Notes on Reprographic Photography

2011

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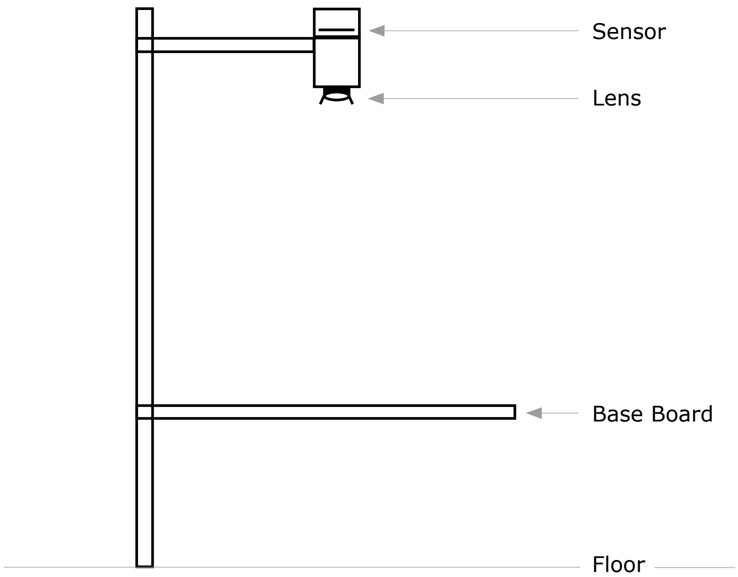
Camera Alignment

Reprographic photography typically employs the highest quality optics optimised for the required reproduction ratio, high resolution sensors, a rigid and stable copy stand incorporating three way geared heads and variable base board height, with flexible and easily variable lighting setups. The objects typically digitised with this hardware are either planar such as letters, etchings, photographs, and herbarium specimen sheets, or 3D objects with a shallow depth of field such as specimen trays less than 100mm in depth. Reproduction ratios typically vary from 1:1 to 1:20, and depending on the sensor's physical dimensions, cover objects from a few centimetres to over a metre in length. Smaller or larger 2D and 3D objects are usually more easily and accurately reproduced in a photographic studio or similar large space rather than via a copy stand setup.

Common to all copy stand arrangements is the importance of physically aligning the planes of the sensor, lens and base board to ensure even distortion free focus across the base board.



Digital SLR cameras like the Hasselblad already have their lenses perfectly aligned with the camera's sensor. This ensures the camera's alignment on a copy stand is as simple as aligning the lens and the baseboard, which can be easily accomplished with a spirit level.

For example, while standing in front of the camera mounted on the copy stand, place the lower surface of the spirit level horizontally across the centre of the base board and note the bubble's position. Next place the upper surface of the spirit level across the lower flange of the lens and adjust the yaw (side to side) of the camera's alignment until the spirit level's bubble is in exactly the same position as on the base board. Reorient the spirit level perpendicular to its original position and note the bubble's position, then adjust the camera's pitch (front to back) to match the base board. Mounting the camera to the copy stand via a heavy duty geared tripod head such as the *Manfrotto 405 Pro Digital Geared Head* effortlessly and quickly facilitates such precise pitch and yaw adjustments.

Aligning the yaw of a DSLR lens relative to the baseboard

When the sensor and lens are mounted on a technical camera (view camera) which unlike a DSLR camera, is typically identified by the bellows joining the sensor and lens planes, the plane of the sensor must also be manually checked and if necessary aligned relative to the lens and base board.

If the digital back has flat external surfaces that are parallel with its sensor the alignment can be accomplished without having to remove the digital back. If this is not the case the digital back (sensor) will first need to be removed from the technical camera so that the lower surface of the spirit level can be placed across the digital back's mounting plate.

When the copy stand is a portable setup or is moved to different locations a mechanism should be included to allow it to be quickly and precisely leveled even on an uneven floor. Also if the copy stand itself is not precisely aligned the sensor/lens/baseboard alignment might be inconsistent at different magnification ratios. This would be inefficent, though it is easy to eliminate if the copy stand's column is initially aligned in a vertical plane.

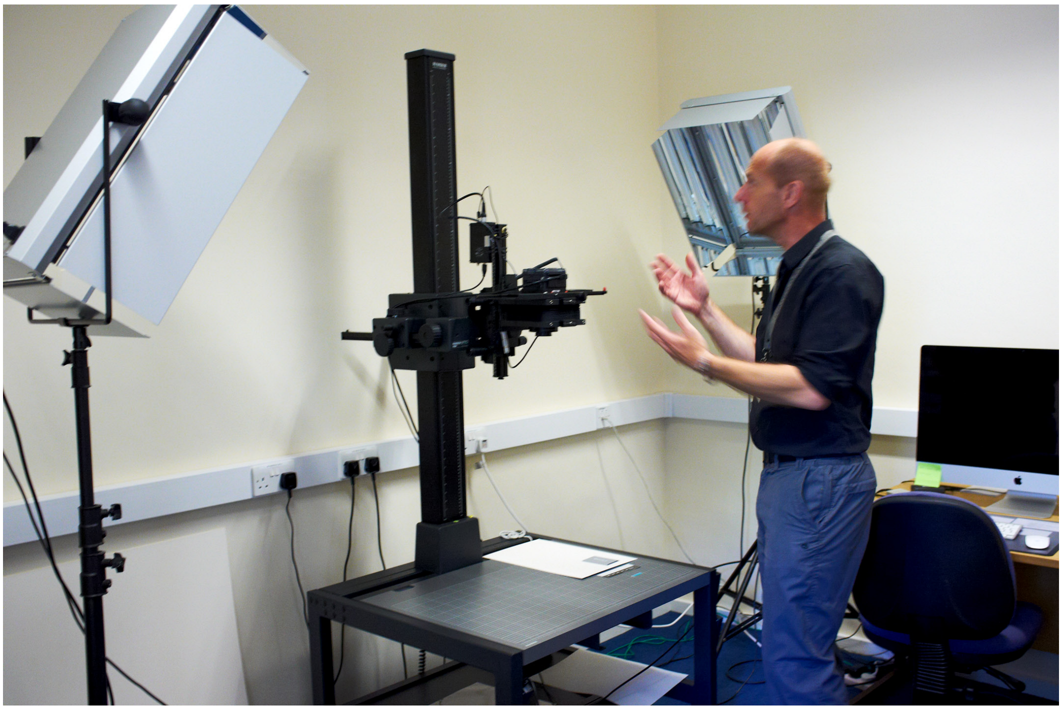
A correctly aligned copy stand, sensor, lens and base board will ensure even and consistent focus across the field of view. Objects will also be reproduced without distortion.

It is recommended that the alignment of the copy stand, baseboard and camera is checked at regular intervals and at least twice a year at a given location.

Lighting Setups

There are two basic lighting setups commonly employed in reprographic photography:

• Uniformly distributed (soft) shadowless lighting for flat 2D objects.



Kew Gardens, UK: Digitising the director's letters (1840 to 1930), 2011

• Asymetrical lighting with a single light source plus reflector for 3D objects.

Kew Gardens, UK: Digitising large herbarium specimens, 2011

An Adaptable Single Camera Lighting Setup

Single camera installations that have to perform a variety of digitising applications can be setup with two medium sized softboxes to provide maximum flexibility as follows: When both softboxes are turned on at the same power setting and are placed at an equal distance and angle from the object, the lighting will be soft and uniform which is ideal for flat 2D sheets, documents, photographs, letters and correspondance.

Muséum National d'Histoire Naturelle, Paris: Digitising herbarium specimens, 2011

When 3D specimens and objects need to be digitised, the left hand softbox's power output can be halved to provide a 1:2 lighting ratio across the object that will gently emphasise the object's morphology. Alternatively the left hand softbox can be turned off, and without having to move the softbox a silver reflector can be placed between it and the camera. This ensures there is only one set of shadows that are all cast in the same direction. This will most clearly (least unbiguously) describe the morphology of a complex 3D object.

The silver reflector also ensures the colour temperature of the 'fill light' illuminating the shadows is the same as the colour temperature of the 'key light' (the right hand softbox) illuminating the highlights. This arrangement maximises productivity and promotes consistency when multiple operators use the same single camera facilitiy over time.

Multiple shadows complicate and confuse our visual comprehension of an object. With multiple objects in close proximity, such as a drawer of insect specimens, completely shadowless lighting will generally provide the best rendering for multiple purposes, from archiving to taxonomy to metadata transcriptions.

Very soft 'enveloping' and shadowless lighting can be easily achieved by directing both softboxes upwards and reflecting their light off the ceiling. In this way the entire room becomes the light source virtually eliminating all shadows inside the tray.

Depth of Field

Drawers containing multiple specimens require sufficient depth of field (small f stop) to resolve all the specimens and identification labels throughout the depth of the drawer.

Small objects and specimens may need to be digitised in multiple planes of focus that are stacked in post production to capture the entire specimen with equal resolution. That is, when sufficient depth of field can't be obtained with the smallest non-diffraction limited lens aperture (f stop), exposures made at multiple planes of focus can be assembled together in post processing with software like ZereneStacker (www.zerenesystems.com) or Helicon Focus (www.heliconsoft.com), thereby extending the effective depth of field.

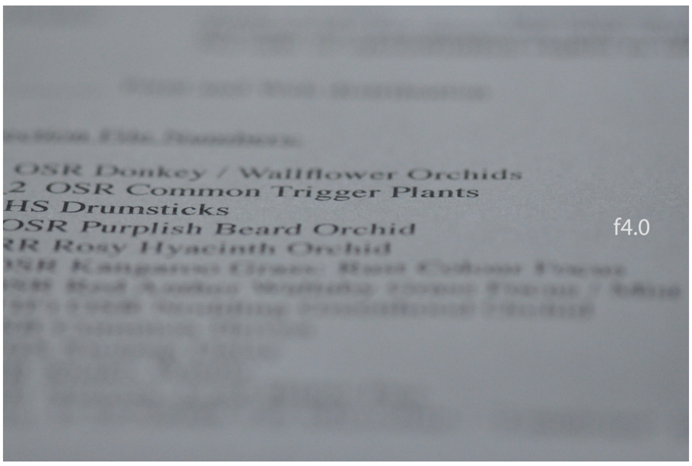
Calculating depth of field (DOF).

Depth of field defines the distance, from near to far, over which the object appears to be satisfactorily sharp and resolved. It is based on the lens to object distance, the focal length of the lens, the aperture and systems's Circle of Confusion.

$$\textbf{DOF near} = HD / H + D \qquad \textbf{DOF far} = HD / H - D$$

D = Lens to object distance
H = Hyperfocal Distance = L^2 / CF
L = Focal length (mm)
C = Circle of Confusion (mm)
F = Aperture (f stop)

The Hasselblad H4D-200MS system (with a minimum Circle of Confusion of 0.012mm) focused at a lens to object distance of 1928 mm (1:15 reproduction) and at the non-diffraction limited aperture of f 11 has an uncompromised depth of field of at least 75mm. Focused at a lens to object distance of 120 mm (1:1 reproduction) and f 11 aperture the depth of field decreases to only 5mm.



Shallow depth of field due to large aperture (f 4)

Depth of field tables that semi-automate depth of field calculations are freely available online and also as smart phone applications (www.dofmaster.com).

Diffraction Limiting in Optical Systems

Diffraction is the deviation of light as it passes an opaque edge, such as the aperture in a camera lens. This results in the lens forming a less well defined 'airy disk' of an otherwise sharply focused point, thereby limiting the maximum optical resolution of the lens according to the following formula:

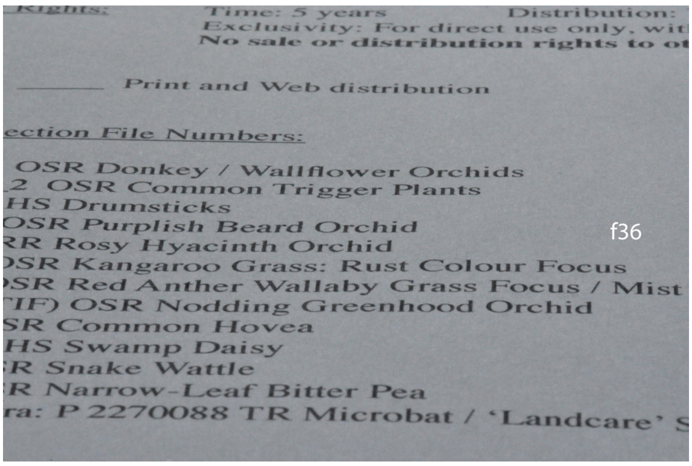
$$\mathbf{A = 2\ (1.22\ \lambda\ F)}$$

A = *diameter of the bright central spot of an airy disk (m)*
λ = *wavelength of light (550 x 10-9 m)*
F = *aperture (f stop)*

Nyquist's sampling theorem infers that twice the pixel pitch of a sensor is required to define a point on that sensor, which will also define the minimum Circle of Confusion for that system. Diffraction limiting will therefore be visible at 100% screen magnification when the airy disk exceeds a 2 x 2 pixel grid on the sensor. A Hasselblad H4D-200MS system has a pixel pitch of 6 microns, so the diagonal of a 2 X 2 pixel grid is 16.97 microns. Beyond this diameter an airy disk will be increasingly noticeable as an unsharp and unresolved point. The following airy disks (in microns) are calculated for the H4D-200MS:

f 16 = 21.47 **f 14** = 18.79 **f 13** = 17.45 **f 12** = 16.10 **f 11** = 14.76 **f 8** = 10.74

Given an f stop is a constant (the ratio of aperture to focal length) and that all Hasselblad lenses can resolve beyond their sensor's pixel limit, the system's diffraction limit is independent of the lens being used.



Large depth of field but diffraction limited at an f 36 aperture

In some circumstances diffraction limiting will not be a pictorial problem if other conditions have already limited the system's optical resolution. For example, camera and/or subject movement during exposure can reduce the resolution of the image more than diffraction; or if the resolution of the object is already less than the resolving power of the lens; or when the scale the image will be displayed or inspected at is less than 100% magnification, such is often the case with low resolution images accessed on the internet.

Calculating Copy Stand Layouts

Magnification = Length of Object ÷ Length of Sensor
Distance from the Sensor to Object = F $(M + 1)^2 \div M$
Area Covered = S x M

where F = *Focal length of lens,* M = *Magnification,* S = *Physical dimensions of sensor*

Example 1:

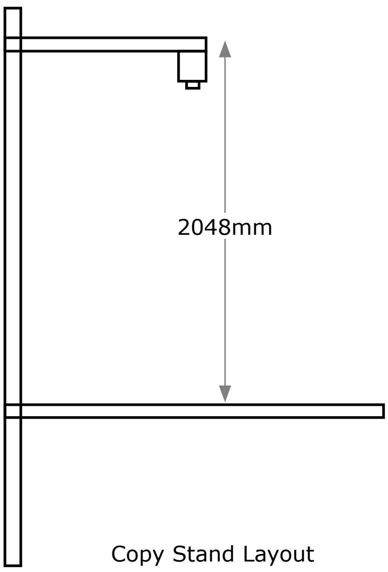
- Sensor = 49.0mm x 36.7mm
- Lens focal length = 80mm
- Distance from Sensor to Object = 2048mm
- Area covered = 1154.4mm x 864.7mm

Magnification = M = *1154.4mm ÷ 49mm = 23.56*
Distance Sensor to Object = $F (M + 1)^2 \div M = 80 (23.56 + 1)^2 \div 23.56 = 2048mm$
Area covered = S x M = *(49.0 x 23.56) x (36.7 x 23.56) = 1154.4mm x 864.7mm*

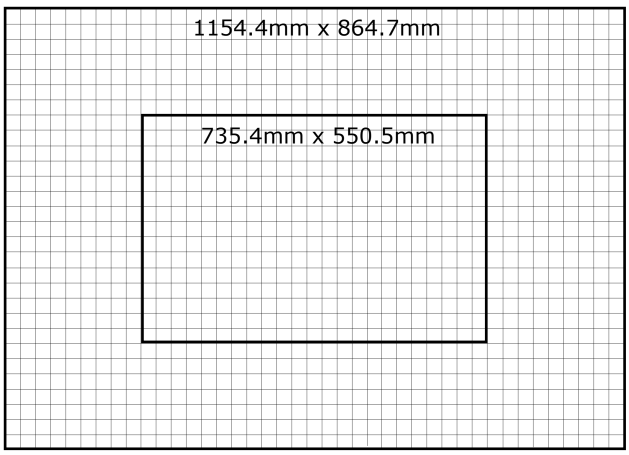
Example 2:

- Sensor = 49.0mm x 36.7mm
- Lens focal length = 120mm
- Distance from Sensor to Object = 2048mm
- Area covered = 735.0mm x 550.5mm

Magnification = M = *735.0mm ÷ 49mm = 15*
Distance Sensor to Object = $F (M + 1)^2 \div M = 120 (15 + 1)^2 \div 15 = 2048mm$
Area covered = S x M = *(49.0 x 15) x (36.7 x 15) = 735.0mm x 550.5mm*



Copy Stand Layout



Baseboard Layout

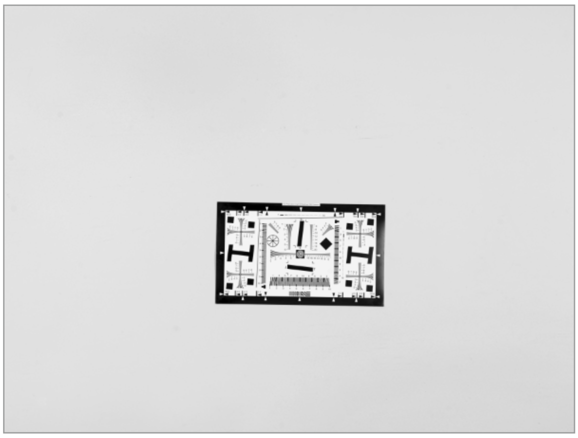
Scene Calibration

Reprographic photography aims to faithfully reproduce the subject. Even lighting across the subject is particularly important with 2D works such as works on paper. Even the most carefully setup lighting and finest optics will not ensure perfectly even lighting and reproduction. Local variations including lighting reflector hot spots, lighting and lens vignetting (light fall off), and sensor and lens colour casts result in uneven colorimetric reproduction.

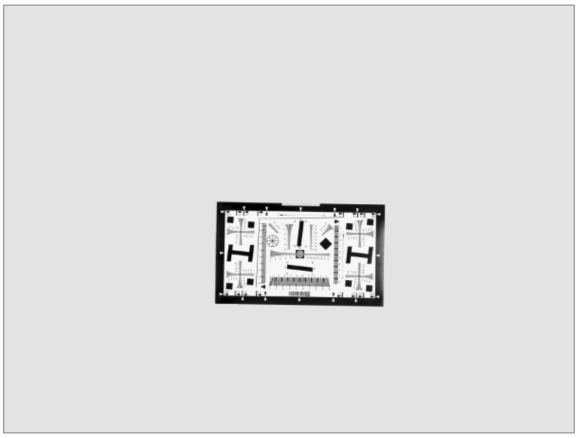
Propriety software for medium format cameras such as Hasselbald's Phocus raw processing software includes a Scene Calibration option that enables lighting, sensor and lens cast variations to be automatically corrected. Phase One's Capture One Pro software has a Light Cast Calibration (LCC) feature in its Lens Correction panel, Leaf Capture uses a Lens Calibration File, and Sinar CaptureShop uses a White Reference File to achieve similar corrections.

The basic procedure for applying a Scene Calibration correction to an image involves initially photographing an even and smooth white surface such as matt or foam board placed on the baseboard and captured with the same lens focus, aperture settings and lighting as will be used to capture the object. After processing and analysis the 'white reference' file is automatically applied by the processing software to the raw capture to correct any lens and lighting fall off and/or colour casts.

For propriety processing software that doesn't contain a scene or lens cast calibration utility, similar results can be obtained with Robin Myers EqualLight software (www.rmimaging.com) that is used in a similar way to correct processed RGB TIFF files.



Before Scene Calibration



After Scene Calibration

Alternatively a white perspex diffuser can be placed in front of the camera lens to create a 'lens cast' file that is applied in a similar manner to correct lens (and sensor) fall off and colour casts. However a lens cast file can not correct fall off and local colour casts in the lighting setup, only in the lens and camera system.

A Scene Calibration should also be applied when photographing camera profiling targets to ensure the most accurate custom ICC camera profiles and colour reproduction.

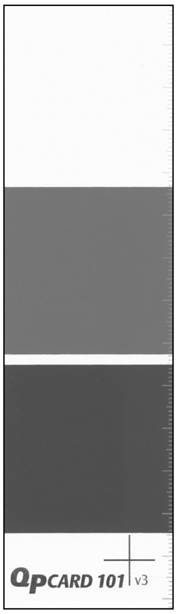
Quality Control and Assurance

Including a neutral reference target within the field of capture is essential for both the white balancing (colour balancing) of the capture as well as its future interpretation. The inclusion of a scale or ruler will also assist the interpretation of objects whose size has not already been recorded. When colour reproduction is important a colour reference such as the ubiquitous Munsell 24 Patch ColorChecker (www.xrite.com) should also be included.

Placing the reference targets within the field of capture but outside of the object area will facilitate the later cropping of the original image in the production of derivatives for secondary applications where the reference targets aren't required.

Measuring and charting the values of the reproduced reference targets will also provide evidence over time of consistency and accuracy in the digitisation of a collection. Deviations from the established reference values will also signal a process error that can be immediately corrected. This simple verification from image to image guarantees the captured data is consistent from day to day, work station to work station, and operator to operator.

At the very least a QP Card (www.qpcard.se) should be included in every image with its mid grey patch rendered as L* 48, a* 0, b* 0. In practice this involves adjusting the camera exposure and/or lighting until the mid grey patch reads L* 48, which is then white balanced (neutralised) during Raw processing.



QP Card 101 v3

It is important to place reference targets in the same plane of focus and lighting as the main subject and without any surface reflections.

Handle reference targets with care and discard when visible damage or soiling occurs.

Large objects may require more than one reference target to provide adequate reporting across the field of capture. With very large objects custom reference targets might need to be considered to ensure they will be reproduced large enough to be measured and verified.


Munsell ColorChecker Classic

Values for each patch in a reference target are provided by the target manufacturer, and multiple patches can be used in proportion to the required level of quality control and assurance, though in practice too many patches may only reduce productivity without any improvement in quality. The placement of reference targets is relatively easy in 2D works, but much more difficult with 3D objects. In both cases it is critical that the target is in the same plane of focus and receives the same lighting and exposure as the main subject.