Federal Agencies
Digital Guidelines Initiative

September 2016

Technical Guidelines for Digitizing Cultural Heritage Materials

Creation of Raster Image Files

Revisions:

These *Guidelines* reflect current best practices shared by members of FADGI. We anticipate they will change as technology and industry standards, as well as institutional approaches, improve over time. As the technical arenas of conversion, imaging, and metadata are highly specialized and constantly evolving, we envision these *Guidelines* to be a continually evolving document as well. The *Guidelines* will be collectively reviewed by participating agencies at regular intervals and updated as necessary.

We welcome your comments and suggestions.

Please note that the **online version** of the *Guidelines* is considered to be the official document.

The FADGI Star System

FADGI defines four quality levels of imaging, from 1 star to 4 star. Higher star ratings relate to more consistent image quality, but require greater technical performance of both operator and imaging system to achieve. The appropriate star performance level for a particular project should be carefully considered in the planning stage of the project.

Conceptually the FADGI four star system aligns with the Metamorfoze[1] three tier system, with a fourth tier (1 star) on the lower end of the performance scale. Both FADGI and Metamorfoze trace their metrics to emerging ISO standards efforts. While similar, there are differences.

This revision of the *Guidelines* more fully expands the use of colorimetric measures like L*a*b* color and ∆E(a*b*) 2000 measurements. These changes align FADGI with ISO TC42/WG18 protocols and Metamorfoze guidelines. Count values metrics (e.g. white balance +/- 3 counts) shown are for reference to the original FADGI specifications and are not precisely matched to the new values.

The star system ratings are summarized below. It is important to understand that the star ratings system is an indicator of acceptability of higher error relative to an aim value (i.e. accuracy). Four star requires much less error tolerance relative to an aim than a one star requirement.

- One star imaging should only be considered informational, in that images are not of a sufficient quality to be useful for optical character recognition or other information processing techniques. One star imaging is appropriate for applications where the intent is to provide a reference to locate the original, or the intent is textual only with no repurposing of the content.

- Two star imaging is appropriate where there is no reasonable expectation of having the capability of achieving three or four star performance. These images will have informational value only, and may or may not be suitable for OCR.

- Three star imaging defines a very good professional image capable of serving for almost all uses.

- Four star defines the best imaging practical today. Images created to a four star level represent the state of the art in image capture and are suitable for almost any use.

Our mission is to define what is practical and achievable today, and provide you with the knowledge and the tools to achieve your intended FADGI compliance level.

Generally, in order to avoid future rescanning and given the high costs and effort for digitization projects, FADGI does not recommend digitizing to less than three-star. This assumes availability of suitable high-quality digitization equipment that meets the assessment criteria described (see the section on Quantifying Scanner/Digital Camera Performance), and produces image files that meet the minimum quality described in the *Technical Guidelines*. If digitization equipment fails any of the assessment criteria or is unable to produce image files of minimum quality, then it may be desirable to invest in better equipment or to contract with a vendor for digitization services.

[1] http://www.metamorfoze.com/english/digitization

TECHNICAL OVERVIEW

Spatial Resolution

Spatial resolution determines the amount of information in a raster image file in terms of the number of picture elements or pixels per unit of measurement, but it does not define or guarantee the quality of the information. Spatial resolution defines how finely or widely spaced the individual pixels are from each other. The higher the spatial resolution, the more finely pixels are spaced and the higher the number of pixels overall. The lower the spatial resolution, the more widely pixels are spaced and the fewer the number of pixels overall.

Spatial resolution is measured as pixels per inch or PPI; pixels per millimeter or pixels per centimeter are also used. Resolution is often referred to as dots per inch or DPI. In common usage, the terms PPI and DPI are used interchangeably. Since raster image files are composed of pixels, technically PPI is a more accurate term and is used in this document (one example in support of using the PPI term is that Adobe Photoshop software uses the pixels per inch terminology). DPI is the appropriate term for describing printer resolution (actual dots vs. pixels); however, DPI is often used in scanning and image processing software to refer to spatial resolution and this usage is an understandable convention.

The spatial resolution and the image dimensions determine the total number of pixels in the image; an 8”x10” photograph scanned at 100 ppi produces an image that has 800 pixels by 1000 pixels or a total of 800,000 pixels. The numbers of rows and columns of pixels, or the height and width of the image in pixels as described in the previous sentence, is known as the pixel array. When specifying a desired file size, it is always necessary to provide both the resolution and the image dimensions; for example 300 ppi at 8”x10” or even 300 ppi at original size.

The image file size, in terms of data storage, is proportional to the spatial resolution (the higher the resolution, the larger the file size for a set document size) and to the size of the document being scanned (the larger the document, the larger the file size for a set spatial resolution). Increasing resolution increases the total number of pixels, resulting in a larger image file. Scanning larger documents produces more pixels resulting in larger image files.

Higher spatial resolution provides more pixels, and generally will render more fine detail of the original in the digital image, but not always. The actual rendition of fine detail is more dependent on the spatial frequency response (SFR) of the scanner or digital camera (see Quantifying Scanner/Digital Camera Performance below), the image processing applied, and the characteristics of the item being scanned.

Signal Resolution

Bit-depth or signal resolution, sometimes called tonal resolution, defines the maximum number of shades and/or colors in a digital image file, but does not define or guarantee the quality of the information.

In a 1-bit file each pixel is represented by a single binary digit (either a 0 or 1), so the pixel can be either black or white. There are only two possible combinations or $2^1 = 2$.

A common standard for grayscale and color images is to use 8 bits (eight binary digits representing each pixel) of data per channel and this provides a maximum of 256 shades per channel ranging from black to white; $2^8 = 256$ possible combinations of zeroes and ones.

High-bit or 16-bits (16 binary digits representing each pixel) per channel images can have a greater number of shades compared to 8-bit per channel images, a maximum of over 65,000 shades vs. 256 shades; 2^{16} - 65,536 possible combinations of zeroes and ones.

Well done 8 bits per channel imaging will meet most needs - with a limited ability for major corrections, transformations, and re-purposing. Gross corrections of 8-bit per channel images may cause shades to drop out of the image, creating a posterization effect due to the limited number of shades.

High-bit images can match the effective shading and density range of photographic originals (assuming the scanner is actually able to capture the information), and, due to the greater shading (compared to 8 bits per channel), may be beneficial when re-purposing images and when working with images that need major or excessive adjustments to the tone distribution and/or color balance.

Color Mode

Grayscale image files consist of a single channel, commonly either 8 bits (256 levels) or 16 bits (65,536 levels) per pixel with the tonal values ranging from black to white. Color images consist of three or more grayscale channels that represent color and brightness information. Common color modes include RGB (red, green, blue), CMYK (cyan, magenta, yellow, black), and L*a*b* (lightness, red-green, blue-yellow). The channels in color files may be either 8- bits (256 levels) or 16-bits (65,536 levels). Display and output devices mathematically combine the numeric values from the multiple channels to form full color pixels, ranging from black to white and to full colors.

RGB represents an additive color process: red, green, and blue light are combined to form white light. This is the approach commonly used by computer monitors and televisions, film recorders that image onto photographic film, and digital printers/enlargers that print to photographic paper. RGB files have three color channels: 3 channels x 8- bits = 24-bit color file or 3 channels x 16-bits = 48-bit color. All scanners and digital cameras create RGB files by sampling for each pixel the amount of light passing through red, green, and blue filters that is being reflected or transmitted by the item or scene being digitized. Black is represented by combined RGB levels of 0-0-0, and white is represented by combined RGB levels of 255-255-255. This is based on 8-bit imaging and 256 levels from 0 to 255; this convention is used for 16-bit imaging as well, despite the greater number of shades. All neutral colors have equal levels in all three color channels. A pure red color is represented by levels of 255-0-0, pure green by 0-255-0, and pure blue by 0-0-255.

CMYK files are an electronic representation of a subtractive process: cyan (C), magenta (M), and yellow (Y) are combined to form black. CMYK mode files are used for prepress work and include a fourth channel representing black ink (K). The subtractive color approach is used in printing presses (four color printing), color inkjet, and laser printers (four color inks, many photo inkjet printers now have more colors), and almost all traditional color photographic processes (red, green, and blue sensitive layers that form cyan, magenta, and yellow dyes).

L*a*b* color mode is a device independent color space that is matched to human perception: three channels representing lightness (L, equivalent to a grayscale version of the image), red and green information (A), and blue and yellow information (B). One benefit of L*a*b* mode is that it is matched to human perception, and also L*a*b* mode does not require color profiles (see section on color management). Disadvantages of L*a*b* include the potential loss of information in the conversion from the RGB mode files from scanners and digital cameras, the need to have high-bit data, and the fact that few applications and file formats support it.

Avoid saving files in CMYK mode. CMYK files have a significantly reduced color gamut (see section on color management) and are not suitable for master image files for digital imaging projects involving holdings/collections in cultural institutions. The conversion from RGB to CMYK involves the replacement of a portion of the neutral color with black (K). This conversion is not reversible back to RGB without the loss of color accuracy.

While theoretically L*a*b* may have benefits, at this time we feel that RGB files produced to the color and tone reproduction described in these *Guidelines* and saved with an appropriate ICC profile, are the most practical option for master files and are relatively device independent. We acknowledge that the workflow described in these *Guidelines* to produce RGB master files may incur some level of loss of data; however, we believe the benefits of using RGB files brought to a common rendering outweigh the minor loss.

Quantifying Scanner/Digital Camera Performance

Much effort has gone into quantifying the performance of scanners and digital cameras in an objective manner. The following tests are used to check the capabilities of digitization equipment, and provide information on how to best use the equipment.

Even when digitization equipment is assessed as described below, it is still necessary to have knowledgeable and experienced staff to evaluate images visually. At this time, it is not possible to rely entirely on the objective test measurements to ensure optimum image quality. It is still necessary to have staff with the visual literacy and technical expertise to do a good job with digitization and to perform quality control for digital images. This is true for the digitization of all types of original materials, but very critical for the digitization of photographic images in particular.

Also, these tests are useful when evaluating and comparing scanners and digital cameras prior to purchase. Ask manufacturers and vendors for actual test results, rather than relying on the specifications provided in product literature, as performance claims in product literature are often overstated. If test results are not available, then try to scan test targets during a demonstration and analyze the target files with DICE or have them reviewed by an analysis service.

During digitization projects, tests should be performed on a routine basis to ensure scanners and digital cameras/copy systems are performing optimally. Again, if it is not possible to analyze the tests in-house, then consider having a service perform the analyses on the resulting image files.

The following standards either are available or are in development. DICE covers all of these elements. These are noted only as a reference for those who are interested in an advanced understanding of the standards.

Terminology	ISO 12231
Opto-Electronic Conversion Function	ISO 14524
Resolution: Still Picture Cameras	ISO 12233
Resolution: Print Scanners	ISO 16067-1
Resolution: Film Scanners	ISO 16067-2
Noise: Still Picture Cameras	ISO 15739
Dynamic Range: Film Scanners	ISO 21550
Best Practices for Digital Image Capture of Cultural Heritage Materials	ISO 19263
Image Quality Analysis –Part 1 Reflective Originals	ISO 19264

These standards can be purchased from ISO at http://www.iso.ch or from IHS Global at http://global.ihs.com. At this time, test methods and standards do not exist for all testing and device combinations. However, many tests are applicable across the range of capture device types and are cited in the existing standards as normative references.

Other test methods may be used to quantify scanner/digital camera performance. We anticipate there will be additional standards and improved test methods developed by the group working on the above standards.

No digitization equipment or system is perfect. They all have trade-offs in image quality, speed, and cost. The engineering of scanners and digital cameras represents a compromise, and for many markets image quality is sacrificed for higher speed and lower cost of equipment. Many document and book scanners, office scanners (particularly inexpensive ones), and high-speed scanners (all types) may not meet the limits specified, particularly for properties like image noise. Also, many office and document scanners are set at the default to force the paper of the original document to pure white in the image, clipping all the texture and detail in the paper (not desirable for most originals in collections of cultural institutions). These scanners will not be able to meet the desired tone reproduction without recalibration (which may not be possible), without changing the scanner settings (which may not overcome the problem), or without modification of the scanner and/or software (not easily done).

Test Frequency and Equipment Variability

After equipment installation and familiarization with the hardware and software, an initial performance capability evaluation should be conducted using the DICE system to establish a baseline for each specific digitization device.

Many scanners can be used both with the software/device drivers provided by the manufacturer and with third-party software/device drivers. However, it is best to characterize the device using the specific software/device drivers to be used for production digitization. Also, performance can change dramatically (and not always for the better) when software/device drivers are updated; therefore, it is best to characterize the device after every update.

DICE testing should be performed at the beginning of each work day, or at the start of each batch, whichever comes first. Testing at the beginning and at the end of each batch to confirm that digitization was consistent for the entire batch is desirable. Scanner/digital camera performance will vary based on actual operational settings. Tests can be used to optimize the scanner/camera settings. The performance of individual scanners and digital cameras will vary over time. Also, the performance of different units of the same model scanner/camera will vary. Test every individual scanner/camera with the specific software/device driver combination(s) used for production. Perform DICE test(s) any time there is an indication of a problem. Compare these results to past performance through a cumulative database. If large variability is noted from one session to the next for given scanner/camera settings, attempt to rule out operator error first.

Reference Targets

FADGI Recommendations

Include reference targets in each image of originals being scanned including, at a minimum, a gray scale, color reference, and an accurate dimensional scale.

- If a target is included in each image, consider making access derivatives from the production masters that have the reference target(s) cropped out. This will reduce file size for the access files and present an uncluttered appearance to the images presented.
- All types of tone and color targets should be replaced on a routine basis. As the targets are used they will accumulate dirt, scratches, and other surface marks that reduce their usability.
- Transmission targets are available from a variety of sources for color references, but only B&W targets are currently available for analysis with DICE.

Alternative Approach

In a high production environment, it may be more efficient to scan targets separately and do it once for each batch of originals.

- The one target per batch approach is acceptable as long as all settings and operation of the equipment remains consistent for the entire batch, and any image processing is applied consistently to all the images.
- For scanners and digital cameras that have an “auto range” function, the single target per batch approach may not work because the tone and color settings will vary due to the auto range function, depending on the density and color of each original.

Placement of Target

Position the target close to, but clearly separated from, the originals being scanned. There should be enough separation to allow easy cropping of the image of the original to remove the target(s) if desired, but not so much separation between the original and target(s) that it dramatically increases the file size.

- If it fits, orient the target(s) along the short dimension of originals. That will produce smaller file sizes compared to having the target(s) along the long dimension. For the same document, a more rectangular shaped image file is smaller than a squarer image.

- Smaller versions of targets can be created by cutting down the full-size targets. Do not make the tone and color targets so small that it is difficult to see and use the targets during scanning. That is particularly important when viewing and working with low resolution image previews within scanning software.
- For digital copy photography set-ups using digital cameras when digitizing items that have depth, it is important to make sure all reference targets are on the same level as the image plane. For example, when digitizing a page in a thick book, make sure the reference targets are at the same height/level as the page being scanned.

Illumination

Make sure that the illumination on the targets is uniform in comparison to the lighting of the item being scanned. Avoid hot spots and/or shadows on the targets. Position targets to avoid reflections.

- If the originals are digitized under glass, place the tone and color reference targets under the glass as well.
- If originals are encapsulated or sleeved with polyester film, place the tone and color reference targets into a polyester sleeve.

Appendix:

This appendix describes the implementation details of the imaging quality measurements in OpenDICE.

Sampling frequency

With an input target image, OpenDICE identifies the feature points, for example, the four border corners of the DICE target and the white cross points at the corners of the ColorChecker SG target (see the red circles in Figure 1), based on which the Euclidean distance (number of pixels) between two feature points can be calculated. The sampling frequency is then computed as the ratio of the pixel number to the pre-measured distance (inches) on the target board.

Using the feature points as the reference, OpenDICE identifies the regions of interest (ROI); see Figure 2, including the color and gray patches, and the edge patches.

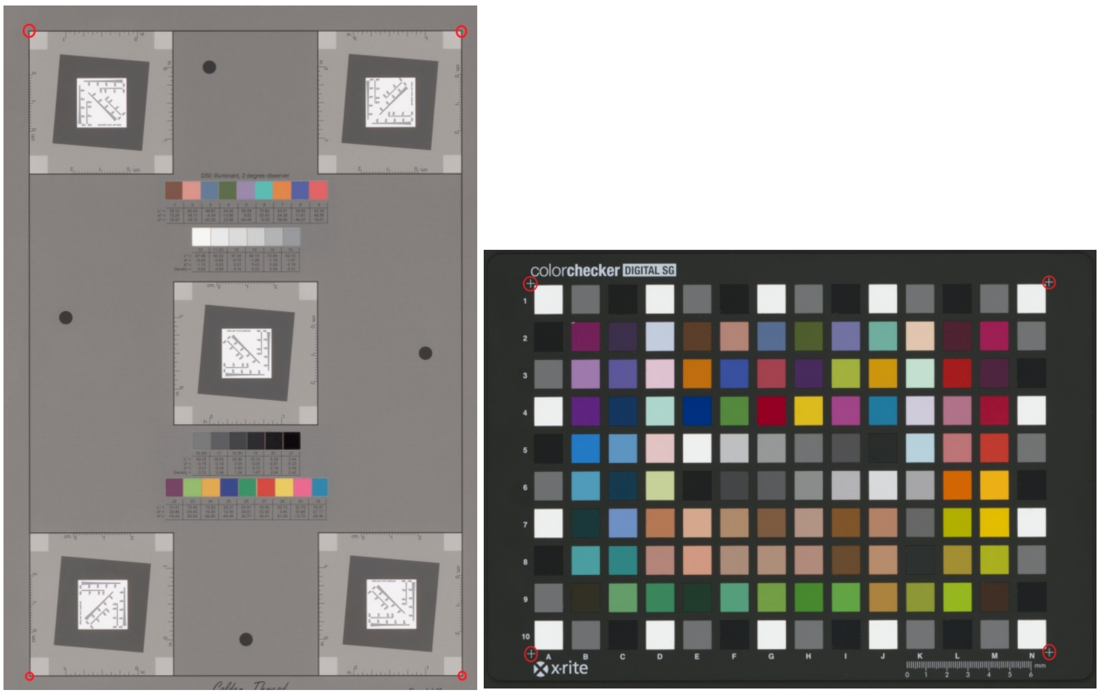

Figure 1. Feature points identified by OpenDICE to measure the sampling frequency

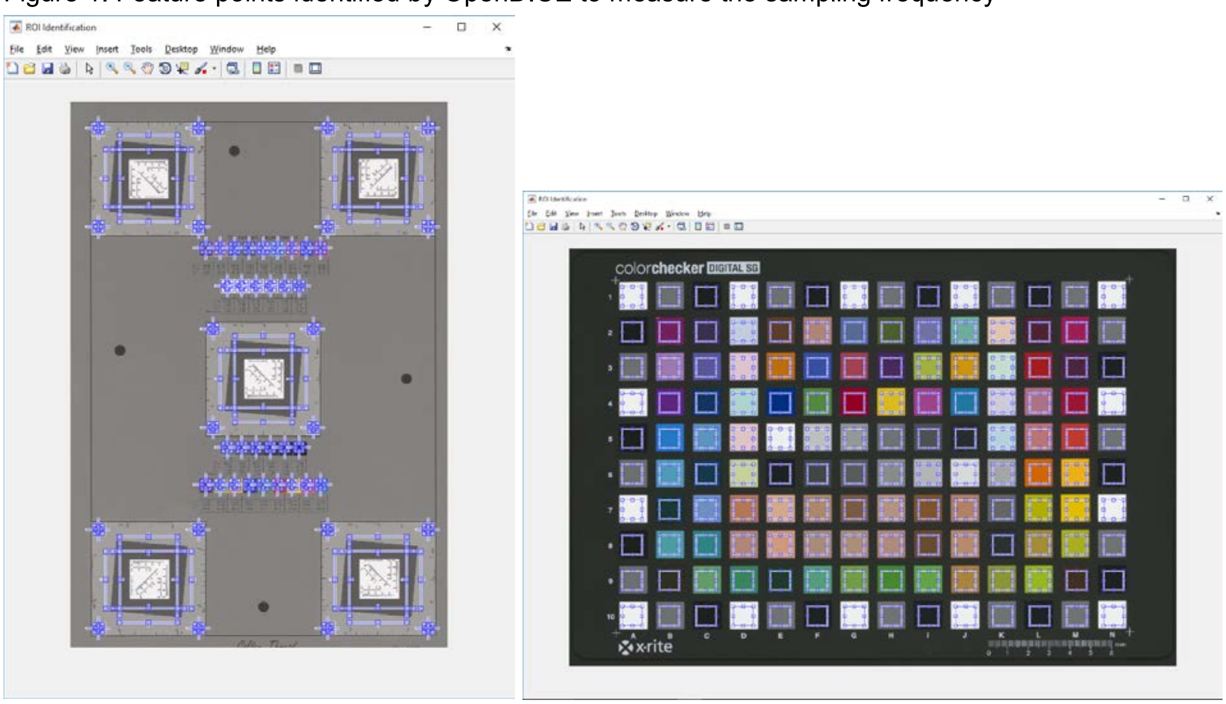

Figure 2. Target regions of interest for imaging quality factor measurements

Tone Response (Opto-Electronic Conversion Function)

Given the input target gray patch (DICE target patches 10 – 21, Colorchecker SG target patches E5 – J6, see Figure 2) density values, OpenDICE draws the OECF curves for each of the RGB and luminance channels. The patch density values may be obtained from the manufacturer's specifications or measured by the users. The desired intensity values are computed as
$I = 255*(10^{-D/\gamma} - b)/a$. OpenDICE provides the interface for users to change the parameter settings. The default values are γ (gamma) = 2.2, gain (a) = 1, and offset (b) = 0.

The imaging intensity values are then compared with the desired values for the difference, which is drawn according to the user pre-selection of the FADGI criteria level.

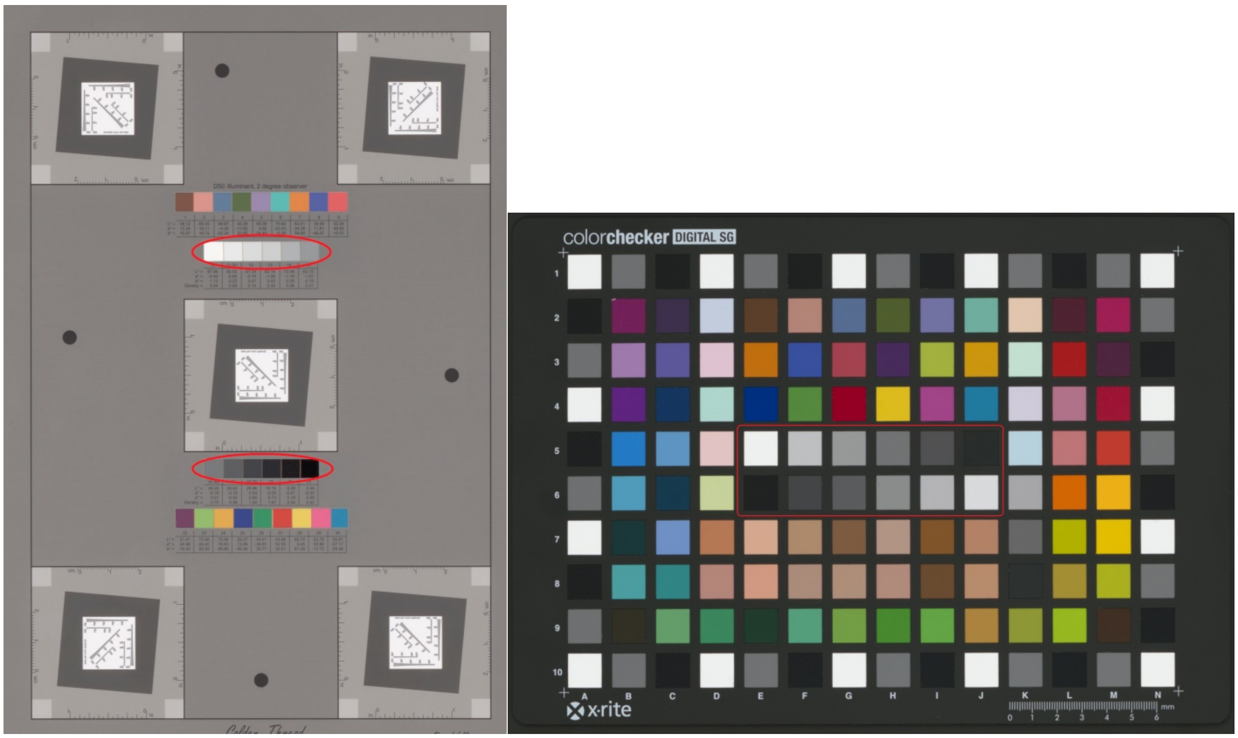

Figure 3. Target gray patches for OECF, white balance, and noise measurements

White Balance Error

Given the input target gray patch (Figure 3) intensity values, OpenDICE computes the channel differences as the white balance error, i.e., B – R, G – R, and G – B.

Illuminance Non-uniformity

Given the input target gray patch (Figure 4) intensity values, OpenDICE computes the non-uniformity metric as: (maxI – minI)/meanI, where the maximum, minimum, and mean intensity values are obtained separately for different locations on the target image. For example, DICE target uses the light gray patches at the top left, top right, center, bottom left, and bottom right locations to compute this metric (see Figure 4), which are different from the gray patches used for tone response, noise, and white balance error computation. The Colorchecker SG target does not support this function.

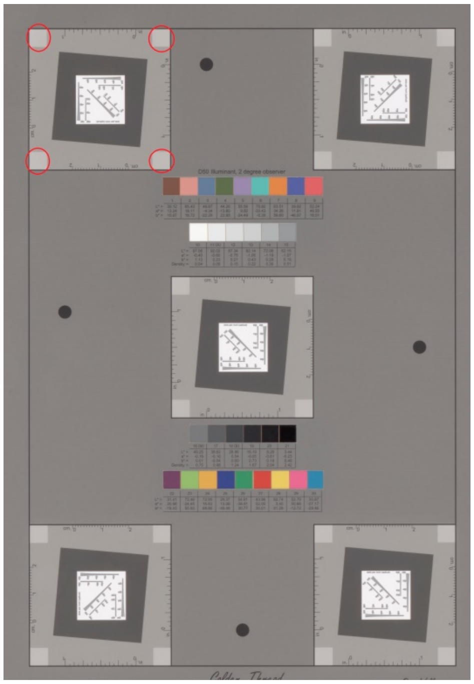

Figure 4. ROIs for the illuminance non-uniformity computation (top left)

Color Accuracy

Given the input target color and gray patch RGB values (DICE target patches 1 – 30 and all the Colorchecker SG target patches), OpenDICE computes the color difference (CIE ΔE2000) between the imaging results and the true color of the patches. Similar to the target gray patch density values, the true color (L*a*b* values) can be obtained from the manufacturer specification or measured by the users. OpenDICE first applies the image ICC profile to transform the RGB values to the profile connection space (PCS) (XYZ or L*a*b* space). If the PCS is the XYZ space, then another conversion is conducted to transform the color to the L*a*b* space. The ΔE2000 values are then computed[12] for each patch and the statistics (maximum, minimum, mean and median) are presented.

Color Channel Mis-Registration

Given the detected edge regions on the target image, OpenDICE fits the edges in these ROIs using Hough transform. For each color channels of the RGB, the edge lines are fitted. The line intercept differences are computed as the color channel mis-registration, i.e., G – B, G – R, and B – R.

SFR/MTF

Given the detected edge regions (Figure 5) on the target image, OpenDICE derives the MTF magnitude values and draws the SFR curves for each channel of the RGB components. ISO 12233:2000 gives the implementation details. The computation steps are summarized as: 1) locate the slanted edge regions; 2) compute the corresponding ESF (the profile across the edges) and LSF (the derivative of the ESF); 3) conduct the Fourier transform of the LSF to derive the SFR. On the figures presenting the SFR curves, OpenDICE draws the FADGI criteria lines (both MTF10 and MTF50) according to the user pre-selection.

[12] http://www.brucelindbloom.com/index.html?Eqn_DeltaE_CIE2000.html

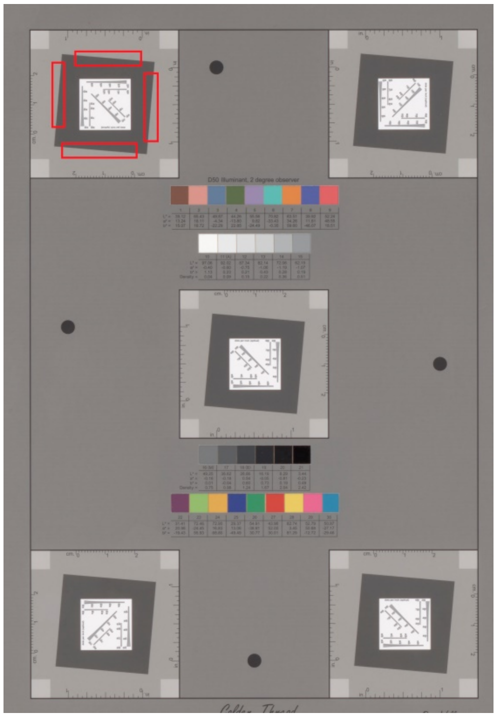

Figure 5. ROIs for the SFR/MTF computation (top left)

Sharpening

After deriving the SFR curves, OpenDICE presents the maximum MTF magnitude values as the over-sharpening measurements. The value is 1 if no over-sharpening is added by the lens or imaging software.

Noise

Given the input target gray patch (Figure 3) intensity values, OpenDICE computes the standard deviation for each channel of the RGB components as the noise measurement.