. On the horizontal axis 0 at the left of the histogram represents pure black and 255 at the right is pure white. The vertical axis shows the number of pixels recorded at that brightness value or frequency. The more pixels at a specific brightness value, the higher the line.

It should be noted however, that the on-camera histogram shows the histogram of the in-camera conversion to JPEG (see Chapter 3) and not that pertaining to the RAW data, and as most cameras apply a fairly strong S-curve to the RAW data so that the JPEGs have a more film-like response, the result is that the on-camera histogram often suggests that the highlights in the image are saturated when, in fact, they are still comfortably in the range.31

**Summary**

<table>
<thead>
<tr>
<th>General camera settings:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Image-recording format</strong></td>
</tr>
<tr>
<td><strong>Image quality (bit depth)</strong></td>
</tr>
<tr>
<td><strong>Colour space</strong></td>
</tr>
<tr>
<td><strong>White balance</strong></td>
</tr>
<tr>
<td><strong>Camera mode</strong></td>
</tr>
<tr>
<td><strong>Picture style (if available)</strong></td>
</tr>
<tr>
<td><strong>Self-timer mode</strong></td>
</tr>
<tr>
<td><strong>Display mode</strong></td>
</tr>
</tbody>
</table>

vi. **Exposure settings**

The settings for the following parameters determine the exposure of the image and will depend on the type of object being imaged and the type of imaging being carried out. Exposure is determined by three camera settings: ISO speed, aperture (F-stop), and shutter speed (the "exposure triangle"). Below are some general guidelines on setting these parameters, for more information the reader is referred to designated texts or websites on photographic techniques and concepts.32
In most real world situations there is no such thing as an ideal or “perfect” exposure. There is simply a combination of settings that places the tonal values found in the scene most appropriately within the capability range of the camera sensor, i.e. the mid-tones found in the image fall roughly half way between the darkest and the brightest values.

**ISO Speed**
The ISO speed determines how sensitive the camera is to incoming light and correlates 1:1 with how much the exposure increases or decreases. Common ISO speeds include 100, 200, 400 and 800, although many cameras also permit lower or higher values. With DSLR cameras, an ISO speed in the range of 50 - 800 (or higher) generally produces acceptably low image noise. A lower ISO speed is almost always desirable, since higher ISO speeds dramatically increase image noise. As a result, ISO speed is usually only increased from its minimum value if the desired aperture and shutter speed aren't otherwise obtainable.

An ISO speed of 100 or lowest setting available is recommended.

**Aperture (F-stop)**
This parameter determines the aperture size and depth of field. An important consideration given the dimensionality of the object being imaged, e.g.:
- Lower F-stop/wide aperture/shallow depth of field: fine for flat or 2D objects.
- Higher F-stop/narrow aperture/larger depth of field: may be more appropriate for 3D objects, e.g. sculpture or reliefs.

In general, in order to maximise depth of field, it is useful to consider the closest and furthest parts of the object which must be in focus. The plane of focus of the lens is then set a third of the way from the closest point. If possible, calibration targets should be positioned on this plane to aid focussing.

In addition, the sensitivity of the sensor to the wavelength of the incoming radiation will be a determining factor in choosing an aperture setting, e.g. the low sensitivity of camera sensors to UV radiation will usually require the use of large apertures (low f-stop number).

**Shutter speed (exposure time)**
This parameter determines the duration of the exposure or how long the camera shutter will be open or closed to incoming light from the camera lens. The influence of shutter speed on exposure correlates exactly 1:1 with the amount of light entering the camera. For example, when the exposure time doubles the amount of light entering the camera doubles. A faster shutter speed equates to shorter exposure time.

Specific settings will be dependent on the sensitivity of the sensor to the wavelength of the incoming radiation, the aperture setting chosen and the type of radiation source (i.e. continuous vs. pulsed).
Summary

**General exposure settings:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ISO Speed</strong></td>
<td>Lowest possible e.g. 100</td>
</tr>
<tr>
<td><strong>Aperture (F-stop)</strong></td>
<td>Dependent on the dimensionality of the object and the sensitivity of the sensor to the wavelength of the incoming radiation</td>
</tr>
<tr>
<td><strong>Shutter Speed (exposure time)</strong></td>
<td>Dependent on the sensitivity of the sensor to the wavelength of the incoming radiation, the aperture setting chosen and the type of radiation source</td>
</tr>
<tr>
<td><strong>Exposure compensation</strong></td>
<td>None</td>
</tr>
</tbody>
</table>
c. Image Capture

The optimised and standardised acquisition protocols for the capture of reflected and photo-induced luminescence images resulting from the iterative process described in Chapter 1 are detailed in the following sections. In formulating these protocols, the sequence in which each of the image sets are captured was also considered in order to facilitate workflow, but also to ensure that all the post-processing requirements for each image set were collected. By comparing the equipment and post-processing requirements for each of the imaging techniques (Table 2-2), it can be observed that these divide themselves into a number of natural groups. The equipment requirements column only notes the light sources and the filters used, as all the other equipment is used in all of the techniques, but it is evident that pairing the techniques which use the same light sources is an efficient way of proceeding. In addition, the post-processing requirements column notes the images employed by each image correction procedure and highlights the order in which the workflows should be completed to ensure that the post-processing requirements for each workflow are met. These considerations have resulted in the recommended sequence shown in Table 2-2.

The reproducibility of the images obtained has been at the forefront of the development of the acquisition protocols. An important step towards such reproducibility is the recording of all aspects of the experimental set-up and parameters used, in order that these may be referred to for images taken both within the same institution by different users or at different points in time and between institutions. The metadata to accompany the image sets acquired should include the following for each of the workflows:

1) Information on the illumination conditions used, namely:
   (a) Make, model and spectral output distribution of the radiation sources;
   (b) Distance between the object and the radiation sources;
   (c) Height of the radiation sources;
   (d) Angle between the normal to the object and the direction of the incident radiation;
   (e) Irradiance (as a setting or light meter measurement);
   (f) Colour temperature;
2) The make and model of the camera and lenses used and any modifications made to this equipment;
3) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.

And for each frame taken this should additionally include:
4) The ISO speed chosen;
5) The aperture value (F-stop) used;
6) The shutter speed (exposure time);
7) Any white balance settings used;
8) The number of that frame in the series.

These are included as a checklist at the end of each image capture workflow. Additionally, the frame should be the same for all technical images, as this will facilitate the processing and comparison of the multispectral image set.
Table 2-2. Comparison of equipment and post-processing requirements for each of the imaging techniques and the sequence recommended for their capture.

<table>
<thead>
<tr>
<th>Equipment requirements</th>
<th>Post-processing requirements (Images only)</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible-reflected (VIS) Images</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Visible/IR radiation sources</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Visible bandpass filter (e.g. IDAS_UIBAR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Infrared-reflected (IRR) Images</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Visible/IR radiation sources</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>• UV/Visible-blocking filter (e.g. Schott RG830)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UV-reflected (UVR) Images</strong></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>• UV radiation sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• UV bandpass filter (e.g. DUG 11X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UV-induced visible luminescence (UVL) Images</strong></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>• UV radiation sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• UV-blocking filter (e.g. Schott KV418 + IDAS_UIBAR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Visible-induced infrared luminescence (VIL) Images</strong></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>• LED light sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• UV/Visible-blocking filter (e.g. Schott RG830)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Visible-induced visible luminescence (VIVL) Images</strong></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>• LED light sources (Blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Blue-blocking filter (e.g. Lee No. 16 or Lee No. 21)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**d. Capturing Reflected Images**

**i. Visible-reflected Images**

The workflow shown in Figure 2-21 summarises the corrections proposed as a result of the discussions in Chapter 1 and also highlights the general transformations to be carried out by the post-processing software.

![Workflow schematic](image)

*Figure 2-21. Schematic of the workflow proposed for visible-reflected images.*

The requirements in order to carry out the image correction procedure are as follows:

1) The camera output file, i.e. the visible-reflected image;
2) The ICC profile (which records all the metadata including the gamma correction applied to the image. This describes and is created on the conversion from RAW into a standard 16-bit TIFF file, see Chapter 3). This profile is contained within the TIFF file and is automatically retrieved by the post-processing software;
3) An image of a uniform reflective board under the same experimental conditions for flat fielding, if available;
4) An image of a Macbeth chart for colour calibration, included as part of the image to be calibrated or in another image taken with the same camera and lighting conditions;
5) An image of a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or in another image taken with the same camera and lighting conditions). Required for comparison to IRR/UVR images and post-processing of luminescence images.

A workflow has been developed to ensure that these requirements are collected according to the optimised and standardised acquisition protocols. The instructions below describe the workflow for the capture of visible-reflected images. A checklist of the requirements for the image correction procedure is included at the end of the workflow.
Workflow for the capture of visible-reflected (VIS) images

**Equipment requirements:**
- Camera
- Visible/IR radiation sources
- Visible bandpass filter (e.g. IDAS/UIBAR)
- Macbeth colour chart (X-Rite ColourChecker)
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (required for comparison to IRR/UVR images and post-processing of luminescence images).

**Set-up**

1) Position the visible/IR radiation sources and the camera as shown in Figure 2-22 and according to the recommendations in section b.

![Figure 2-22](image)

2) Place the visible band-pass filter (e.g. IDAS/UIBAR) in front of the camera.

3) If working in the studio, position the object following the recommendations referred to in section b.

4) If working outside the studio or in the field, position the visible/IR radiation sources and the camera around the subject accordingly.
5) If site constraints allow, position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) If working outside the studio or in the field, use the recommended procedure of “twin” images, described in section b.

7) Turn on the visible/IR radiation sources and ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

8) If using flashes, set these to their lowest setting and check that these are synchronised with the camera. The room lights overhead may remain on.

9) If using continuous radiation sources such as tungsten lamps, turn the room lights off now.

### Camera capture settings

10) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

### Exposure settings

11) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

12) Particular recommendations for acquiring visible-reflected images:
   (a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b;
   (b) The high irradiance of visible/IR radiation sources usually allows the use of smaller apertures (high f-stop number), especially if using flashes;
   (c) Shutter speed will vary according to whether continuous radiation sources or flashes are used but can generally be quite short (e.g. 1/8 sec for continuous sources and 1/200 for flashes). Adjust this as required for correct exposure.

### Obtain an image of the uniform reflective board (If site constraints allow)

13) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

14) Focus on the board. Defocus slightly. Take the image.

15) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-23) in playback mode are a good indicator but note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).
(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   – Move the light sources further away from the subject
   – Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**White balance**

16) Note that the image of the uniform reflective board can also be set as the custom white balance if required. Follow the manufacturer’s instructions for the camera model in use.

17) Otherwise the white balance can be set to a camera standard preset corresponding to the illumination source being used, (e.g Tungsten). Note that the correct setting here is not crucial as this can always be modified in post-processing (see Chapter 3).

**Obtain the visible-reflected image**

18) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

19) If using the live view mode, adjust the focus by zooming all the way into the frame.

20) Take the image.

**Evaluate the visible-reflected image**

21) Check the framing by looking at the image in playback mode.

22) Check the focus by zooming into the image in playback mode.

23) Check the exposure by ensuring that the white patches on the Macbeth colour chart and the Spectralon diffuse reflectance standards are not saturated. If any of these are saturated either:
   (a) Move the light sources further away from the subject; or
   (b) Stop down the aperture (increase the f-stop number)

   Retake the image until it is not saturated, and if the lighting conditions or geometry have changed, retake the image of the uniform reflective board under these conditions.

24) Check the tonal range by checking the image histogram in playback mode.
Record the metadata for the visible-reflected workflow and image(s)

25) Record the following information for the workflow:
   (a) Information on the illumination conditions used, namely:
       – Make, model and spectral output distribution of the radiation sources;
       – Distance between the object and the radiation sources;
       – Height of the radiation sources;
       – Angle between the normal to the object and the direction of the incident radiation;
       – Irradiance (as a setting or light meter measurement);
       – Colour temperature;
   (b) The make and model of the camera and lenses used and any modifications made to this equipment;
   (c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.

26) Additionally, record the following information for each image:
   (a) ISO speed;
   (b) Aperture value (F-stop);
   (c) Shutter speed (exposure time);
   (d) White balance settings (if any used);
   (e) Number of the frame in series.

Checklist:

| ✔ | Camera output file (TIFF) – Visible-reflected image. |
|   | ICC profile for conversion from RAW (contained within the TIFF file). |
|   | Image of uniform reflective board under experimental conditions for flat fielding. |
|   | Image of Macbeth chart for colour calibration (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions). |
|   | Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions). |
ii. Infrared-reflected Images

The workflow shown in Figure 2-24 summarises the corrections proposed as a result of the discussions in Chapter 1 and also highlights the general transformations to be carried out by the post-processing software.

![Figure 2-24. Schematic of the workflow proposed for infrared-reflected images.](image)

The requirements in order to carry out the image correction procedure are as follows and are included as a checklist at the end of the image capture workflow (see below):

1) The camera output file, i.e. the infrared-reflected image;
2) The ICC profile (which records all the metadata including the gamma correction applied to the image. This describes and is created on the conversion from RAW into a standard 16-bit TIFF file, see Chapter 3). This profile is contained within the TIFF file and is automatically retrieved by the post-processing software;
3) An image of a uniform reflective board under the same experimental conditions for flat fielding, if available;
4) An image of a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions);
5) A visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above).

A workflow has been developed to ensure that these requirements are collected according to the optimised and standardised acquisition protocols. The instructions below describe the workflow for the capture of infrared-reflected images.
Workflow for the capture of infrared-reflected (IRR) images

**Equipment requirements:**
- Camera
- Visible/IR radiation sources
- UV/Visible-blocking filter (e.g. Schott RG830)
- Macbeth colour chart (not required but remains in the shot from previous image for continuity)
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.

**Set-up**

1) Position the visible/IR radiation sources and the camera as shown in Figure 2-25 and according to the recommendations in section b.

![Figure 2-25](image)

2) Place the UV/visible-blocking filter (e.g. Schott RG830) in front of the camera.

3) If working in the studio, position the object following the recommendations referred to in section b.

4) If working outside the studio or in the field, position the visible/IR radiation sources and the camera around the subject accordingly.
5) If site constraints allow, position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) If working outside the studio or in the field, use the recommended procedure of “twin” images, described in section b.

7) Turn on the visible/IR light sources and ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

8) If using flashes, set these to their highest setting and check that these are synchronized with the camera. The room lights overhead may remain on.

9) If using continuous light sources such as tungsten lamps, turn the room lights off now.

**Camera capture settings**

10) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

**Exposure settings**

11) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

12) Particular recommendations for acquiring IR-reflected images:
   (a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b;
   (b) The high irradiance of visible/IR radiation sources usually allows the use of smaller apertures (high f-stop number), especially if using flashes;
   (c) Shutter speed will vary according to whether continuous radiation sources or flashes are used but can generally be quite short (e.g. 1/8 sec for continuous sources and 1/200 for flashes). Adjust this as required for correct exposure.

**Obtain an image of the uniform reflective board (if site constraints allow)**

13) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

14) Focus on the board. Defocus slightly. Take the image.

15) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-26) in playback mode are a good indicator. Note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).
(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   – Move the radiation sources further away from the subject
   – Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**White balance**

16) Note that the image of the uniform reflective board can also be set as the custom white balance if required. Follow the manufacturer’s instructions for the camera model in use.

17) Otherwise the white balance can be set to a camera standard preset corresponding to the illumination source being used, (e.g Tungsten). Note that the correct setting here is not crucial as this can always be modified in post-processing (see Chapter 3).

**Obtain the infrared-reflected image**

18) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

19) If using the live view mode, adjust the focus by zooming all the way into the frame. It may be useful to use an incandescent torch to illuminate the object whilst focussing as depending on the aperture setting, the image on screen can appear quite dark when the visible-blocking filter is in front of the lens.

20) Take the image.

**Evaluate the infrared-reflected image**

21) Check the framing by looking at the image in playback mode.

22) Check the focus by zooming into the image in playback mode.

23) Check the exposure by ensuring that the white patches on the Spectralon diffuse reflectance standards are not saturated. If any of these are saturated either:
   (a) Move the radiation sources further away from the subject; or
   (b) Stop down the aperture (increase the f-stop number).
   Retake the image until it is not saturated and if the lighting conditions or geometry have changed, retake the image of the uniform reflective board under these conditions.

24) Check the tonal range by checking the image histogram in playback mode.
Record the metadata for the infrared-reflected workflow and image(s)

25) Record the following information for the workflow:
   (a) Information on the illumination conditions used, namely:
       – Make, model and spectral output distribution of the radiation sources;
       – Distance between the object and the radiation sources;
       – Height of the radiation sources;
       – Angle between the normal to the object and the direction of the incident radiation;
       – Irradiance (as a setting or light meter measurement);
       – Colour temperature;
   (b) The make and model of the camera and lenses used and any modifications made to this equipment;
   (c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera

26) Additionally, record the following information for each image:
   (a) ISO speed;
   (b) Aperture value (F-stop);
   (c) Shutter speed (exposure time);
   (d) White balance settings (if any used);
   (e) Number of the frame in series.

**Checklist:**

<table>
<thead>
<tr>
<th></th>
<th>Camera output file (TIFF) – Infrared-reflected image.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC profile for conversion from RAW (contained within the TIFF file).</td>
</tr>
<tr>
<td></td>
<td>Image of uniform reflective board under experimental conditions for flat fielding.</td>
</tr>
<tr>
<td></td>
<td>Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions).</td>
</tr>
</tbody>
</table>

**Additional requirements from other imaging workflows:**

<table>
<thead>
<tr>
<th></th>
<th>Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image.</td>
</tr>
</tbody>
</table>
iii. **UV-reflected Images**

The workflow shown in Figure 2-27 summarises the corrections proposed as a result of the discussions in Chapter 1 and also highlights the general transformations to be carried out by the post-processing software.

![Workflow Diagram](image)

**Figure 2-27. Schematic of the workflow proposed for UV-reflected images.**

The requirements in order to carry out the image correction procedure are as follows and are included as a checklist at the end of the image capture workflow (see below):

1) The camera output file, i.e. the UV-reflected image;
2) The ICC profile (which records all the metadata including the gamma correction applied to the image. This describes and is created on the conversion from RAW into a standard 16-bit TIFF file, see Chapter 3). This profile is contained within the TIFF file and is automatically retrieved by the post-processing software;
3) An image of a uniform reflective board under the same experimental conditions for flat fielding, if available;
4) An image of a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions);
5) A visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above).
A workflow has been developed to ensure that these requirements are collected according to the optimised and standardised acquisition protocols. The instructions below describe the workflow for the capture of Infrared-reflected images.

**Workflow for the capture of UV-reflected (UVR) images**

**Equipment requirements:**
- Camera
- UV radiation sources
- UV bandpass filter (e.g. DUG 11X)
- UV safety glasses
- Macbeth colour chart (not required but remains in the shot from previous image for continuity)
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.

**Set-up**

1) Position the UV radiation sources and the camera as shown in Figure 2-28 and according to the recommendations in section b.

![Figure 2-28](image)

2) Place the UV bandpass filter (e.g. DUG 11X) in front of the camera.

3) If working in the studio, position the object following the recommendations referred to in section b.
4) If working outside the studio or in the field, position the UV radiation sources and the camera around the subject accordingly.

5) Position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) Put on UV safety glasses.

7) Turn on the UV radiation sources and allow them to warm up for 20 mins.

8) Turn the room lights off.

9) Ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

### Camera capture settings

10) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

### Exposure settings

11) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

12) Particular recommendations for acquiring UV-reflected images:

   a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b.

   b) The low sensitivity of camera sensors to UV radiation usually means the use of large apertures (low f-stop number).

   c) As a result of this limited sensor sensitivity, shutter speed will generally be quite long (e.g. 1 sec). Adjust this as required for correct exposure.

### Obtain an image of the uniform reflective board

13) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

14) Focus on the board. Defocus slightly. Take the image.

15) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-29) in playback mode are a good indicator but note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).
(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   - Move the radiation sources further away from the subject
   - Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**White balance**

16) Note that the image of the uniform reflective board can also be set as the custom white balance if required. Follow the manufacturer’s instructions for the camera model in use.

17) Otherwise the white balance can be set to a camera standard preset corresponding to the illumination source being used, (e.g 6500K or equivalent). Note that the correct setting here is not crucial as this can always be modified in post-processing (see Chapter 3).

**Obtain the UV-reflecte image**

18) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

19) If using the live view mode, adjust the focus by zooming all the way into the frame. It may be useful to use a UV LED torch to illuminate the object whilst focussing as the image on screen can appear quite dark when the UV bandpass filter is in front of the lens.

20) Take the image.

**Evaluate the UV-reflecte image**

21) Check the framing by looking at the image in playback mode.

22) Check the focus by zooming into the image in playback mode.

23) Check the exposure.

24) Check the tonal range by checking the image histogram in playback mode.
### Record the metadata for the UV-reflected workflow and image(s)

25) Record the following information for the workflow:

   (a) Information on the illumination conditions used, namely:
       - Make, model and spectral output distribution of the radiation sources;
       - Distance between the object and the radiation sources;
       - Height of the radiation sources;
       - Angle between the normal to the object and the direction of the incident radiation;
       - Irradiance (as a setting or light meter measurement);
       - Colour temperature;

   (b) The make and model of the camera and lenses used and any modifications made to this equipment;

   (c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.

26) Additionally, record the following information for each image:

   (a) ISO speed;
   (b) Aperture value (F-stop);
   (c) Shutter speed (exposure time);
   (d) White balance settings (if any used);
   (e) Number of the frame in series.

### Checklist:

| ✓ | Camera output file (TIFF) – UV-reflected image. |
|   | ICC profile for conversion from RAW (contained within the TIFF file). |
|   | Image of uniform reflective board under experimental conditions for flat fielding. |
|   | Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions). |

### Additional requirements from other imaging workflows:

| Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above). |
| Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image. |
e. Capturing Photo-induced Luminescence Images

iv. UV-induced Visible Luminescence (UVL) Images

The workflow shown in Figure 2-30 summarises the corrections proposed as a result of the discussions in Chapter 1 and also highlights the general transformations to be carried out by the post-processing software.

![Workflow Diagram](image)

**Figure 2-30. Schematic of the workflow proposed for UV-induced visible luminescence images.**

The requirements in order to carry out the image correction procedure are as follows and are included as a checklist at the end of the image capture workflow (see below):

1) The camera output file, i.e. UV-induced visible luminescence image;
2) The ICC profile (which records all the metadata including the gamma correction applied to the image. This describes and is created on the conversion from RAW into a standard 16-bit TIFF file, see Chapter 3). This profile is contained within the TIFF file and is automatically retrieved by the post-processing software;
3) An image of a uniform reflective board under the same experimental conditions for flat fielding;
4) An image of a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions);
5) A visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above);
6) Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image;
7) A UV-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section iii (See above);
8) Image of uniform reflective board under experimental conditions for flat fielding the UV-reflected image.

A workflow has been developed to ensure that these requirements are collected according to the optimised and standardised acquisition protocols. The instructions below describe the workflow for the capture of UV-induced visible luminescence images.

### Workflow for the capture of UV-induced visible luminescence (UVL) images

#### Equipment requirements:
- Camera
- UV radiation sources
- UV safety glasses
- UV-blocking filter (e.g. Schott KV418 + IDAS-UIBAR)
- Macbeth colour chart (not required but remains in the shot from previous image for continuity/image registration)
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.

#### Set-up

1) Position the UV radiation sources and the camera as shown in Figure 2-31 and according to the recommendations in section b.

2) Place the UV-blocking filter(s) (e.g. Schott KV418 + IDAS-UIBAR) in front of the camera.
3) If working in the studio, position the object following the recommendations referred to in section b.

4) If working outside the studio or in the field, position the UV radiation sources and the camera around the subject accordingly.

5) Position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) Put on UV safety glasses.

7) Turn on the UV radiation sources and allow them to warm up for 20 mins if not already on from the previous workflow).

8) Turn the room lights off.

9) Ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

**Camera capture settings**

10) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

**Exposure settings**

11) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

12) Particular recommendations for acquiring UV-induced visible luminescence images:

   (a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b.

   (b) Aperture settings will be dependent on the intensity of the luminescence emitted, which will in turn be dependent on the nature of the material being examined. For weakly emitting cases, large apertures (low f-stop number) may be required.

   (c) Shutter speed will generally be quite long (e.g. 1 sec) but will again be dependent on the intensity of the luminescence emitted. Adjust this as required for correct exposure.

**Obtain an image of the uniform reflective board**

13) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

14) Focus on the board. Defocus slightly. Take the image.
15) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-32) in playback mode are a good indicator but note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).

(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   – Move the radiation sources further away from the subject
   – Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**White balance**

16) Set the white balance to 6500K (or equivalent). Follow the manufacturer’s instructions for the camera model in use.

**Obtain the UV-induced visible luminescence image**

17) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

18) If using the live view mode, adjust the focus by zooming all the way into the frame. It may be useful to use a UV LED torch to illuminate the object whilst focussing as the image on screen can appear quite dark.

19) Take the image.

**Evaluate the UV-induced visible luminescence image**

20) Check the framing by looking at the image in playback mode.

21) Check the focus by zooming into the image in playback mode.

22) Check the exposure.

23) Check the tonal range by checking the image histogram in playback mode.

**Record the metadata for the UV-induced visible luminescence workflow and image(s)**

24) Record the following information for the workflow:
   (a) Information on the illumination conditions used, namely:
       – Make, model and spectral output distribution of the radiation sources;
       – Distance between the object and the radiation sources;
       – Height of the radiation sources;
– Angle between the normal to the object and the direction of the incident radiation;
– Irradiance (as a setting or light meter measurement);
– Colour temperature;

(b) The make and model of the camera and lenses used and any modifications made to this equipment;
(c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.

25) Additionally, record the following information for each image:
(a) ISO speed;
(b) Aperture value (F-stop);
(c) Shutter speed (exposure time);
(d) White balance settings (if any used);
(e) Number of the frame in series.

**Checklist:**

| ✓ | Camera output file (TIFF) – UV-induced visible luminescence image. |
| ICC profile for conversion from RAW (contained within the TIFF file). |
| Image of uniform reflective board under experimental conditions for flat fielding. |
| Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions). |

**Additional requirements from other imaging workflows:**

| Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above). |
| Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image. |
| UV-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section iii (See above). |
| Image of uniform reflective board under experimental conditions for flat fielding the UV-reflected image. |
v. **Visible-induced Infrared Luminescence (VIL) Images**

The workflow shown in Figure 2-33 summarises the corrections proposed as a result of the discussions in Chapter 1 and also highlights the general transformations to be carried out by the post-processing software.

![Figure 2-33. Schematic of the workflow proposed for Visible-induced infrared luminescence images.](image)

The requirements in order to carry out the image correction procedure are as follows and are included as a checklist at the end of the image capture workflow (see below):

1) The camera output file, i.e. Visible-induced infrared luminescence image;
2) The ICC profile (which records all the metadata including the gamma correction applied to the image. This describes and is created on the conversion from RAW into a standard 16-bit TIFF file, see Chapter 3). This profile is contained within the TIFF file and is automatically retrieved by the post-processing software;
3) An image of a uniform reflective board under the same experimental conditions for flat fielding, if available;
4) An image of a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated) or another image taken with the same camera and lighting conditions;
5) A visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above);
6) Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image;
7) An IR-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section ii (See above);
8) Image of uniform reflective board under experimental conditions for flat fielding the IR-reflected image.
A workflow has been developed to ensure that these requirements are collected according to the optimised and standardised acquisition protocols. The instructions below describe the workflow for the capture of visible-induced infrared luminescence images.

**Workflow for the capture of visible-induced infrared luminescence (VIL) images**

**Equipment requirements:**
- Camera
- LED light sources
- UV/Visible-blocking filter (e.g. Schott RG830)
- Macbeth colour chart (not required but remains in the shot from previous image for continuity/image registration)
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.

**Set-up**

1) Position the LED light sources and the camera as shown in Figure 2-34 and according to the recommendations in section b.

![Figure 2-34](image)

2) Place the UV/visible-blocking filter (e.g. Schott RG830) in front of the camera.

3) If working in the studio, position the object following the recommendations referred to in section b.
4) If working outside the studio or in the field, position the visible light sources and the camera around the subject accordingly.

5) Position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) Turn on the LED light sources.

7) Turn the room lights off.

8) Ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

---

**Camera capture settings**

9) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

---

**Exposure settings**

10) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

11) Particular recommendations for acquiring visible-induced IR luminescence images:

   (a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b.

   (b) Aperture settings will be dependent on the intensity of the luminescence emitted, which will in turn be dependent on the nature of the material being examined. For weakly emitting cases, large apertures (low f-stop number) may be required.

   (c) Shutter speed will generally be quite long (e.g. 1 sec) but will again be dependent on the intensity of the luminescence emitted. Adjust this as required for correct exposure.

---

**Obtain an image of the uniform reflective board**

12) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

13) Focus on the board. Defocus slightly. Take the image.

14) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-35) in playback mode are a good indicator but note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).
(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   – Move the light sources further away from the subject
   – Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**Figure 2-35**

**White balance**

15) Note that the image of the uniform reflective board can also be set as the custom white balance if required. Follow the manufacturer’s instructions for the camera model in use.

16) Otherwise the white balance can be set to a camera standard preset corresponding to the illumination source being used. Note that the correct setting here is not crucial as this can always be modified in post-processing (see Chapter 3).

**Obtain the visible-induced infrared luminescence image**

17) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

18) If using the live view mode, adjust the focus by zooming all the way into the frame. It may be useful to use an incandescent torch to illuminate the object whilst focussing as the image on screen can appear quite dark when the visible-blocking filter is in front of the lens.

19) Take the image.

**Evaluate the visible-induced infrared luminescence image**

20) Check the framing by looking at the image in playback mode.

21) Check the focus by zooming into the image in playback mode.

22) Check the exposure by ensuring that the white patches on the Spectralon diffuse reflectance standards are not saturated. If any of these are saturated either:
   (a) Move the light sources further away from the subject; or
   (b) Stop down the aperture (increase the f-stop number).

   Retake the image until it is not saturated and if the lighting conditions or geometry have changed, retake the image of the uniform reflective board under these conditions.

23) Check the tonal range by checking the image histogram in playback mode.
Record the metadata for the visible-induced infrared luminescence workflow and image(s)

24) Record the following information for the workflow:
   (a) Information on the illumination conditions used, namely:
       – Make, model and spectral output distribution of the radiation sources;
       – Distance between the object and the radiation sources;
       – Height of the radiation sources;
       – Angle between the normal to the object and the direction of the incident radiation;
       – Irradiance (as a setting or light meter measurement);
       – Colour temperature;
   (b) The make and model of the camera and lenses used and any modifications made to this equipment;
   (c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.

25) Additionally, record the following information for each image:
   (a) ISO speed;
   (b) Aperture value (F-stop);
   (c) Shutter speed (exposure time);
   (d) White balance settings (if any used);
   (e) Number of the frame in series.

**Checklist:**

| ✔ | Camera output file (TIFF) – visible-induced infrared luminescence image. |
| ICC profile for conversion from RAW (contained within the TIFF file). |
| Image of uniform reflective board under experimental conditions for flat fielding. |
| Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions). |

**Additional requirements from other imaging workflows:**

| Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (See above). |
| Image of uniform reflective board under experimental conditions for flat fielding the visible-reflected image. |
| IR-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section ii (See above). |
| Image of uniform reflective board under experimental conditions for flat fielding the IR-reflected image. |
vi. Visible-induced Visible Luminescence (VIVL) Images

The correction of visible-induced visible luminescence images has not been included within the scope of this work. However, as discussed in Chapter 1, it is envisaged that a workflow based on that for UV-induced visible luminescence images could be adapted for use for the correction of this image type.

As a result, a workflow has been developed to not only collect these images according to optimised and standardised acquisition protocols but also to ensure that the requirements for any future development of post-processing strategies for this image type along the lines discussed would be satisfied.

In addition to the visible-induced visible luminescence image, the requirements in order to carry out the image correction procedure for factors discussed in Chapter 1 would be as follows:

1) Correction for the spatial inhomogenities of the radiation source would require an image of a uniform reflective board under the same experimental conditions as the visible-induced visible luminescence image for flat fielding;

2) Correction for camera response;

3) Correction for ambient stray radiation would require a reflected image in the same spectral region as the luminescence image, i.e. a visible-reflected image collected between 500-700 nm, although the exact range would be dependent on the visible-blocking filter selected;

4) Correction for the “pigment-binder” interaction would require the above-mentioned image plus a reflected image in the spectral range in which the luminescence of interest was induced i.e. a visible-reflected image collected between 400-500 nm, although the exact range would be dependent on the visible-blocking filter selected.

These requirements are included as a checklist at the end of the image capture workflow for reference.

The instructions below describe the workflow for the capture of visible-induced visible luminescence images.
**Workflow for the capture of visible-induced visible luminescence (VIVL) images**

**Equipment requirements:**
- Camera
- LED light sources
- Blue-blocking filter (e.g. Lee No. 16 or Lee No. 21)
- Visible bandpass filter (e.g. IDAS-UIBAR)
- Macbeth colour chart
- Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.

**Set-up**

1) Position the LED light sources and the camera as shown in Figure 2-36 and according to the recommendations in section b.

![Diagram of VIVL setup](image)

2) Place the blue-blocking and bandpass filters (e.g. Lee No. 16 or Lee No. 21 and IDAS-UIBAR) in front of the camera.

3) If working in the studio, position the object following the recommendations referred to in section b.

4) If working outside the studio or in the field, position the LED light sources and the camera around the subject accordingly.
5) Position the reference standards as recommended in section b. A scale may also be inserted in the image if required.

6) Turn on the LED light sources. Switch to blue light if using a switchable source.

7) Turn the room lights off.

8) Ensure that both the subject and reference standards are evenly illuminated, checking with a light meter if preferred.

**Camera capture settings**

9) Camera settings will vary according to the equipment used but some general camera settings are recommended in section b.

**Exposure settings**

10) The exact exposure settings will vary with the equipment used but some general exposure recommendations were made in section b.

11) Particular recommendations for acquiring visible-induced visible luminescence images:

   (a) Aperture settings in the middle of your lens range (e.g. f8) are usually a good starting point for maximum sharpness, but choose depth of field according to dimensionality of subject, as advised in section b.

   (b) Aperture settings will be dependent on the intensity of the luminescence emitted, which will in turn be dependent on the nature of the material being examined. For weakly emitting cases, large apertures (low f-stop number) may be required.

   (c) Shutter speed will generally be quite long (e.g. 1 sec) but will again be dependent on the intensity of the luminescence emitted. Adjust this as required for correct exposure.

**Obtain an image of the uniform reflective board**

12) Place the uniform reflective board so that it is evenly illuminated and fills the frame of the camera. As far as possible the board should be in the same plane as the subject so that the illumination on it is representative of the illumination on the object.

13) Focus on the board. Defocus slightly. Take the image.

14) Check the image exposure. The RGB values of the image on the image histogram (Figure 2-37) in playback mode are a good indicator but note that these values pertain to the preview JPEG generated by the camera not the RAW data (see Chapter 3).
(a) The RGB values must not exceed 255 grey levels.
(b) If any of the pixels are saturated either:
   – Move the light sources further away from the subject
   – Stop down the aperture (increase the f-stop number)
(c) Retake the image until it is not saturated.
(d) Note that if the lighting conditions or geometry change, this image should be retaken.

**White balance**

15) Set the white balance to 6500K (or equivalent). Follow the manufacturer’s instructions for the camera model in use.

**Obtain the visible-induced visible luminescence image**

16) Set up the image by using either the eyepiece or preferably the live view mode on the screen if this is available.

17) If using the live view mode, adjust the focus by zooming all the way into the frame. It may be useful to use an incandescent torch to illuminate the object whilst focussing as the image on screen can appear quite dark when the visible-blocking filter is in front of the lens.

18) Take the image.

**Evaluate the visible-induced visible luminescence image**

19) Check the framing by looking at the image in playback mode.

20) Check the focus by zooming into the image in playback mode.

21) Check the exposure by ensuring that the white patches on the Spectralon diffuse reflectance standards are not saturated. If any of these are saturated either:
   (a) Move the light sources further away from the subject; or
   (b) Stop down the aperture (increase the f-stop number)
   Retake the image until it is not saturated and if the lighting conditions or geometry have changed, retake the image of the uniform reflective board under these conditions.

22) Check the tonal range by checking the image histogram in playback mode.
Record the metadata for the visible-induced visible luminescence workflow and image(s)

<table>
<thead>
<tr>
<th>Record the following information for the workflow:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Information on the illumination conditions used, namely:</td>
</tr>
<tr>
<td>– Make, model and spectral output distribution of the radiation sources;</td>
</tr>
<tr>
<td>– Distance between the object and the radiation sources;</td>
</tr>
<tr>
<td>– Height of the radiation sources;</td>
</tr>
<tr>
<td>– Angle between the normal to the object and the direction of the incident radiation;</td>
</tr>
<tr>
<td>– Irradiance (as a setting or light meter measurement);</td>
</tr>
<tr>
<td>– Colour temperature;</td>
</tr>
<tr>
<td>(b) The make and model of the camera and lenses used and any modifications made to this equipment;</td>
</tr>
<tr>
<td>(c) The make, model and transmittance characteristics of the filter or filter sets used, both in front of radiation source and in front of the camera.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additionally, record the following information for each image:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) ISO speed;</td>
</tr>
<tr>
<td>(b) Aperture value (F-stop);</td>
</tr>
<tr>
<td>(c) Shutter speed (exposure time);</td>
</tr>
<tr>
<td>(d) White balance settings (if any used);</td>
</tr>
<tr>
<td>(e) Number of the frame in series.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Checklist:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Camera output file (TIFF) – visible-induced visible luminescence image (500-700 nm, exact range dependent on filter selected).</td>
</tr>
<tr>
<td>ICC profile for conversion from RAW (contained within the TIFF file).</td>
</tr>
<tr>
<td>Image of uniform reflective board under experimental conditions for flat fielding.</td>
</tr>
<tr>
<td>Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional requirements from other imaging workflows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (see above) but collected between 500-700 nm.</td>
</tr>
<tr>
<td>Visible-reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained as described in section i (see above) but collected between 400-500 nm.</td>
</tr>
<tr>
<td>Image of uniform reflective board under experimental conditions for flat fielding these visible-reflected images.</td>
</tr>
</tbody>
</table>
f. **Naming convention**

The general naming convention, with the exception of visible-induced infrared luminescence, follows this rule:

**Registration number_description/identifier_sequential number_filter used_sequential number**

- A description/identifier is optional but allows separate frames of the same subject to be identified, e.g. full frame vs. details.
- The first sequential number allows the images to be kept in the right order.
- The filter used identifies the type of image.
- The second sequential number identifies the number of variants of the same image type.

Example:

![VIS image](image1.jpg)

VIS image: 65346_01_idas.CR2

![IRR image (first exposure)](image2.jpg)

IRR image (first exposure): 65346_02_rg830_01.CR2

![IRR image (second exposure)](image3.jpg)

IRR image (second exposure): 65346_02_rg830_02.CR2

![UVR image (first exposure)](image4.jpg)

UVR image (first exposure): 65346_03_dug11_01.CR2
UVR image (second exposure): 65346_03_dug11_02.CR2

UVL image (first exposure): 65346_04_kv418+idas_01.CR2

UVL image (second exposure): 65346_04_kv418+idas_02.CR2

For the visible-induced infrared luminescence images, the following naming convention is used:

Registration number_description/identifier_sequential number Excitation setup Emission setup_sequential number

- The excitation setup corresponds to the radiation source used for exciting the luminescence: LED, fluo=fluorescent tubes, tung = tungsten.

Examples:

VIL image (LED excitation, first exposure):
65346_05_Ex.LED_Em.rg830_01.CR2
VIL image (LED excitation, second exposure):
65346_05_Ex.LED_Em.rg830_02.CR2

VIL image (LED excitation+ tungsten, first exposure):
65346_05_Ex.LED+tung_Em.rg830_01.CR2

Visible-induced luminescence image (LED excitation+ tungsten, second exposure):
65346_05_Ex.LED+tung_Em.rg830_02.CR2
Appendix 2

i. Equipment suppliers list

*Spectralon diffuse reflectance standards*

*Macbeth (X-rite) ColorChecker Chart*

*Uniform reflective board*

*Plastazote LD45*
http://www.conservation-by-design.co.uk/productdetails.aspx?id=369&itemno=BDPLAW0015

*Quartz lenses*
http://ukaoptics.com/uvquartz.html

*Modification of cameras*
http://www.advancedcameraservices.co.uk

*Filters*
References


5 http://www.sciencecenter.net/hutech/idas/uibar.htm


7 http://www.sydor.com/pdfs/Schott_RG830.pdf

8 Alternative systems are described by:


10 http://www.newportglass.com/kdkcat.htm

11 http://motion.kodak.com/motion/Products/Lab_And_Post_Production/Kodak_filters/wrattten2.htm


13 http://www.conservation-by-design.co.uk/productdetails.aspx?id=369&itemno=BDPLAW0015


18 Verri, G., 'The spatially resolved characterisation of Egyptian blue, Han blue and Han purple by photo-induced luminescence digital imaging', Analytical and Bioanalytical Chemistry 394(4) (2009), 1011-1021.


20 http://www.conservation-by-design.co.uk/productdetails.aspx?id=369&itemno=BDPLAW0015


32 For example; http://www.cambridgeincolour.com/
3. **Image post-processing**

The importance of developing post-processing methodologies to aid in the interpretation of luminescence and other multispectral images is increasingly being recognised, both as a means to extract the maximum information from the images but also to standardise images and make them device-independent, allowing them to be compared more directly. Many of the approaches reported\(^1,2,3,4\) have included corrections for some of the experimental factors and phenomena discussed in Chapter 1. Some have included existing nip2 tools (see below), such as that used to carry out colour corrections based on use of a Macbeth target. Others have proposed similar workflow approaches but have built these into proprietary software programs, such as Matlab, which require the purchase of these specialist programs and considerable knowledge of their use by the user. In almost all cases, the post-processing methodologies have been slow to implement, are in many cases at least partly subjective and require the use of several different software programs making them unsuitable for wide adoption by a broad range of users with varying understanding of the mathematical processes involved.

The current approach has developed a unified set of user-friendly tools housed in a dedicated ‘workspace’ for nip2, the graphical interface of the free image processing system VIPS\(^5\) (see below). This chapter describes how the transformations outlined described in Chapter 1, and the data collected as a result of the acquisition protocols outlined in Chapter 2, have been combined in a nip2 workspace to form a series of image correction workflows.

Prior to carrying out any post-processing of the images recorded however, these must first be correctly transferred from the camera and converted to TIFF files from their native digital camera RAW formats. Instructions on how to carry this out are provided below, together with instructions on how to download and install the nip2 software and the workspace developed to undertake the post-processing. Finally, the four workflows for the correction of the multispectral image sets as proposed in Chapter 1 and collected as described in Chapter 2, are described and a full set of instructions for their use is provided, together with the post-processing requirements (the images or other information) required to complete them. The workflows are considered in terms of the two categories of images established in previous chapters: reflected and photo-induced luminescence images. Some quick reference instructions, intended for use once familiarity with the operation of the workspace and the various workflows for the correction of the image types described has been achieved, are included in Appendix 3.

**a. Transferring images from the camera and converting from RAW**

As discussed briefly in Chapter 1, whenever a captured image is converted into a standard JPEG or TIFF file by the camera or the RAW image conversion software (such as Adobe Photoshop or the software from the camera manufacturer), a number of processes are carried out to the data from the sensor. These are summarised in Figure 3-1.
Figure 3.1. (a) Processes carried out by the camera to the data from the sensor to produce JPEG and/or RAW files and (b) Processes carried out to the RAW file by the RAW image conversion software to produce JPEG and/or TIFF files. Adapted from the output from each of the original red, green and blue sensitive pixels of the image sensor, are read out of the array by the array electronics and pass through an analog to digital converter. The readout electronics collect and amplify the sensor data according to the ISO setting (little amplification for a low ISO setting and greater amplification for a high ISO setting). At this point the data can be saved into a RAW file on the memory card, or it can be further processed to yield a JPEG image file by the camera (Figure 3.1(a)) or the RAW image conversion software (Figure 3.1(b)). Note that some cameras can store a JPEG image along with the RAW file.

The RAW file contains two different types of information: the image pixels themselves, and the image metadata that RAW converters need in order to process the sensor data into an RGB image. This metadata tells RAW converters which colour each pixel represents. The RAW converter then uses this to convert the greyscale RAW data into a colour image by interpolating the “missing” colour information for each pixel from its neighbours. This process is known as Bayer interpolation or demosaicing. However, in addition to demosaicing RAW conversion typically also involves the following steps:

1) White balance. The white balance setting on the camera is recorded as a metadata tag in the RAW file. Some RAW converters can read this tag and apply it as the default white balance (which the user can then override if desired), while others may ignore it completely and analyse the image to determine white balance.

2) Colorimetric interpretation. Each pixel in the RAW file records a luminance value for either red, green, or blue. The RAW converter has to assign the correct, specific colour meanings to the “red,” “green,” and “blue” pixels, usually in a colorimetrically defined colour space such as CIE XYZ, which is based directly on human colour perception.

3) Gamma correction. Digital RAW captures have linear gamma (gamma 1.0), a very different tonal response from that of either film or the human eye. The RAW converter applies a gamma correction curve to redistribute the tonal information so that it corresponds more closely to the way our eyes see light and shade. Most converters use an encoding gamma of 1/2.2 but this may vary.
4) Noise reduction, antialiasing, and sharpening. Problems can arise with very small details in an image. If the detail is only captured on a red-sensing pixel or a blue-sensing pixel, the RAW converter may find it difficult to assign a colour to that pixel. Simple demosaicing methods are also not proficient at maintaining edge detail, so most RAW converters also perform some combination of edge-detection and antialiasing to avoid colour artefacts, noise reduction, and sharpening.

In general, RAW converters perform all of these tasks, but they may use very different algorithms to do so, which is why the same image may look quite different when processed through different RAW converters. If the captured image is converted to a JPEG file by the camera, a RAW converter built into the camera carries out all the tasks listed above to turn the RAW capture into a colour image, and then compresses it using JPEG compression (Figure 3-1(a)). Some cameras allow parameters to be set for this conversion, typically a choice of sRGB or Adobe RGB as colour space, a sharpness value, and perhaps a tone curve or contrast setting but it is difficult to adjust these parameters on an image-by-image basis, and generally the JPEG produced is locked into the camera’s interpretation of the scene.

Image capture in RAW format and conversion to a JPEG or TIFF file from the RAW file by external RAW conversion software (Figure 3-1(b)) is therefore recommended, as this returns control over the interpretation of the image to the user by allowing all the aforementioned aspects of the conversion to be adjusted. The only on-camera settings that have an effect on the captured pixels are the ISO speed, the shutter speed, and the aperture setting. This allows all the settings such as contrast, saturation, tone curves typically employed by the camera for aesthetic enhancement and which distort the sensor data, to be turned off.

In addition, conversion by external RAW conversion software also allows control over the tonal information contained per pixel. In RAW format almost all cameras capture at least 12 bits, or 4096 shades, of tonal information per pixel. The JPEG format, however, is limited to 8 bits per channel per pixel. This means that the camera’s built-in RAW converter throws away a large amount of the captured data with essentially no control by the user over what gets discarded. In order to access all 12 bits of the original RAW file, the data should preferentially be converted to a 16-bit TIFF file.

Finally, on conversion the external RAW conversion software automatically produces a unique ICC profile which records all the metadata (including the gamma correction applied to the image) describing this conversion (Figure 3-2). This profile is contained within the TIFF file and can be used by the post-processing software to recover the linear data observed by the camera sensor. The transformation from the converted TIFF file to linear data using the ICC profile has been integrated into the various image correction workflows in the nip2 workspace.
Figure 3.2. Flow diagram to illustrate the conversion of a RAW file to a TIFF file by RAW conversion software and the use of the resulting embedded ICC profile by the nip2 workspace to return the image to linear light (XYZ).

The instructions below describe the procedure for the conversion of images from RAW into a standard 16-bit TIFF file, which is the preferred format of the post-processing workspace. The presets recommended can be applied using either the camera software or external programs, such as Adobe Photoshop which allows these presets to be saved as a ‘settings’ file which can then be uploaded for batch processing. The example below uses Adobe Photoshop CS4 Extended but other software versions including freely available open-source software such as Raw Therapee can be used to convert images from RAW. Additionally, free utilities such as the Adobe DNG Converter are available, which enable the conversion of camera-specific RAW files from more than 350 cameras to the more universal DNG raw format. The DNG files can then be opened by external programs for conversion to TIFF files.

A series of files (e.g. BM_raw_adjustment.xmp) with the recommended presets for use with Adobe Photoshop can be downloaded from: http://www.britishmuseum.org/charisma and copied to the Application Data\Adobe\Cameraraw\Settings folder. The location of this folder will vary depending on how the computer is set up but it is typically found in C:\Documents and Settings.

Alternatively, if the location of this folder is not clear, the settings can be adjusted manually as detailed below for the first images converted and preset RAW settings files saved for use with subsequent images.

If carrying out the conversion of images from RAW using other software versions or the camera software, ensure that the same recommended presets are applied to the image before conversion to TIFF.
Workflow and Presets for conversion of images from RAW in Adobe Photoshop

Download the RAW image files from the camera via USB connection or other in their native digital camera RAW formats, e.g. CR2 (Canon), ERF (Epson), DCR, K25, KDC (Kodak), NEF (Nikon), ORF (Olympus), PEF (Pentax), RAF (Fuji), RW2 (Panasonic) and ARW, SRF, SR2 (Sony).

Applying RAW presets to images

1) Open a RAW image in Adobe PhotoShop.

   Note: Adobe PhotoShop’s “Camera Raw” functionality should automatically open most RAW formats (if this plug-in for the version of Photoshop used), if this does not happen:

   (a) In Photoshop, go to Edit/Photoshop > Preferences > File Handling. Under File Compatibility, check Prefer Adobe Camera Raw for Supported Raw Files, then click OK. When you double-click a RAW file, it will open into Camera Raw; Or

   (b) Convert the RAW file to DNG format first using a converter such as Adobe DNG Converter (see above).

   ![Figure 3-3](image)

2) If necessary, rotate the image using the controls on the top right menu, as shown in Figure 3-3.

3) If a preset raw settings file (.xmp file) has already been created or previously uploaded (as detailed above), open this as follows:

   (a) Click on the small Camera raw settings menu icon in the upper right corner just above the white balance adjuster, Figure 3-4.
(b) Select "Load settings" from the menu (Figure 3-4) and load the appropriate raw adjustments file (e.g. BM_raw_adjustment.xmp). The image presets will be applied to the RAW image.

If no preset raw settings (.xmp) file has already been created or cannot be uploaded:

4) Apply the settings manually and save the preset raw settings files based on the following procedure:

(a) If converting a VIS or UVL image:
   The Temperature slider on the “Basic” menu (1st tab on the menu on the right, Figure 3-5), must be adjusted to the colour temperature of the illuminant used to capture the VIS image or to 6500 for a UVL image. The Tint slider should be set to zero.

(b) For all image types:
   Adjust all the other settings to zero (Figure 3-5):
   
   Recovery: 0  
   Fill Light: 0  
   Blacks: 0  
   Contrast: 0  
   Brightness: 0  
   Clarity: 0  
   Vibrance: 0  
   Saturation: 0
(c) On the “Tone curve” menu (2nd tab on the menu on the right, Figure 3-6), adjust the tonal curve under the “Point” tab to “Linear”.

(d) Click on the small Camera raw settings menu icon in the upper right corner, Figure 3-7 and Select “Save settings” from the menu (Figure 3-7).

(e) Select only the following settings, as shown in the red box in Figure 3-8. (everything else should remain unchecked. Except for VIS or UVL images which will require White balance to be checked also):

- Recovery
- Fill Light
- Blacks
- Contrast
- Brightness
- Clarity
- Vibrance
- Saturation
- Parametric Curve
- Point Curve
Click on save (Figure 3-8) and name the xmp file:
- BM_raw_adjustment.xmp;
- BM_raw_adjustment_VIS.xmp (for VIS images);
- BM_raw_adjustment_UVL.xmp (for UVL images).

The pre-set raw settings files are now saved for use as in point 3.

### Setting the output depth and size of the images

5) Click on the link directly below the image (Figure 3-9), which brings up the “Workflow Options” menu shown.

   - (a) Select an output depth of 16 Bits/Channel from the pull-down “Depth” menu.
   - (b) Choose the largest possible image size from the pull-down “Size” menu in order to maximise the level of detail.
   - (c) Click “OK” on the top right hand corner of the pop-up menu (Figure 3-9).

![Figure 3-9](image)

Note that the colour space setting can be altered at will but the exact setting is not important as the ICC profile created on converting to the TIFF file will contain the necessary information to convert the data to CIE XYZ colour space (Figure 3-2) whatever the colour space setting chosen here.

### Saving images as TIFF files

6) Save the image as a TIFF file using the “Save image” button in the bottom left corner (Figure 3-10), which brings up the “Save Options” pop-up menu shown.

   - (a) Name the file according to the naming conventions outlined in Chapter 2.
   - (b) Select “TIFF” from pull-down file format menu (Figure 3-10).
(c) Click “Save” on the top right hand corner of the pop-up menu (Figure 3-10).
(d) Repeat the process to save files in other formats such as JPEG, if required.

7) Click “Done” in the bottom right corner (Figure 3-11) to record the changes made to your RAW file.

8) Click “Cancel” if you don’t wish to record the changes made to the RAW file.

Note that the data in the RAW file does not actually change on clicking “Done”, the program just saves an xmp file with the changes made. As long as this xmp file is kept in the same location as the RAW file, it will re-apply the changes made to the image whenever the RAW file is re-opened. If “Cancel” is selected no such xmp file will be saved.

9) Note that the above procedure for the conversion of RAW images to TIFF files will also apply to the associated images of the uniform reflective board captured under experimental conditions for flat fielding.
The images are now ready to open in Adobe Photoshop for viewing or in the nip2 software for processing.
b. VIPS, nip2 software and the post-processing workspace

VIPS is a free image processing system first developed in the 1990s in two EU-funded ESPRIT programmes and which has been used in a number of EU-funded projects since. Nip2 is the graphical user-interface of VIPS. For an introduction to nip2 and detailed instructions on it operation, see:
http://www.vips.ecs.soton.ac.uk/supported/current/doc/html/nipguide/nipguide.html

As nip2 is entirely open-source and has full online instructions. Users wishing to investigate how the transformations described in the workflows are carried out in more detail or needing to modify these to their specific needs will be able to do so. In addition, nip2 is freely available ensuring that, although the tools produced will be the property of the CHARISMA project, the coding will remain open-source under the terms of the nip2 licence. As a result, the workspace developed within the CHARISMA project will form part of a freely available, non-proprietary image processing system, which will be maintained beyond the duration of the project, and be as widely accessible as possible to the cultural heritage community.

i. Nip2 Software Installation

The instructions below describe the download and installation of nip2. For further instructions on the operation of the software, see the instructions or press F1 after opening the program.

**Downloading and installing nip2**

**Downloading nip2**

1) The current supported version of the nip2 software for a number of operating systems or as source code can be downloaded from: http://www.britishmuseum.org/charisma or http://www.vips.ecs.soton.ac.uk/supported/current/
2) Choose the operating system of choice and click on the appropriate link (Figure 3-12). Download the most current version of the nip2 installer for that operating system from the menu (e.g. nip2-7.x.x-setup.zip for Windows or nip2-7.x.x.app.dmg for Mac OS).

**Installing nip2**

3) Unpack the downloaded file as appropriate and run the program to install nip2. The installer will copy the necessary files to the hard drive and add the program to the start menu.

**Opening nip2**

4) Click on the nip2 icon to open (Figure 3-13).

5) The nip2 interface opens as shown below (Figure 3-14). For a quick interface tour go to: http://www.vips.ecs.soton.ac.uk/supported/current/doc/html/nipguide/nipguide.html or press F1.

6) For instructions on how to open workspaces see below.
ii. **Nip2 workspace**

A nip2 ‘workspace’ is a file which holds a set of definitions or software components that adds specific abilities to the larger software application (a so-called ‘plug-in’), that are used to carry out a number of transformations on a set of input images. Internally, workspaces are XML (Extensible Markup Language) files and can be manipulated with the standard XML tools. Once loaded into nip2 however, they provide an accessible visual framework within which the nip2 tools carry out their tasks. The modular design and organization of these workspaces minimise the need for specialised knowledge by the user and reduce user subjectivity, since for each imaging method, the relevant fields can simply be filled with the images required and the transformations can be carried out aided by a set of simple instructions.

Creation of the workspace to undertake the suite of post-processing transformations developed within the CHARISMA project was sub-contracted to John Cupitt, one of the original authors of the nip2 software.

The four workflows as proposed in Figures 1.17-18 and 1.27-28 (see Chapter 1) and detailed in Table 3-1, have been combined to form this workspace which applies the series of transformations required to address the correction of a particular type of image (e.g. UVL images) or class of images (e.g. IRR/UVR images). It has been designed to allow the correction of individual image sets or a complete set of multispectral images. However, the post-processing requirements for some workflows may require that previous workflows be completed prior to running through that workflow, e.g. the workflow for correction of visible-reflected images must already have been completed in order to acquire the calibrated visible-reflected image required for carrying out the workflow for the correction of IR/UV-reflected images. In general, the order in which these workflows are described in this Chapter (and ordered in Table 3-1) is the recommended sequence in which they should be carried out.
Table 3-1. Description of the image corrections/transformations which must be applied for each type of image correction and the workflow developed to carry it out.

<table>
<thead>
<tr>
<th>IMAGE CORRECTIONS / TRANSFORMATIONS</th>
<th>WORKFLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Reflected Images (UV-VIS-IR)</strong></td>
<td></td>
</tr>
<tr>
<td>i. VIS images</td>
<td>VIS</td>
</tr>
<tr>
<td>• Spatial inhomogeneities of light source</td>
<td></td>
</tr>
<tr>
<td>• Spectral density of the light source and non-linear camera response</td>
<td></td>
</tr>
<tr>
<td>• Camera response (colour calibration for visible-reflected images)</td>
<td></td>
</tr>
<tr>
<td>ii. IRR-UVR images:</td>
<td>IRR/UVR/false-colour</td>
</tr>
<tr>
<td>• Spatial inhomogeneities of radiation source</td>
<td></td>
</tr>
<tr>
<td>• Spectral density of the radiation source and non-linear camera response</td>
<td></td>
</tr>
<tr>
<td>• Image registration (for the creation of false colour images)</td>
<td></td>
</tr>
<tr>
<td>• Generation of false colour images</td>
<td></td>
</tr>
<tr>
<td><strong>2) Photo-induced Luminescence Images (UVL-VIVL-VIL)</strong></td>
<td></td>
</tr>
<tr>
<td>i. VIL images</td>
<td>VIL</td>
</tr>
<tr>
<td>• Spatial inhomogeneities of light source</td>
<td></td>
</tr>
<tr>
<td>• Subtraction of ambient stray radiation</td>
<td></td>
</tr>
<tr>
<td>ii. UVL images</td>
<td>UVL</td>
</tr>
<tr>
<td>• Spatial inhomogeneities of radiation source</td>
<td></td>
</tr>
<tr>
<td>• Subtraction of ambient stray radiation</td>
<td></td>
</tr>
<tr>
<td>• Correction for camera response/camera calibration</td>
<td></td>
</tr>
<tr>
<td>• Pigment-binder interaction</td>
<td></td>
</tr>
<tr>
<td>iii. VIVL images</td>
<td>Not in scope (but could be developed based on UVL workspace)</td>
</tr>
<tr>
<td>• As for UVL images?</td>
<td></td>
</tr>
</tbody>
</table>
The instructions below describe how to download the workspace and open it in nip2. It also gives a basic description of the workspace and its functions, which will be expanded upon in the workflows for the correction of various image sets in the sections below. For further instructions on the operation of the nip2 software, press F1 after opening the program.

### Downloading and opening the workspace for the correction of Images

#### Downloading the workspace

1) The workspace for the correction of images is available for download from: [http://www.britishmuseum.org/charisma](http://www.britishmuseum.org/charisma)

2) Download the workspace and save it to a suitable location.

#### Opening the workspace

3) Open nip2.

4) Drag the workspace file (*bm-workspace.ws*) directly into the empty nip2 window, as shown in Figure 3-15.

![Figure 3-15](image.png)

OR

5) Select “File” > “Open” from the top left hand corner. (Figure 3-16), which brings up the “Open file” pop-up menu shown.

![Figure 3-16](image.png)
6) Select the `bm-workspace.ws` file from the appropriate location and click “Open”.

7) The workspace interface opens as shown below (Figure 3-17).

8) A series of tabs can be observed along the top of the workspace (Figure 3-17). These correspond to the various operations or types of transformations to be carried out on the image sets. The sections below describe these. For more details, refer to the workflows for the correction of image sets in the sections below.
Navigating the workspace

9) The “input” tab allows the images to be post-processed, together with any associated images required (e.g. for flat-field correction) to be added into the workspace.

(a) There are 5 columns for the input of images under this tab: “visible light reflectance” (column A), “IR reflectance” (column E), “UV reflectance” (column F), “UV-induced visible luminescence” (column G) and “visible-induced IR luminescence” (column H).

(b) Each column has four separate boxes. The top two containing the image to be used to generate the calibration and the associated flat-field image (if available) and lower two containing the image to be calibrated and the associated flat-field image (if available). These two sets can be the same (and are automatically entered as such) or another frame (e.g. a “twin” image not containing the calibration targets, as described in Chapter 2) taken with the same camera and under the same lighting conditions can be added to the lower set of images. For more details, refer to the workflows for the correction of image sets in the sections below.

(c) If processing a complete multispectral image set, the relevant images can be uploaded all at once or at the start of the workflow for each particular frame. It must however be kept in mind that the results from some workflows may be required in order to complete others. Not all the columns must be filled, only those required to complete the workflows of interest. At minimum only a visible-reflected image (including Macbeth chart for colour calibration) is required.

(d) To input the images, either drag them into the appropriate slot or left-click on the thumbnail, click “Replace From File”, and select the image required (Figure 3-18). For more details, refer to the workflows for the correction of image sets in the sections below.
(e) A sixth column (I) selects the output depth at which the images will be saved following post-processing.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>10) The “linear” tab converts the images to linear light (XYZ) using the embedded ICC profile and applies a flat-field correction to the images (if an image of a uniform reflective board under the same experimental conditions for flat-fielding is available and the option is checked). It also generates monochrome images based on the output from a single channel for the images where this is required. For more details, refer to the workflows for the correction of image sets in the sections below.</td>
<td></td>
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<tr>
<td><img src="linear.png" alt="linear" /></td>
<td></td>
</tr>
<tr>
<td>11) The “markup” tab straightens and extracts the Macbeth chart from the linearized, flat-field corrected VIS image to be used for calibration. It also marks the position of the Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available.</td>
<td></td>
</tr>
<tr>
<td><img src="markup.png" alt="markup" /></td>
<td></td>
</tr>
<tr>
<td>12) The “viscalib” tab (visible-light calibration) generates the colour calibration matrix from the extracted Macbeth chart and sets the brightness (luminance) of the image from the Macbeth chart greyscale. It then applies the colour calibration to the VIS image to be calibrated (based on the calibration matrix generated from the Macbeth chart).</td>
<td></td>
</tr>
<tr>
<td><img src="viscalib.png" alt="viscalib" /></td>
<td></td>
</tr>
<tr>
<td>13) The “uvlcalib” (UV-induced Luminescence calibration) tab applies the camera calibration and the white-point adjustment to the UVL image. For more details, refer to the workflows for the correction of UVL image sets in section iii below.</td>
<td></td>
</tr>
<tr>
<td><img src="uvlcalib.png" alt="uvlcalib" /></td>
<td></td>
</tr>
<tr>
<td>14) The “align” tab carries out the registration (rotation and scaling) of two images to ensure that these are overlapped.</td>
<td></td>
</tr>
<tr>
<td><img src="align.png" alt="align" /></td>
<td></td>
</tr>
<tr>
<td>15) The “specden” tab (spectral density) corrects for spectral density in the IRR and/or UVR images by comparing this to a calibrated VIS image. For more details, refer to the workflows for the correction of IRR/UVR image sets in section ii below.</td>
<td></td>
</tr>
<tr>
<td><img src="specden.png" alt="specden" /></td>
<td></td>
</tr>
<tr>
<td>16) The “falsecolour” tab generates the IRR and/or UVR false-colour images. For more details, refer to the workflows for the correction of IRR/UVR image sets in section ii below.</td>
<td></td>
</tr>
<tr>
<td><img src="falsecolour.png" alt="falsecolour" /></td>
<td></td>
</tr>
<tr>
<td>17) The “uvlstray” tab (UV-induced Luminescence Stray light) removes ambient stray radiation from the UVL image. For more details, refer to the workflows for the correction of UVL image sets in section iii below.</td>
<td></td>
</tr>
<tr>
<td><img src="uvlstray.png" alt="uvlstray" /></td>
<td></td>
</tr>
</tbody>
</table>
18) The “uvlk” tab (UV-induced Luminescence Kubelka-Munk) compensates for the extent to which the pigment particles absorb the light emitted by the luminescent materials (“pigment-binder” interaction). For more details, refer to the workflows for the correction of UVL image sets in section iii below.

19) The “vilstray” tab (Visible-Induced Luminescence Stray light) removes ambient stray radiation from the VIL image. For more details, refer to the workflows for the correction of VIL image sets in section iv below.

20) The “vilkm” tab (visible-induced Luminescence Kubelka-Munk) compensates for the extent to which the pigment particles absorb the light emitted by the luminescent materials (“pigment-binder” interaction). For more details, refer to the workflows for the correction of VIL image sets in section iv below.

21) The “results” tab summarises all the results obtained from the different workflows and applies an output ICC profile which converts the resultant images to sRGB (or RGB16) colour space. It also allows these images to be saved as TIFF files.

**Saving the workspace**

22) If required the workspace can be saved for reference or further work (“File” > “Save Workspace As”).

The following sections describe the four workflows outlined in Table 3-1. They are considered in terms of the two categories of images established previous chapters: reflected and photo-induced luminescence images. The recommended sequence in which they should be carried out is as they appear below, as this will ensure that the post-processing requirements for each workflow are met.
c. Post-processing Reflected Images

i. Correction of Visible-reflected Images

The workflow for the correction of visible-reflected (VIS) images is designed to carry out correction for the factors affecting visible-reflected images, as summarised in Table 3-1 and discussed in Chapter 1, and using the data collected as a result of the acquisition protocols outlined in Chapter 2. Figure 3-19 shows a schematic of the workflow developed in the nip2 software indicating the transformations/corrections to be applied.

Figure 3-19. Workflow for the correction of visible-reflected images in the nip2 post-processing workspace.

The workflow is composed of the following steps:

1) Loading the input images converted from RAW:
   - VIS image (with Macbeth chart) and associated VIS flat-field image (if available) for generating the calibration.
   - VIS image to be calibrated (can be the same as above image or another image taken with the same camera and under the same lighting conditions) and associated VIS flat-field image (if available).

2) Converting the images to linear light (XYZ) using the embedded ICC profiles.

3) Applying a flat-field correction to the images (if this option is checked).

4) Straightening and extracting the Macbeth chart from the linearized, flat-field corrected (flat-fielded) VIS image used to generate the calibration.

5) Generating a colour calibration matrix:
   - Sets brightness (luminance) of the image from the Macbeth chart greyscale
   - Generates a colour calibration matrix from a linear regression.

6) Applying the colour calibration to the VIS image to be calibrated (based on the calibration matrix generated from the Macbeth chart).

7) Applying an output ICC profile which converts the linearized, flat-fielded, colour-calibrated VIS image to sRGB (or RGB16) colour space.

8) Saving the sRGB (or RGB16) flat-fielded, colour-calibrated VIS image.
The images or other information required in order to complete the steps described in this workflow are summarised below, together with detailed instructions describing the workflow for the correction of visible-reflected images.

**Workflow for the correction of visible-reflected (VIS) images**

Check that all images or other information required in order to run this workspace is available:

- Camera output file (TIFF) – Visible-reflected image(s) converted from RAW as per instruction in section a;
- ICC profile for conversion from RAW (contained within the TIFF file);
- Image of uniform reflective board under experimental conditions for flat fielding, if available;
- Image of Macbeth chart for colour calibration (included as part of the image to be calibrated or another image taken with the same camera and lighting conditions);
- Image of Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (required for comparison to IRR/UVR images and post-processing of luminescence images).

**Opening the workspace and loading the input images**

1) Start nip2 and open the workspace as shown above. Under the “input” tab (Figure 3-20), the first column on the left (column A) holds the input images required for this workflow (correction of visible-reflected images). The images are divided into two sets:

   (a) The top two images under the “targets” thumbnail contain the image to be used to generate the calibration and the associated flat-field image (if available).

   (b) The lower two images under the “object” thumbnail contain the image to be calibrated (which can be the image same as above) and the associated flat-field image (if available).
2) Images are opened by dragging them into the appropriate slot or by left-clicking on the thumbnail, clicking “Replace From File”, and selecting the image required.

(a) Load an image containing the calibration targets into the top box on the “targets” thumbnail (Figure 3-21). This image will be used to generate the calibration and can be the image you want to calibrate or another image taken with the same camera and under the same lighting conditions. It can remain in place for batch-processing (see later) as long as the camera or lighting conditions remain the same.

(b) If available, load an image of a uniform reflective board (under the same experimental conditions of the top image) for flat fielding into the bottom box on the “targets” thumbnail and check the option to "Flatfield visible reflectance with calibration targets image" (Figure 3-21). If this is not available leave this option unchecked.

(c) Load the image(s) you want to calibrate into the top box on the “object” thumbnail (Figure 3-22). This can be the same image as above or another frame (e.g. another frame in a series or a “twin” image not containing the calibration targets, as described in Chapter 2 and shown in Figure 3-23) taken with the same camera and under the same lighting conditions.

(d) If available, load an image of a uniform reflective board under the same experimental conditions of the image for flat fielding into the bottom box on the “object” thumbnail (Figure 3-22) and check the option to “Flatfield visible reflectance of object image”. If this is not available leave this option unchecked (as in Figure 3-23).
Note that the images uploaded in the “targets” tab will also automatically be uploaded to “object” tab. The latter can easily be replaced by dragging in the desired images.

3) Scroll down. Column (I) selects the output depth at which the images will be saved following post-processing. To select an output depth of 16 bits, check the “Output format is 16-bit” option. Leave unchecked to keep the bit depth of the input image as the default.

Converting the images to linear light (XYZ) using the embedded ICC profile and applying a flat-field correction to the images.

4) Click on the “linear” tab to the right. Column J imports all the images in the “input” tab to linear light (Figure 3-25) and applies a flat-field correction to the images.

5) The resultant flat-fielded, linear light (XYZ) images can be observed in J13 (Figure 3-25).

6) Note that if an image of a uniform reflective board under the same experimental conditions of the images was not uploaded (or the options in the “input” tab indicated above were not checked), the images in the “targets” and “object” thumbnails are in linear light but no flat field correction has been applied to them.
Straightening and extracting the Macbeth chart and diffuse reflectance standards from the linearized, flat-fielded VIS image.

7) Click on the “markup” tab to the right. Column A on the left straightens and extracts the Macbeth chart from the image in A21 (the linearized, flat-fielded VIS image automatically carried over from the “linear” tab).

8) Double left-click on the “straighten_image” thumbnail to open an image view window (Figure 3-26).
9) Move the endpoints of the line A21 (Figure 3-26) so that the line follows any of the edges of the Macbeth chart. The image will be rotated to straighten it. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”) respectively. Note that the image will update in real time, which may cause a slight response delay in larger images.

10) Next, double left-click on the “box-image” thumbnail (Figure 3-27) and adjust the box A21 on the image view window so that it just encloses the chart. The selection appears in the “box” thumbnail.

11) Finally pick a rotation option from the drop-down menu in the “rotate” thumbnail (Figure 3-27) that orients the Macbeth chart correctly, with the white patch in the bottom left-hand corner.

12) Scroll right. Column B marks the position of the Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available, from the image in B1. Note that this step is required for later workflows and can be omitted if only correcting visible-reflected images.

13) Double left-click on the “straighten_image” thumbnail to open an image view window (Figure 3-28).

14) Move the endpoints of the line B1 so that the line follows the edge of the Spectralon diffuse reflectance grey scale (Figure 3-28) or the available Spectralon diffuse reflectance standards (as in Figure 3-29). The image will be rotated to straighten it. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”) respectively. Note that the image will update in real time.
15) Next, double left-click on the “box_image” thumbnail (Figure 3-30 and Figure 3-31) and adjust the box B1 on the image view window so that it just encloses the diffuse reflectance standards. The selection appears in the “box” thumbnail.
16) Pick a rotation option from the drop-down menu in the “rotate” thumbnail (Figure 3-30 and Figure 3-31) that orients the white diffuse reflectance standard at the bottom left-hand corner.

17) Enter the number of diffuse reflectance grey scale targets or available standards in the “pacross” thumbnail (e.g. 8 in Figure 3-30 and 5 in Figure 3-31). Click on the number to edit.
18) A matrix of values is created by subdividing the image of the standards by the number entered and determining the average X, Y and Z values for each of these. Double left-clicking on the “sample” thumbnail (Figure 3-30 and Figure 3-31) opens a window (B1.sample), which aids in the visualisation of the areas being sampled to create this matrix of values. A slider is provided to adjust this area. Thus in Figure 3-30, 50% of the area of each target is sampled. In Figure 3-31 this has been adjusted to 40%, to ensure the area sampled is within the targets (as these are further apart and vary in shape). Adjust as necessary for the available Spectralon diffuse reflectance standards.

**Generating the colour calibration matrix**

19) Click on the “viscalib” tab to the right. Column D on the left carries out the analysis and generates the calibration matrix from the Macbeth chart (Figure 3-32). The image at D1 is automatically carried over from the “markup” tab.

![Figure 3-32](image)

20) Double left-clicking on the “sample” thumbnail (Figure 3-32) opens a window (D8.sample), which aids in the visualisation of the areas being sampled to create the calibration matrix. A slider is provided to adjust this area if necessary.

21) Check that the file “macbeth_lab_d65.mat” has been selected in the “Pick a Macbeth data file” option (this should be loaded automatically on loading the workspace), (Figure 3-32).

22) Check that the “Linear output, set brightness from chart” option has been selected from the “Input LUT” menu in D8, (Figure 3-32). This sets the brightness or luminance of the image from the grey scale on the Macbeth chart.
23) The 3x3 calibration matrix M is generated by comparison with the uploaded .mat file (Figure 3-32) and the rows below show the average ΔE (colour error) and list the worst colour match. Note that ΔE values should not be greater than 5 to be deemed an accurate calibration.

Applying the colour calibration to the VIS image to be calibrated (based on the calibration matrix generated from the Macbeth chart).

24) Scroll right to column H, which applies the colour calibration to the VIS image to be calibrated. This can be the same image as was used to generate the calibration (Figure 3-33) or another image taken with the same camera and under the same lighting conditions (Figure 3-34). The colour calibration matrix generated in column D is applied to the image in the “object” thumbnail from the “linear” tab (J13).

25) The result is shown in the “object” thumbnail at H10 (Figure 3-33 and Figure 3-34).

26) Scroll right to column C, which uses the position of the Spectralon diffuse reflectance standards in the VIS image defined in the “markup” tab to extract their position in the calibrated VIS image at H10. Note that this step is required for later workflows and can be omitted if only correcting visible-reflected images. A matrix of values is created by subdividing the image of the standards by the number entered and determining the average X, Y and Z values for each of these (Figure 3-35). The sampling visualisation tool and slider are again provided here (not shown).
Applying an output ICC profile which converts colour calibrated flat-field corrected visible-reflected image to sRGB (or RGB16) colour space.

27) Click on the “results” tab to the right. An output ICC profile is automatically applied to the results of the workflow which converts the colour calibrated flat-fielded VIS images to sRGB (or RGB16) colour space (Column A, Figure 3-36).
28) Note that the images in the “targets” and “object” thumbnails can be the same image (if image used to generate the calibration was also the image to be calibrated) or a different image (as in Figure 3-37).

29) The sRGB (or RGB16) colour calibrated flat-field corrected visible-reflected images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails (Figure 3-36 and Figure 3-37). Save the image from the image view window (“File” > ”Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”.

30) Note that the “Output depth” of these images will be as selected in the “input” tab (Column I).
31) On the “Save Image” pop-up window (Figure 3-36):
   (a) Name the file according to the naming conventions outlined in Chapter 2.
   (b) Select “TIFF” from pull-down file format menu.
   (c) Click “Save” on the bottom right hand corner of the pop-up menu.
   (d) Repeat the process to save files in other formats such as JPEG, if required.

**Batch-processing**

32) If multiple images have been taken with the same camera under the same lighting conditions, they can be processed as a batch. The images are loaded by left-clicking on the “object” thumbnail, in the “input” tab and clicking “Replace From File”, and selecting the first image required, shift-clicking on the last image required, and pressing “Open”. The above steps will be applied to all the images selected.

33) The image in “objects” in the “results” tab (A3) will become a group of images. To save these left-click on the “objects” thumbnail, and click on “Save As”. Name the files according to the naming conventions outlined in Chapter 2. The images will be saved as “x_001.tif, x_002.tif, x_003.tif,...” etc.
ii. Correction of IR/UV-reflected Images and Generation of False-colour images

The workflow for the correction of IR/UV-reflected images is designed to carry out correction for the factors affecting IR or UV-reflected images, as summarised in Table 3-1 and discussed in Chapter 1, and using the data collected as a result of the acquisition protocols outlined in Chapter 2. In addition, this workflow also generates IR- or UV-reflected false-colour images, if these are required. Figure 3-38 shows a schematic of the workflow developed in the nip2 software, indicating the transformations/corrections to be applied.

Figure 3-38. Workflow for the correction of IR or UV-reflected images and the generation of IR or UV-reflected false-colour images in the nip2 post-processing workspace.
The workflow is composed of the following steps:

1) Loading the input images converted from RAW:
   – IRR and/or UVR image for generating the spectral density correction and associated flat-field image (if available).
   – IRR and/or UVR to be calibrated (can be the same as above image or another image taken with the same camera and under the same lighting conditions) and associated flat-field image (if available).

2) Converting the images to linear light (XYZ) using the embedded ICC profiles.

3) Applying a flat-field correction to the images (if this option is checked).

4) Generating monochrome images based on the output from a single channel (red channel for IRR images and blue channel for UVR images).

5) Image registration: aligning the calibrated VIS image and the IRR or UVR image.

6) Matching the brightness (luminance) of the calibrated VIS image and IRR or UVR image.
   – Sets brightness of image from Spectralon diffuse reflectance standards on the calibrated VIS image.

7) Applying an output ICC profile which converts corrected IRR or UVR image to sRGB (or RGB16) colour space.

8) Saving the sRGB (or RGB16) corrected IRR or UVR image.

9) Generating the IRR or UVR false-colour image.

10) Saving the IRR or UVR false-colour image.

The images or other information required in order to complete the steps described in this workflow are summarised below, together with detailed instructions describing the workflow for the correction of IR and/or UV-reflected images and the generation of IR and/or UV-reflected false-colour images.
Workflow for the correction of IR and/or UV-reflected images (IRR/UVR) and the generation of IR and/or UV-reflected false-colour (IRRFC/UVRFC) images.

Check that all images or other information required in order to run this workspace is available:

- **Calibrated VIS image(s)** (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained by processing the corresponding visible-reflected image(s) using the workflow for correction of visible-reflected images (See above);
- **Camera output file (TIFF)** – IR and/or UV-reflected images (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) converted from RAW as per instruction in section a;
- **ICC profile** for conversion from RAW (contained within the TIFF file);
- **Image(s)** of uniform reflective board under experimental conditions of IR and/or UV-reflected images for flat fielding, if available.

### Loading the input images

1) Note that the previous workflow for correction of visible-reflected (VIS) images must already have been completed prior to running through this workflow. If this has not been done, return to section i and proceed as directed before continuing.

2) Click on the “input” tab (Figure 3-39), the second row of columns on the left (column E and F) hold the input images required for this workflow (correction of IR and/or UV-reflected images). If these were not uploaded previously, add them as directed below.

3) Images are opened by dragging them into the appropriate slot or by left-clicking on the thumbnail, clicking “Replace From File”, and selecting the image required (Figure 3-40).
(a) **To correct an IRR image:** Load an image containing a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available into the top box on the “targets” thumbnail (Figure 3-40). This image will be used to generate the spectral density correction and can be the image you want to correct or another image taken with the same camera and under the same lighting conditions. It can remain in place for batch-processing (see later) as long as the camera and lighting conditions remain the same.

(b) If available, load an image of a uniform reflective board (under the same experimental conditions) for flat fielding into the bottom box on the “targets” thumbnail and check the option to “Flatfield IR reflectance with calibration targets image” (Figure 3-41). If this is not available leave this option unchecked.

(c) Load the image(s) you want to correct into the top box on the “object” thumbnail (Figure 3-41). This can be the same image as above or another frame (e.g. another frame in a series or a “twin” image not containing the spectralon diffuse reflectance standards, as described in Chapter 2 and shown in Figure 3-42) taken with the same camera and under the same lighting conditions.

(d) If available, load an image of a uniform reflective board (under the same experimental conditions of the image) for flat fielding into the bottom box on the “object” thumbnail (Figure 3-41 and Figure 3-42) and check the option to “Flatfield IR reflectance of object image”. If this is not available leave this option unchecked (as in Figure 3-42).
(e) **To correct an UVR image:** Scroll down to column F and follow the same procedure as above.

Note that if both IRR and UVR images are available, processing can proceed in tandem. If only one of the images is required, follow only the indications in the workflow for the image of interest.

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Converting the images to linear light (XYZ) using the embedded ICC profile and applying a flat-field correction to the images.

4) Click on the “linear” tab to the right. Column J imports all the images in the “input” tab to linear light (Figure 3-43) and applies a flat-field correction to the images.

5) Scroll down. The resultant flat-fielded, linear light (XYZ) images can be observed in J14 (IRR images) and J15 (UVR images) (Figure 3-43).
6) Note that if an image of a uniform reflective board under the same experimental conditions of the images was not uploaded (or the options in the “input” tab indicated above were not checked), the images in the “targets” and “object” thumbnails are in linear light but no flat field correction has been applied to them.

**Generating monochrome images**

7) Scroll right to column K. This generates monochrome images (Figure 3-44) based on the output from a single channel (the red channel for IRR images and the blue channel for UVR images). This is the procedure described as “mono-izing” in Chapter 1.

8) The resultant images can be observed in K1 (IRR images) and K2 (UVR images).

![Figure 3-44](image)

**Image registration: aligning the calibrated VIS image and the IRR or UVR image.**

9) Click on the “align” tab to the right. Columns D and E register the VIS image and the IRR or UVR images, respectively (Figure 3-45).

10) Two sets of images are observed in each column to allow the independent registration of the Spectron diffuse reflectance standards in the images containing these (D26 and E8) and the images themselves (D1 and E9). This allows greater flexibility in order to address various scenarios, e.g.:

(a) Where the images used for calibration are the same images to be calibrated and no alteration in the position of the standards has occurred in the VIS vs. the IRR and/or UVR images (as in Figure 3-45). This would be the expected situation in a studio setting:
(b) As above but some alteration in the position of the standards has occurred in the VIS vs. the IRR and/or UVR images;

(c) Where the images used for calibration are not the same images to be calibrated, either because it is a “twin” image not containing the standards (as in Figure 3-49) or another frame taken with the same camera and lighting conditions. This may be the situation if carrying out work in the field where site constraints may not allow the standards to be easily included in the frame or if batch processing a number of different frames taken with the same camera and under the same lighting conditions.

11) The alignment is carried out by selecting a pair of points in each image, the corresponding IRR or UVR images are rotated and scaled according to the position of these points in the corresponding images until these are aligned. Note that the VIS images in the “reference” thumbnails are automatically carried over from the “viscalib” tab. The IRR and UVR images in the “adjust” thumbnails are carried over from the “linear” tab.

12) To align the Spectron diffuse reflectance standards in the VIS and IRR images, double left-click on the D26 “reference” thumbnail to bring up the image view window containing the VIS image and two points, D26.ap1 and D26.ap2 (Figure 3-46). Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”), respectively. Note that the image will update in real time, which may cause a slight response delay in larger images.

13) The points are moved by left-clicking and dragging on the label. Move these to indicate a pair of features on the standards which are recognisable in both images. Better accuracy is achieved if these points as far apart as possible. Note that it is not essential
to use the standards themselves for the alignment (which may be difficult if, for example, the image is quite dark), as long as these are correctly aligned in both images.

14) Repeat the procedure for the IRR image by double left-clicking on the D26 “adjust” thumbnail and moving the points D26.bp1 and D26.bp2 to the same locations as for the VIS image (Figure 3-47). It may be useful to have the window containing the VIS image open simultaneously.
15) If the image is too dark or light, click View > Toolbar and check the “Display Control” box. This will bring up a slider which allows the brightness to be adjusted. This change is purely for visual purposes and will not alter the data.

16) To test the accuracy of the alignment, double left-click on the D26 “test alignment” thumbnail (Figure 3-48). This shows monochrome versions of the VIS and IRR images in the green and red channels, respectively. The IRR image is transparent and overlaid onto the VIS image to enable the accuracy of the alignment to be easily visualized.

17) Scroll down to the VIS and IRR images to be calibrated (D1). These can be the same as those in D26 (as shown in the above examples) or different images (as in Figure 3-49).

18) Double left-click on the D1 “reference” thumbnail to bring up the image view window containing the VIS image and two points, D1.ap1 and D1.ap2 (Figure 3-49). Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”) respectively. Note that the image will update in real time, which may cause a slight response delay in larger images.

19) Move these to indicate a pair of features which are recognisable in both images. Better accuracy is achieved if these points are as far apart as possible.

20) Repeat the procedure for the IRR image by double left-clicking on the D1 “adjust” thumbnail and moving the points D1.bp1 and D1.bp2 to the same locations as for the VIS image.

21) Test the accuracy of the alignment by double left-clicking on the D1 “test_alignment” thumbnail.
22) To align the Spectralon diffuse reflectance standards in the VIS and UVR images, scroll right to column E and follow the same procedure as detailed in points 12) to 15) above for the images in E8. Note that the points E8.ap1 and E8.ap2 on the E8 “reference” VIS image are automatically placed in the same locations as for the D26 “reference” VIS image (Figure 3-50).
23) Double left-click on the E8 “adjust” thumbnail and move the points E8.bp1 and E8.bp2 to the same locations as for the VIS image. Test the accuracy of the alignment by double left-clicking on the E8 “test_alignment” thumbnail.

24) To align the VIS and UVR images (whether these are the same images as those in E8, or different images, as in Figure 3-51), scroll down and follow the same procedure as detailed in points 17) to 20) above for the images in E9. Note that the points E9.ap1 and E9.ap2 on the E9 “reference” VIS image are automatically placed in the same locations as for the D1 “reference” VIS image.

![Figure 3-51](image)

*Matching the brightness (luminance) of the IRR and/or UVR image to the calibrated VIS image.*

25) Click on the “spcden” tab (Figure 3-52). The spectral density correction of the IRR and UVR images is carried out by matching the luminance of these images to that of the calibrated VIS image.

26) The matrix of average X, Y and Z values for each of the standards created for the VIS image in the “markup” tab and calibrated in the “viscalib” tab (from previous workflow for the correction of VIS images) is automatically carried over to columns O and A (at O17 and A7, respectively) for comparison with the matrices generated as described below for the IRR and UVR images.

27) The positions of the Spectralon diffuse reflectance standards in the IRR or UVR image are extracted from the alignments carried out in the “align” tab, as described above (see B9, Figure 3-52 and E2, Figure 3-53).
28) As with the VIS image, a matrix of values is created by subdividing the image of the standards by the number entered and determining the average X, Y and Z values for each of these. Double left-clicking on the “sample” thumbnail opens a window (B9.sample), which aids in the visualisation of the areas being sampled to create this matrix of values. As previously, a slider is provided for adjustment to ensure that the areas sampled are within the targets. Adjust as necessary for the available Spectralon diffuse reflectance standards.
Note that this should not be necessary if the position of the targets has not moved significantly between frames and the alignment procedure was carried out in the previous tab.

29) If the image is too dark or light and the targets cannot be seen clearly, click View > Toolbar and check the “Display Control” box. This will bring up a slider which allows the brightness to be adjusted. This change is purely for visual purposes and will not alter the data.

30) The resultant matrix for the IRR image is shown in columns O (at O16, Figure 3-52). The matrix for the UVR image is shown in column A (at A8, Figure 3-53).

31) The matrices generated for the IRR and UVR images are matched with that for the VIS image by linear regression (see columns O and A). The corrected IRR and UVR images can be observed by scrolling down to columns O (O34) and A (A16).

Applying an output ICC profile which converts the corrected IRR and/or UVR image to sRGB (or RGB16) colour space.

32) Click on the “results” tab to the right. An output ICC profile is automatically applied to the results at O34 and A16 of the “specden” tab which converts the corrected IRR and UVR images to sRGB (or RGB16) colour space (B6 and B7, Figure 3-54).
33) Note that the images in the “targets” and “object” thumbnails can be the same image (if image used to generate the calibration was also the image to be calibrated) or a different image (as in Figure 3-55).

**Figure 3-55**

**Saving the corrected sRGB (or RGB16) IRR or UVR image**

34) The sRGB (or RGB16) luminance matched flat-field corrected IRR or UVR images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails.

35) Save the image from the image view window (“File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”.

**Figure 3-56**
36) Note that the “Output depth” will be as selected in the “input” tab (Column I) for the previous workflow for correction of visible-reflected images.

37) On the “Save Image” pop-up window (Figure 3-56):
(a) Name the file according to the naming conventions outlined in Chapter 2;
(b) Select “TIFF” from pull-down file format menu;
(c) Click “Save” on the bottom right hand corner of the pop-up menu;
(d) Repeat the process to save files in other formats such as JPEG, if required.

Generating the IRR and/or UVR false-colour image(s).

38) The IRR and/or UVR false-colour images are generated in the “falsecolour” tab (Figure 3-57) from the calibrated VIS image and the corrected IRR and/or UVR images.

39) To generate the IRR false-colour image check that “X-RG” option is selected at K9. This takes the monochrome image generated in the “linear” tab and puts this data into the R channels in sRGB space. The red and green components of the VIS image are shifted into the green and blue channels respectively.¹

40) To generate the UVR false-colour image check that “GB-X” option is selected at K2. This takes the monochrome image generated in the “linear” tab and puts this data into the B channels in sRGB space. The blue and green components of the VIS image are shifted into the green and red channels respectively.¹
Saving the false-colour IRR or UVR image.

41) Click on the “results” tab. The false-colour IRR and/or UVR images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails.

![Figure 3-58](image)

42) Note that the images in the “targets” and “object” thumbnails can be the same image or a different image.

43) Save the image from the image view window (“File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”, as shown previously.

44) Note that the “Output depth” will be as selected in the “input” tab (Column I) for the previous workflow for correction of visible-reflected images.

**Batch-processing**

45) If multiple images have been taken **under the same lighting conditions**, they can be processed as a batch. The images are loaded by left-clicking on the relevant “object” thumbnail, in the “input” tab and clicking “Replace From File”, and selecting the first image required, shift-clicking on the last image required, and pressing “Open”. The above steps will be applied to all the images selected.

46) The image in “objects” in the “results” tab will become a group of images. To save these left-click on the “objects” thumbnail, and click on “Save As”. Name the files according to the naming conventions outlined in Chapter 2. The images will be saved as “x_001.tif, x_002.tif, x_003.tif,…” etc.
d. Post-processing Photo-induced Luminescence Images

iii. Correction of UV-induced Visible Luminescence Images

The workflow for the correction of UV-induced visible luminescence (UVL) images is designed to carry out correction for the factors affecting UV-induced visible luminescence images, as summarised in Table 3-1 and discussed in Chapter 1, and using the data collected as a result of the acquisition protocols outlined in Chapter 2. Figure 3-59 shows a schematic of the workflow developed in the nip2 software indicating both the transformations/corrections to be applied.

![Workflow diagram](image-url)

*Figure 3-59. Workflow for the correction of UV-induced visible luminescence (UVL) images in the nip2 post-processing workspace.*
The workflow is composed of the following steps:

1) Loading the input images converted from RAW:
   - UVL image for generating the calibration and associated flat-field image (if available).
   - UVL to be calibrated (can be the same as above image or another image taken with the same camera and under the same lighting conditions) and associated flat-field image (if available).

2) Converting the images to linear light (XYZ) using the embedded ICC profile(s).

3) Applying a flat-field correction to the images (if this option is checked).

4) Applying the camera colour calibration and white-point adjustment to the UVL images.

5) Image registration: aligning the calibrated VIS image and UVL image.

6) Mathematically reconstructing the ambient stray radiation:
   - From the VIS image and the Spectralon greyscale on the UVL image.

7) Subtracting the ambient stray radiation from the UVL image.

8) Correcting for the “pigment-binder” interaction (Kubelka-Munk).

9) Applying an output ICC profile which converts the calibrated UVL image to sRGB (or RGB16) colour space.

10) Saving the sRGB (or RGB16) corrected UVL image.

The images or other information required in order to complete the steps described in this workflow are summarised below, together with detailed instructions describing the workflow for the correction of UV-induced visible luminescence images.
Workflow for the correction of UV-induced visible luminescence (UVL) images.

Check that the all images or other information required in order to run this workspace is available:

- Calibrated VIS reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained by processing the corresponding visible-reflected image using the workflow for correction of visible-reflected images (See above);
- Calibrated UVR image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained by processing the corresponding IRR image using the workflow for correction of IR and/or UV-reflected images (See above);
- Camera output file – UVL image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) converted from RAW as per instruction in section a;
- ICC profile for conversion from RAW (contained within the TIFF file);
- Image of uniform reflective board under the experimental conditions of visible-induced infrared luminescence image for flat fielding, if available.

Loading the input images

1) Note that the previous workflow for correction of visible-reflected images and the workflow for correction of IR and/or UV-reflected images must already have been completed prior to running through this workflow. If this has not been done, return to sections i and ii, and proceed as directed before continuing.
2) Click on the “input” tab (Figure 3-60), the third column from the left (column G) holds the input images required for this workflow (correction of UV-induced visible luminescence images). If these were not uploaded previously, add them as directed below.

3) Images are opened by dragging them into the appropriate slot or by left-clicking on the thumbnail, clicking “Replace From File”, and selecting the image required (Figure 3-61).

(a) Load an image containing a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available into the top box on the “targets” thumbnail (Figure 3-61). This image will be used to generate the calibration and can be the image you want to correct or another image taken with the same camera and under the same lighting conditions. It can remain in place for batch-processing (see later) as long as the camera and lighting conditions remain the same.

(b) If available, load an image of a uniform reflective board (under the same experimental conditions) for flat fielding into the bottom box on the “targets” thumbnail and check the option to “Flatfield UV-induced visible luminescence with calibration targets image” (Figure 3-62). If this is not available leave this option unchecked.

(c) Load the image(s) you want to correct into the top box on the “object” thumbnail (Figure 3-62). This can be the same image as above or another frame (e.g. another frame in a series or a “twin” image not containing the spectralon diffuse reflectance standards, as described in Chapter 2 and shown in Figure 3-63) taken with the same camera and under the same lighting conditions.
(d) If available, load an image of a uniform reflective board (under the same experimental conditions of the image) for flat fielding into the bottom box on the “object” thumbnail (Figure 3-62 and Figure 3-63) and check the option to “Flatfield UV-induced visible luminescence of object image”. If this is not available leave this option unchecked (as in Figure 3-63).

Converting the images to linear light (XYZ) using the embedded ICC profile and applying a flat-field correction to the images.

4) Click on the “linear” tab to the right. Column J imports all the images in the “input” tab to linear light (Figure 3-64) and applies a flat-field correction to the images.

5) Scroll down. The resultant flat-fielded, linear light (XYZ) images can be observed in J16 (Figure 3-64).

6) Note that if an image of a uniform reflective board under the same experimental conditions of the images was not uploaded (or the options in the “input” tab indicated above were not checked), the images in the “targets” and “object” thumbnails are in linear light but no flat field correction has been applied to them.
Applying the camera colour calibration and white-point adjustment to the UVL images.

7) Click on the “uvlcalib” tab. Column A calculates the colour temperature adjustment required to compensate for the difference in colour temperature between D65 (the colour temperature at which the colour calibration is carried out for the VIS images - see workflow for the correction of VIS images) and the colour temperature at which the VIS images are acquired. This is described in more detail in Chapter 1.

8) Move the slider at A1 (Figure 3-65) to select the VIS illuminant colour temperature, from a source with known colour temperature (e.g. for a D50 flash, choose the 5000K) or as measured with a colour temperature meter. A9 shows the resultant white-point adjustment.

9) Scroll right to column B, which applies the colour calibration for the VIS image (automatically carried over to B1 from the “viscalib” tab) to the UVL images to be calibrated (automatically carried over to B2 from the “linear” tab).

10) The colour calibrated images can be seen at B3 (Figure 3-65). Note that the calibration is applied to the images at both the “target” and “object” thumbnails, which can be the same image (as in Figure 3-65) or another image taken with the same camera and under the same lighting conditions (Figure 3-66).

11) The adjustment is applied to the images at B3 to give the colour-calibrated and white point adjusted images at B6 (Figure 3-65 and Figure 3-66).

12) Figure 3-67 shows a comparison of one of the image sets discussed above before (right) and after calibration (left).
13) The sRGB (or RGB16) colour calibrated UVL images can be viewed and saved in the “results” tab (see later).

**Image registration: aligning the calibrated VIS and UVL images.**

14) Click on the “align” tab and scroll right. Column A registers the VIS and the UVL images (Figure 3-68).

15) Two sets of images are observed to allow the independent registration of the Spectralon diffuse reflectance standards in the images containing these (A2) and the images themselves (A3). This allows greater flexibility in order to address various scenarios:
   (a) Where the images used for calibration are the same images to be calibrated and no alteration in the position of the standards has occurred in the VIS vs. the UVL images (as in Figure 3-68). This would be the expected situation in a studio setting;
   (b) As above but some alteration in the position of the standards has occurred in the VIS vs. UVL images;
(c) Where the images used for calibration are not the same images to be calibrated, either because it is a “twin” image not containing the standards (as in Figure 3-71) or another frame taken with the same camera and lighting conditions. This may be the situation if carrying out work in the field where site constraints may not allow the standards to be easily included in the frame or if batch processing a number of different frames taken with the same camera and lighting conditions.

16) As with the previous workflow, alignment is carried out by selecting a pair of points in each image. The corresponding UVL images are rotated and scaled according to the position of these points in the corresponding images until these are aligned. The VIS images in the “reference” thumbnails are automatically carried over from the “viscalib” tab. The UVL images in the “adjust” thumbnails are carried over from the “linear” tab.

17) To align the Spectralon diffuse reflectance standards in the VIS and UVL images, double left-click on the A2 “reference” thumbnail to bring up the image view window containing the VIS image and two points, A2.ap1 and A2.ap2 (Figure 3-68). These should be automatically placed in the same locations as for the D26 “reference” VIS image. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”), respectively.

18) Double left-click on the A2 “adjust” thumbnail to bring up the image view window containing the corresponding UVL image (Figure 3-69). Move the points A2.bp1 and A2.bp2 to the same locations as for the VIS image. It may be useful to have the image view window containing the VIS image open simultaneously. If the image is too dark or light, click View > Toolbar and check the “Display Control” box. This will bring up a slider which allows the brightness to be adjusted. This change is purely for visual purposes and will not alter the data.
19) The points are moved by left-clicking and dragging on the label. Move these to indicate a pair of features on the standards which are recognisable in both images. Better accuracy is achieved if these points as far apart as possible. Note that it is not essential to use the standards themselves for the alignment (which may be difficult if, for example, the image is quite dark), as long as these are correctly aligned in both images. Note that the image will update in real time, which may cause a slight response delay in larger images.

![Image of the software interface with labeled points and alignment features]

Figure 3-69

20) To test the accuracy of the alignment, double left-click on the A2 “test_alignment” thumbnail (Figure 3-70).

21) Scroll down to the VIS and UVL images to be calibrated (A3). These can be the same as those in A2 (as shown in the above examples) or different images (as in Figure 3-71).

22) Double left-click on the A3 “reference” thumbnail to bring up the image view window containing the VIS image and two points, A3.ap1 and A3.ap2. These should be automatically placed in the same locations as for the D1 “reference” VIS image. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”) respectively.

23) Move these to indicate a pair of features which are recognisable in both images. Better accuracy is achieved if these points as far apart as possible. Note that the image will update in real time, which may cause a slight response delay in larger images.
24) Repeat the procedure for the UVL image by double left-clicking on the A3 “adjust” thumbnail (as in Figure 3-71) and moving the points A3.bp1 and A3.bp2 to the same locations as for the VIS image.

25) Test the accuracy of the alignment by double left-clicking on the A3 “test_alignment” thumbnail.
26) Click on the “uvlstray” tab. This uses the Spectralon diffuse reflectance standards in the UVL and corresponding VIS images to generate a mathematical reconstruction of the ambient stray radiation present in the UVL image (for more details see Chapter 1).

27) The positions of the Spectralon diffuse reflectance standards in UVL image are extracted from the alignments carried out in the “align” tab, as described above (Figure 3-72).

28) A matrix of values is created by subdividing the image into the number of standards present (this should be automatically carried over as the number of standards entered for the corresponding VIS image in the “markup” tab in the workflow for the correction of VIS images) and determining the average X, Y and Z values for each of these (Figure 3-72).

47) Double left-clicking on the “sample” thumbnail opens a window (C33.sample), which aids in the visualisation of the areas being sampled to create this matrix of values. As previously, a slider is provided for adjustment to ensure that the areas sampled are within the targets. Adjust as necessary for the available Spectralon diffuse reflectance standards. Note that this should not be necessary if the position of the targets has not moved significantly between frames and the alignment procedure was carried out in the previous tab.

48) If the image is too dark and the targets cannot be seen clearly, click View > Toolbar and check the “Display Control” box. This will bring up a slider which allows the brightness to be adjusted. This change is purely for visual purposes and will not alter the data.
29) Scroll right to column Q. This extracts the X, Y and Z values from the 99% Spectralon reflectance standard from the matrix generated for the UVL image (Q38, Figure 3-73). The corresponding values for the VIS image (Q39, Figure 3-73) are automatically carried over from the “viscalib” tab (as determined in the workflow for the correction of VIS images).

30) Images of the mathematically reconstructed ambient stray radiation present (Q3, Figure 3-73) are generated using the above values, as described in Chapter 1.

31) These are subtracted from the corresponding UVL images. The resultant images can be observed at Q47. Note that the images in the “targets” and “object” thumbnails can be the same image (as in Figure 3-74) or a different image. To view the images, double-click on the “targets” or “object” thumbnails (Figure 3-74).

32) Figure 3-75 shows a comparison of the image set discussed above before (right) and after subtraction of the ambient stray radiation (left).
Exposure compensation of the UVL image

33) Trials have shown that very bright UVL images are likely to incur RGB gamut clipping in nip2, leading to loss of colour information on conversion from XYZ to sRGB.¹¹
34) Column A allows the possibility to adjust the exposure (luminance values) of the UVL image using the slider provided (Figure 3-76), so that these are accommodated comfortably within the sRGB colour space gamut. However this should only be required if any of the XYZ values of the images in A1 are greater than 100.

35) Double-click on the “targets” or “object” thumbnails in A1 to view the images. The toolbar at the top gives live XYZ values at any point where the cursor is rested. If values greater than 100 are observed, adjust the slider shown.

36) The sRGB (or RGB16) UVL images corrected for ambient stray radiation (and exposure compensated, if required) can be viewed and saved in the “results” tab. Images of the mathematically reconstructed ambient stray radiation are also available in this column of the “results” tab (see later).

**Correcting for the “pigment-binder” interaction (Kubelka-Munk)**

37) Click on the “uvlkm” tab to the right (Figure 3-77). Column J uses the corrected VIS, UVR and UVL images (automatically carried over from the “viscalib”, “specden” and “uvlstray” tabs, respectively) to calculate $\gamma$, a function which expresses the extent to which the pigment particles absorb the light emitted by the luminescent materials (for more details see Chapter 1).

38) The resultant UVL images divided by the calculated $\gamma$ function can be observed in A1 (Figure 3-77). Note that the images in the “targets” and “object” thumbnails can be the same image (as above) or a different image. To view the images, double-click on the “targets” or “object” thumbnails (Figure 3-77).
Applying an output ICC profile which converts the corrected UVL image to sRGB (or RGB16) colour space.

39) Click on the “results” tab and scroll right to column C. An output ICC profile is automatically applied to the results of the “uvlcalib”, “uvlstray” and “uvlkm” tabs which converts the corrected UVL images to sRGB colour space (or RGB16) (Figure 3-78). The possibility to view and save these different stages in the correction of the image individually allows greater flexibility and choice in the post-processing procedure (e.g. a user may want to view the image after colour calibration but before the subtraction of ambient radiation).

![Figure 3-78](image)

40) The images in the “targets” and “object” thumbnails can be the same image or a different image.

Saving the sRGB (or RGB16) flat-field corrected UVL image

41) The sRGB (or RGB16) flat-field corrected UVL images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails (Figure 3-78).

42) Save the image from the image view window (“File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”. Note that the “Output depth” will be as selected in the “input” tab (Column I).

43) Double left-click on the “targets” and/or “object” thumbnails to open an image view window. Save the image by clicking on “File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”.
44) On the “Save Image” pop-up window (Figure 3-78):
   (a) Name the file according to the naming conventions outlined in Chapter 2;
   (b) Select “TIFF” from pull-down file format menu;
   (c) Click “Save” on the bottom right hand corner of the pop-up menu;
   (d) Repeat the process to save files in other formats such as JPEG, if required.

Batch-processing

45) If multiple images have been taken under the same lighting conditions, they can be processed as a batch. The images are loaded by left-clicking on the relevant “object” thumbnail, in the “input” tab and clicking “Replace From File”, and selecting the first image required, shift-clicking on the last image required, and pressing “Open”. The above steps will be applied to all the images selected.

46) The image in “objects” in the “results” tab will become a group of images. To save these left-click on the “objects” thumbnail, and click on “Save As”. Name the files according to the naming conventions outlined in Chapter 2. The images will be saved as “x_001.tif, x_002.tif, x_003.tif,…” etc.
iv. Correction of Visible-induced Infrared Luminescence Images

The workflow for the correction of VIL images is designed to carry out correction for the factors affecting visible-induced infrared luminescence images, as summarised in Table 3-1 and discussed in Chapter 1, and using the data collected as a result of the acquisition protocols outlined in Chapter 2. Figure 3-79 shows a schematic of the workflow developed in the nip2 software, indicating the transformations/corrections to be applied.

Figure 3-79. Workflow for the VIL workspace for the correction of visible-induced infrared luminescence images in the nip2 post-processing workspace.
The workflow is composed of the following steps:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1)    | Loading the input images converted from RAW:  
|       | – VIL image for generating the calibration and associated flat-field image (if available).  
|       | – VIL to be calibrated (can be the same as above image or another image taken with the same camera and under the same lighting conditions) and associated flat-field image (if available). |
| 2)    | Converting the images to linear light (XYZ) using the embedded ICC profile(s). |
| 3)    | Applying a flat-field correction to the images (if this option is checked). |
| 4)    | Generating monochrome images based on the output from a single channel (red channel for VIL images). |
| 5)    | Image registration: aligning the calibrated IRR image and VIL image. |
| 6)    | Mathematically reconstructing the ambient stray radiation:  
|       | – From the IRR image and the Spectralon greyscale on the VIL image. |
| 7)    | Subtracting the ambient stray radiation from the VIL image. |
| 8)    | Correcting for the “pigment-binder” interaction (Kubelka-Munk) |
| 9)    | Applying an output ICC profile which converts the calibrated VIL image to sRGB (or RGB16) colour space. |
| 10)   | Saving the sRGB (or RGB16) corrected VIL image. |

The images or other information required in order to complete the steps described in this workflow are summarised below, together with detailed instructions describing the workflow for the correction of visible-induced infrared luminescence images.
Workflow for the correction of visible-induced infrared luminescence (VIL) images.

Check that all images or other information required in order to run this workspace are available:

- Calibrated VIS reflected image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained by processing the corresponding visible-reflected image using the workflow for correction of visible-reflected images (See above);
- Calibrated IRR image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) obtained by processing the corresponding IRR image using the workflow for correction of IR and/or UV-reflected images (See above);
- Camera output file – VIL image (including a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available) converted from RAW as per instruction in section a;
- ICC profile for conversion from RAW (contained within the TIFF file);
- Image of uniform reflective board under the experimental conditions of visible-induced infrared luminescence image for flat fielding, if available.

Loading the input images

1) Note that the previous workflow for correction of visible-reflected images and the workflow for correction of IR and/or UV-reflected images must already have been completed prior to running through this workflow. If this has not been done, return to section i and ii, and proceed as directed before continuing.

2) Click on the “input” tab. Scroll along to the third column from the left and scroll down to column H. This holds the input images required for this workflow (correction of visible-induced infrared luminescence images). If these were not uploaded previously, add them as directed below. Open images by dragging them into the appropriate slot or left-click on the thumbnail, clicking “Replace From File”, and selecting the image required.

(a) Load an image containing a Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available into the top box on the “targets” thumbnail (Figure 3-80). This image will be used to generate the calibration and can be the image you want to correct or another image taken with the same camera and under the same lighting conditions. It can remain in place for batch-processing (see later) as long as the camera and lighting conditions remain the same.

Figure 3-80
(b) If available, load an image of a uniform reflective board (under the same experimental conditions) for flat fielding into the bottom box on the “targets” thumbnail and check the option to “Flatfield visible-induced IR luminescence with calibration targets image” (Figure 3-81). If this is not available leave this option unchecked.

(c) Load the image(s) you want to correct into the top box on the “object” thumbnail (Figure 3-81). This can be the same image as above or another frame (e.g. another frame in a series or a “twin” image not containing the spectralon diffuse reflectance standards, as described in Chapter 2) taken with the same camera and under the same lighting conditions.

(d) If available, load an image of a uniform reflective board (under the same experimental conditions of the image) for flat fielding into the bottom box on the “object” thumbnail (Figure 3-81) and check the option to “Flatfield visible-induced IR luminescence of object image”. If this is not available leave this option unchecked.

Converting the images to linear light (XYZ) using the embedded ICC profile and applying a flat-field correction to the images.

3) Click on the “linear” tab to the right. Column J imports all the images in the “input” tab to linear light (Figure 3-82) and applies a flat-field correction to the images.

4) Scroll down. The resultant flat-fielded, linear light (XYZ) images can be observed in J17 (Figure 3-82).

5) Note that if an image of a uniform reflective board under the same experimental conditions of the images was not uploaded (or the options in the “input” tab indicated above were not checked), the images in the “targets” and “object” thumbnails are in linear light but no flat field correction has been applied to them.
Generating monochrome images

6) Scroll right to column K. This generates monochrome images based on the output from a single channel (the red channel for VIL images). This is the procedure described as “mono-izing” in Chapter 1.

7) The resultant images can be observed in K9 (Figure 3-82).

Image registration: aligning the calibrated VIS image and VIL image.

8) Click on the “align” tab and scroll right. Column B registers the VIS and the VIL images (Figure 3-83).

9) Two sets of images are observed to allow the independent registration of the Spectralon diffuse reflectance standards in the images containing these (B2) and the images themselves (B3). This allows greater flexibility in order to address various scenarios:

(a) Where the images used for calibration are the same images to be calibrated and no alteration in the position of the standards has occurred in the VIS vs. the VIL images (as in Figure 3-83). This would be the expected situation in a studio setting;
(b) As above but some alteration in the position of the standards has occurred in the VIS vs. VIL images;
(c) Where the images used for calibration are not the same images to be calibrated, either because it is a “twin” image not containing the standards or another frame taken with the same camera and lighting conditions. This may be the situation if carrying out work in the field where site constraints may not allow the standards to be easily included in the frame or if batch processing a number of different frames taken with the same camera and lighting conditions.
10) As with the previous workflow, alignment is carried out by selecting a pair of points in each image. The corresponding VIL images are rotated and scaled according to the position of these points in the corresponding images until these are aligned. The VIS images in the “reference” thumbnails are automatically carried over from the “viscalib” tab. The VIL images in the “adjust” thumbnails are carried over from the “linear” tab.

11) To align the Spectralon diffuse reflectance standards in the VIS and VIL images, double left-click on the B2 “reference” thumbnail to bring up the image view window containing the VIS image and two points, B2.ap1 and B2.ap2 (Figure 3-83). These should be automatically placed in the same locations as for the D26 “reference” VIS image. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”), respectively.

12) Double left-click on the B2 “adjust” thumbnail to bring up the image view window containing the corresponding VIL image. Move the points B2.bp1 and B2.bp2 (Figure 3-84) to the same locations as for the VIS image. It may be useful to have the window containing the VIS image open simultaneously.

13) The points are moved by left-clicking and dragging on the label. Move these to indicate a pair of features on the standards which are recognisable in both images. Better accuracy is achieved if these points as far apart as possible. Note that it is not essential to use the standards themselves for the alignment (which may be difficult if, for example, the image is quite dark), as long as these are correctly aligned in both images. The image will update in real time, which may cause a slight response delay in larger images.

14) If the image is too dark or light, click View > Toolbar and check the “Display Control” box. This will bring up a slider which allows the brightness to be adjusted. This change is purely for visual purposes and will not alter the data.
15) To test the accuracy of the alignment, double left-click on the B2 “test_alignment” thumbnail (Figure 3-85).

16) Scroll down to the VIS and VIL images to be calibrated (B3). These can be the same as those in B2 (as shown in the above examples) or different images.
17) Double left-click on the B3 “reference” thumbnail to bring up the image view window containing the IRR image and two points, B3.ap1 and B3.ap2. These should be automatically placed in the same locations as for the D1 “reference” VIS image. Zoom in or out of the image as necessary by pressing “+” or “-” (or “i” or “o”) respectively. Note that the image will update in real time.

![Image Description](image_url)

**Figure 3-86**

18) Move these to indicate a pair of features which are recognisable in both images. Better accuracy is achieved if these points as far apart as possible.

19) Repeat the procedure for the VIL image by double left-clicking on the B3 “adjust” thumbnail and moving the points B3.bp1 and B3.bp2 (Figure 3-86) to the same locations as for the IRR image.

20) Test the accuracy of the alignment by double left-clicking on the B3 “test_alignment” thumbnail.

**Mathematically reconstructing the ambient stray radiation and subtracting it from the VIL image**

21) Click on the “vilstray” tab. This uses the Spectralon diffuse reflectance standards in the VIL and corresponding IRR images to generate a mathematical reconstruction of the ambient stray radiation present in the VIL image (for more details see Chapter 1).

22) The positions of the Spectralon diffuse reflectance standards in VIL image are extracted from the alignments carried out in the “align” tab, as described above (Figure 3-87).
23) A matrix of values is created by subdividing the image into the number of standards present (this should be automatically carried over as the number of standards entered for the corresponding VIS image in the “markup” tab in the workflow for the correction of VIS images) and determining the average X, Y and Z values for each of these (Figure 3-87).

24) Double left-clicking on the “sample” thumbnail opens a window (C33.sample), which aids in the visualisation of the areas being sampled to create this matrix of values. As previously, a slider is provided for adjustment to ensure that the areas sampled are within the targets. Adjust as necessary for the available Spectralon diffuse reflectance standards. Note that this should not be necessary if the position of the targets has not moved significantly between frames and the alignment procedure was carried out in the previous tab.

25) Scroll right to column Q. This extracts the X, Y and Z values from the 99% Spectralon reflectance standard from the matrix generated for the VIL image (Q38, Figure 3-88). The corresponding values for the IRR image (Q39, Figure 3-88) are automatically carried over from the x tab (as determined in the workflow for the correction of IRR images).

26) Images of the mathematically reconstructed ambient stray radiation present (Q3, Figure 3-88) are generated using the above values, as described in Chapter 1.

27) These are subtracted from the corresponding VIL images. The resultant images can be observed at Q47. To view the images, double-click on the “targets” or “object” thumbnails (Figure 3-89).
28) Figure 3-90 shows a comparison of the images before (right) and after subtraction of the ambient stray radiation (left).

29) The sRGB (or RGB16) VIL images corrected for ambient stray radiation can be viewed and saved in the “results” tab. Images of the mathematically reconstructed ambient stray radiation are also available in this column of the “results” tab (see later).

**Correcting for the “pigment-binder” interaction (Kubelka-Munk)**

30) Click on the “vilkm” tab (Figure 3-91). Column J uses the corrected VIS, IRR and VIL images (automatically carried over from the “viscalib”, “specden” and “vilstray” tabs, respectively) to calculate \( \gamma \), a function which expresses the extent to which the pigment particles absorb the light emitted by the luminescent materials (for more details see Chapter 1).
31) The resultant VIL images divided by the calculated $\gamma$ function can be observed in I1 (Figure 3-91). Note that the images in the “targets” and “object” thumbnails can be the same image (as above) or a different image. To view the images, double-click on the “targets” or “object” thumbnails (Figure 3-91).
Applying an output ICC profile which converts the corrected VIL image to sRGB (or RGB16) colour space.

32) Click on the “results” tab and scroll right to column C. An output ICC profile is automatically applied to the results of the “vilstray” and “vilkm” tabs which converts the corrected VIL images to sRGB colour space (Figure 3-92). The possibility to view and save these different stages in the correction of the image individually allows greater flexibility and choice in the post-processing procedure (e.g. a user may want to view the image after the subtraction of ambient radiation but before the correction for the pigment-binder interaction).

33) Note that the images in the “targets” and “object” thumbnails can be the same image (if image used to generate the calibration was also the image to be calibrated) or a different image.

Saving the sRGB (or RGB16) flat-field corrected VIL image

34) The sRGB (or rgb16) flat-field corrected VIL images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails.

35) Save the image from the image view window (“File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”. Note that the “Output depth” will be as selected in the “input” tab (Column I).

36) Double left-click on the “targets” and/or “object” thumbnails to open an image view window. Save the image by clicking on “File” > “Save Image as”) or by left-clicking on the thumbnail, and clicking on “Save As”.

Figure 3-92
37) On the “Save Image” pop-up window (Figure 3-92):
   (a) Name the file according to the naming conventions outlined in Chapter 2;
   (b) Select “TIFF” from pull-down file format menu;
   (c) Click “Save” on the bottom right hand corner of the pop-up menu;
   (d) Repeat the process to save files in other formats such as JPEG, if required.

**Batch-processing**

38) If multiple images have been taken under the same lighting conditions, they can be processed as a batch. The images are loaded by left-clicking on the relevant “object” thumbnail, in the “input” tab and clicking “Replace From File”, and selecting the first image required, shift-clicking on the last image required, and pressing “Open”. The above steps will be applied to all the images selected.

39) The image in “objects” in the “results” tab will become a group of images. To save these left-click on the “objects” thumbnail, and click on “Save As”. Name the files according to the naming conventions outlined in Chapter 2. The images will be saved as “x_001.tif, x_002.tif, x_003.tif,…” etc.
e. Calibrating monitors and printers

The calibration of monitors and printers is the last step in minimising device-dependent issues which inhibit the inter-comparison and interpretation of multispectral images. All the efforts invested into the collection of these images according to the optimised and standardised acquisition protocols (Chapter 2) and their calibration and correction using the post-processing methodology (Chapter 3), are perilously in vain if the means of visualising these images (typically on a screen or as print-outs) have not themselves undergone calibration. It should be noted that even in the case of linear images (as used in the post-processing software), a gamma function is always finally applied to visualise them on a screen.

The calibration of such devices is beyond the scope of this work, but affordable and accessible solutions to the problem of colour managing these resources are becoming increasingly available. The reader is therefore encouraged to refer to the AIC Guide to Digital Photography and Conservation Documentation and references contained therein for a more detailed consideration of this topic.
Appendix 3

i. Quick reference instructions for the operation of the post-processing workspace

Below are some quick reference instructions intended for use once familiarity with the operation of the workspace and the various workflows for the correction of the image types described has been achieved. Before commencing check that all images or other information required in order to run the workspace are available. For more details refer to workflows indicated.

Open the workspace and load the input images

1) Start nip2 and open the workspace as shown above. Under the “input” tab upload all the relevant images required to complete the workflows of interest. If available, upload the images of the corresponding uniform reflective boards under experimental conditions for flat fielding and check the associated “flatfield” boxes.

Straighten and extract the Macbeth chart and diffuse reflectance standards from the linearized, flat-fielded VIS image

2) Click on the “markup” tab to the right. Straighten and extract the Macbeth chart from the linearized, flat-fielded VIS image (see Workflow for the correction of visible-reflected (VIS) images).

3) Straighten and mark the position of the Spectralon diffuse reflectance grey scale or any number of Spectralon diffuse reflectance standards as available (see Workflow for the correction of visible-reflected (VIS) images).

Check on the average ∆E on generation of the colour calibration matrix

4) Click on the “viscalib” tab to the right. Check that the average ∆E (colour error) is less than or close to 5 available (see Workflow for the correction of visible-reflected (VIS) images).

Apply the camera colour calibration and white-point adjustment to the UVL images

5) If processing UVL images, click on the “uvicalib” tab to the right. Set the slider to the colour temperature of the illuminant used to capture the VIS image, e.g. for a D50 flash, choose the 5000K or as measured with a colour temperature meter (see Workflow for the correction of UV-induced visible luminescence (UVL) images).

Image registration: align the images to the VIS image

6) Click on the “align” tab to the right. Align the images in each column to the VIS image (see Workflow for the correction of IR and/or UV-reflected images and the generation of IR and/or UV-reflected false-colour images etc.).
### Match the brightness (luminance) of the IRR and/or UVR image to the calibrated VIS image

7) If processing the IRR and/or UVR images, click on the “specden” tab to the right. The spectral density correction of the IRR and UVR images is carried out by matching the luminance of these images to that of the calibrated VIS image (see **Workflow for the correction of IR and/or UV-reflected images and the generation of IR and/or UV-reflected false-colour images**).

8) Check that the areas being sampled to create the matrix of values for comparison with the VIS image are within the targets by double left-clicking on the “sample” thumbnail which opens a window (B9.sample). A slider is provided to adjust this as necessary for the available Spectralon diffuse reflectance standards, although this should not be necessary if the position of the targets has not moved significantly between frames and the alignment procedure was carried out in the previous tab.

### Generate the IRR and/or UVR false-colour image

9) If processing the IRR and/or UVR images, click on the “falsecolour” tab to generate the IRR and/or UVR false-colour images from the calibrated VIS image and the corrected IRR and/or UVR images (see **Workflow for the correction of IR and/or UV-reflected images and the generation of IR and/or UV-reflected false-colour images**).

10) To generate the IRR false-colour image, check that “X-RG” option is selected at K9. To generate the UVR false-colour image, check that “GB-X” option is selected at K2.

### Mathematically reconstruct the ambient stray radiation and subtract it from the UVL and/or VIL images

11) If processing UVL and/or VIL images, click on the “uvlstray” tab (or the “vilstray” tab for VIL images). This uses the Spectralon diffuse reflectance standards in the UVL (or VIL) and corresponding VIS images to generate a mathematical reconstruction of the ambient stray radiation present in the UVL (or VIL) image (for more details see Chapter 1).

12) Check that the areas being sampled to create the matrix of values for use in generating the mathematical reconstruction are within the targets by double left-clicking on the “sample” thumbnail which opens a window. A slider is provided to adjust this as necessary for the available Spectralon diffuse reflectance standards, although this should not be necessary if the position of the targets has not moved significantly between frames and the alignment procedure was carried out in the previous tab (see **Workflow for the correction of UV-induced visible luminescence (UVL) images**).

### Exposure compensation of the UVL image

13) If processing UVL images, the possibility to adjust the exposure (luminance values) of the UVL image using a slider is provided, so that these are accommodated comfortably within the sRGB colour space gamut. However this should only be required if any of the XYZ values of the images in A1 are greater than 100. (see **Workflow for the correction of UV-induced visible luminescence (UVL) images**).
14) Double-click on the “targets” or “object” thumbnails in A1 to view the images. The toolbar at the top gives live XYZ values at any point where the cursor is rested. If values greater than 100 are observed, adjust the slider shown.

**Apply an output ICC profile which converts the corrected images to sRGB (or RGB16) colour space and save the images**

15) Click on the “results” tab. An output ICC profile is automatically applied to the corrected images resulting from all the tabs, converting these to sRGB (or RGB16) colour space.

16) The sRGB (or RGB16) corrected images can be viewed by double left-clicking on the “targets” and/or “object” thumbnails.

17) Save the images from the image view window (“File” > “Save Image as”) or by left-clicking on the thumbnails, and clicking on “Save As”. Note that the “Output depth” will be as selected in the “input” tab (Column I).

**Save the workspace**

18) If required save the workspace for reference or further work (“File” > “Save Workspace As”).
References


www.vips.ecs.soton.ac.uk


8 http://en.wikipedia.org/wiki/RawTherapee


10 http://www.vips.ecs.soton.ac.uk/supported/current/doc/html/nipguide/nipguide.html


12 See for example; http://www.xrite.com/i1display-pro