A Simplified Standard Method of Digital Image Tonal Capture for Archival Projects

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Introduction

In the period from 1995 to 1997, the UC Berkeley Library began an ongoing series of digital access projects which involved the digital capture of many thousands of images from the Library's archival collections. These (largely grant-supported) projects had a variety of immediate objectives, primarily focussed on providing web access to primary historical sources and on allowing detailed study via the web of manuscripts of special interest to scholars. Because the investment of effort and expense required by the digital capture workflow (selection, description, preparation, scanning, etc.) was very considerable, an important planning consideration for each project was to maximize the usefulness of the resulting digital image files. In practice, this meant creating and maintaining a new archive of the digital image master files, and managing the digital image capture process so that the master files would be useful for other purposes not included in the immediate project goals.

The Library's project management teams developed a standardized protocol for direct digital image capture from reflective archival originals, which specifies standard practices for things like capture resolution, cropping and layout, and master file format, based largely on recommendations gleaned from published sources of best practices recommendations. One subject where practical advice was difficult to find, however, was how to standardize the capture of tonal information, so the Berkeley staff developed their own procedures, as will be described. In researching digital tonal capture, it was seen that the general problem—measuring the precise color of a random sample from an original document and encoding it as eight bit pixel values for the three RGB channels—was very complex. The problem could be simplified, however, by restricting it to consider only the capture device's response to the neutral colors of a grayscale target. The response of each of the three channels could readily be measured and adjusted separately, to bring the capture device into a predetermined state. The resulting procedures are based on calibrating a scanner or digital camera by scanning a grayscale target, measuring the digital values representing the target patches in the scanned file, and adjusting the scanner to make the scanned values match pre-determined ideal values.

Summary of the Tonal Capture Protocol

- The tonal response of the scanner or camera is measured for the three (R, G, B) channels by scanning a grayscale target and reading the channel values of the grayscale patches in the digital image.
- Ideal aimpoints for the channel values of the patches are calculated from the reflectances of the patches, using a function which is the inverse of a simple gamma display function.
- Scanner software controls are used to adjust the scanner's tonal capture response and the scan is repeated, until the RGB channel values as scanned match the calculated aimpoints.
- With the scanner (or camera) in this calibrated state, archival originals are scanned, and the resulting digital image files are archived as the digital masters without further tonal adjustment. Digital masters are stored as 8 bits per channel RGB TIFF files.

What this Methodology Standardizes

Using this calibration procedure, all RGB master files will be color-balanced (i.e., the RGB channel values recorded for each grayscale target patch will be identical for the three color channels), and calibrated for a chosen display gamma. The neutral colors of the grayscale target will be captured identically by any camera or scanner calibrated in this way. Non-neutral colors will be captured repeatably for a given scanner (or camera, for a given illumination source), but different models of scanners and cameras will tend to capture non-neutral colors somewhat differently from one another.

The Grayscale Target

The grayscale target which is available as part of the Kodak Q-13 Color Separation Guide and Grayscale set is well suited for this purpose. Eight inches long, it has 20 color-neutral patches from paper white to near-black, numbered 0 to 19. In literature included with the set, Kodak has published nominal values for the reflection densities of the patches, which can be used to compute the reflectance of each patch from the relation,

$$Reflectance = 10^{-Density} \tag{1}$$

Density and reflectance values for the patches of the target are shown in table 1. Note table 1 also includes density and reflectance values for two imaginary patches: a "white point" patch with perfect reflectance of 1.0, and a "black point" patch with zero reflectance. These values mark the absolute limits of the possible reflectance of any original document to be scanned, assuming the document has the optical properties of a diffuse reflector. The tonal capture function will be chosen to set these limits as the highest and lowest values of the RGB channels (zero and 255, for eight bit channels).
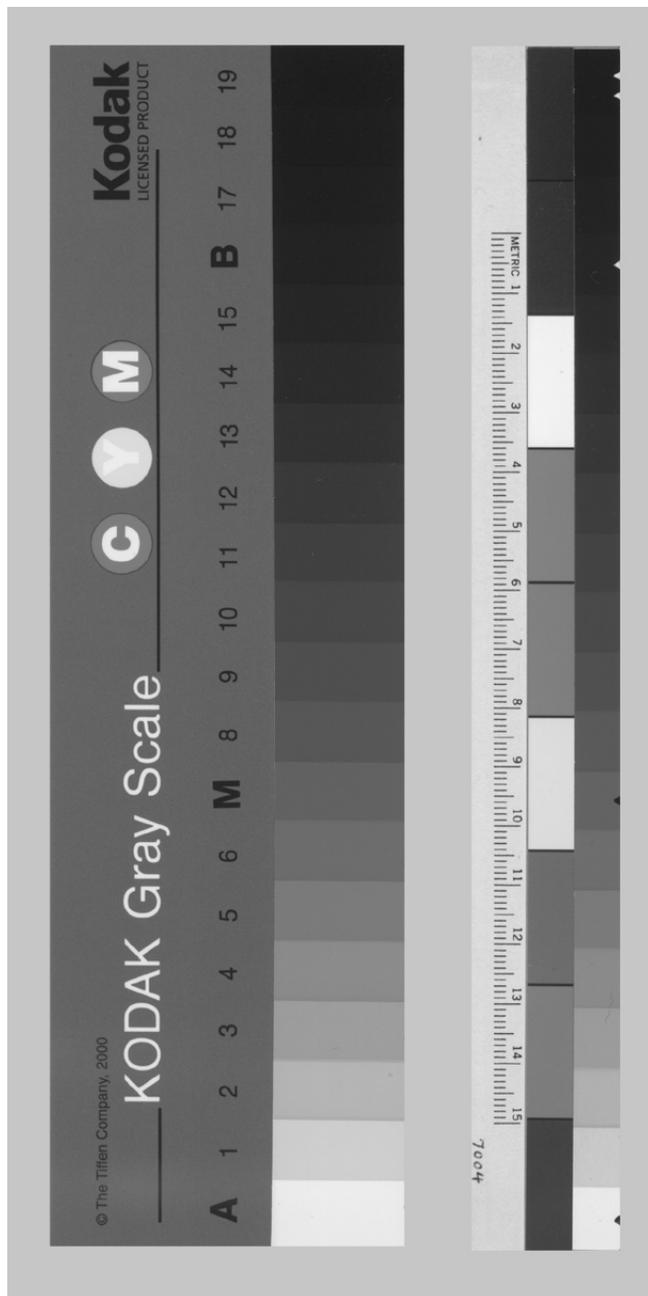

Figure 1. The Q-13 grayscale target, and a modified version which includes a linear scale and color patches.

The Berkeley Library uses a modified version of the Q-13 grayscale target which combines the grayscale with a linear scale and a set of primary color patches in a single target which is included along one edge of every digital capture as a standard practice. The Q-13 grayscale target and the modified version are shown in figure 1.

Measuring the RGB Channel Values from the Scan

At the Berkeley Library, the channel values are read from the grayscale patches using the Photoshop Info window in RGB mode. Some capture device software also has similar tools for measuring the preview image. It is helpful to set the measuring tool to give the average of many pixels. Also, in Photoshop version 5 and later, be careful that no color management process such as a color space conversion alters the native RGB channel data from the scan.

Table 1. Density and Reflectance Values for the Q-13 Grayscale, and Ideal RGB Image Channel Values for Gamma 1.8 and Gamma 2.2 Display Conditions.

patch number	density	reflectance	RGB values	
			γ 2.2	γ 1.8
(white pt)	0	1.000	255	255
0 (A)	0.05	0.891	242	239
1	0.15	0.708	218	210
2	0.25	0.562	196	185
3	0.35	0.447	177	163
4	0.45	0.355	159	143
5	0.55	0.282	143	126
6	0.65	0.224	129	111
7 (M)	0.75	0.178	116	98
8	0.85	0.141	105	86
9	0.95	0.112	94	76
10	1.05	0.089	85	67
11	1.15	0.071	77	59
12	1.25	0.056	69	52
13	1.35	0.045	62	45
14	1.45	0.035	56	40
15	1.55	0.028	50	35
16 (B)	1.65	0.022	45	31
17	1.75	0.018	41	27
18	1.85	0.014	37	24
19	1.95	0.011	33	21
(black pt)	∞	0.000	0	0

How the Aimpoints Are Determined

The process of image capture can be seen as a kind of reversal of the process of digital image display on a computer monitor. In the capture transformation, the tonal properties of the original are coded into the RGB channel values of the digital image, while in the display transformation, the RGB channel values of the image are used to determine the tonal values of the image consisting of the light radiated from the display screen. This display transformation is often modeled as a simple gamma function of the form,

$$y = x^\gamma \tag{2}$$

where γ (gamma) is a constant, and x and y are restricted to values from zero to one. The shape of this curve can be seen on figure 2 (dashed line) for a gamma value of 2.2.
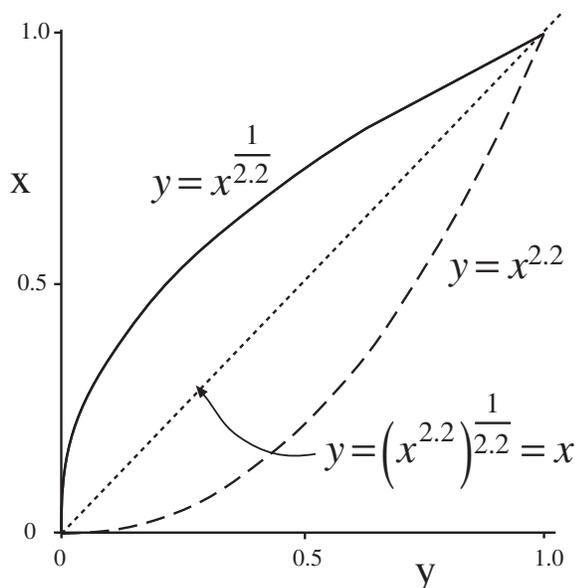

Figure 2. Simple gamma functions

As an example, the following equation could be used to characterize a gamma 2.2 display:

$$\frac{ScreenRadiance}{MaxScreenRadiance} = \left(\frac{ChannelValue}{MaxChannelValue}\right)^{2.2} \tag{3}$$

This would characterize the display for one channel, so three such equations would be used to characterize an RGB display. Note that the denominators MaxChannelValue (which would have a value of 255 for an eight bit channel) and MaxScreenRadiance (the radiance produced by a 255 channel value) are used to normalize the variables to the zero-to-one range. In order to calibrate a display to gamma 2.2, hardware and software controls would be used to adjust the video display system to fit equation 3; this can be accomplished with screen calibration software.

For our model function to characterize our tonal capture response, we will want an inverted form of the display function. Because the inverse of a gamma function is another gamma function with the value of the exponent inverted, we will use this equation for our capture function:

$$\frac{ChannelValue}{MaxChannelValue} = Reflectance^{\frac{1}{\gamma}} \tag{4}$$

This curve can also be seen plotted in figure 2 (solid line). If we choose a value for gamma of 2.2 in equation 4 and substitute the right side of equation 4 for the normalized channel variable on the right side of equation 3, then equation 3 becomes,

$$\frac{ScreenRadiance}{MaxScreenRadiance} = \left(Reflectance^{\frac{1}{\gamma}}\right)^{\gamma} = Reflectance \tag{5}$$

This shows that if we can calibrate our scanner using equation 4 and our computer display using equation 3 then the screen radiance of the display will be proportional to the reflectance of the original, at least for our grayscale target. If we solve equation 4 for ChannelValue, we get,

$$ChannelValue = 255\left(Reflectance^{\frac{1}{\gamma}}\right) \tag{6}$$

This is the equation used to compute the RGB aimpoint values listed in table 1.

Choosing a Value for Gamma

Since the value chosen for gamma will be integrated into the format of the master files, this value should be chosen with some care. Values of 2.2 and 1.8 are widely used in digital imaging applications.

Guidelines for Adjusting the Scanner or Digital Camera

The software programs supplied as drivers for the many different makes and models of scanners and digital cameras vary widely in terms of the tools they offer to measure and adjust the tonal capture parameters of the capture devices. If a scanner has a numerical setting for capture gamma, begin by setting it appropriately (to 2.2 for example). Some devices, primarily cameras, allow setting the gray balance by selecting a neutral patch in the preview; use this tool on the number one or two patch of the grayscale to balance the three channels. Many scanners and cameras have tonal adjustment tools which are similar to the Photoshop levels tool. Use the combined RGB levels controls to adjust the three channels together, and use the individual channel controls to fine-tune each channel independantly. Rather than tracking the channel values for all 20 patches of the target, try tracking just the A (paper white), M (middle gray), and B (near black) patches, and see if the other patches don't fall into place as these three are adjusted. Use the white slider to adjust the value for the A patch and the black slider to adjust the level for the B patch, then use the middle slider to adjust the level for the M patch. These sliders adjust the white point, black point, and gamma of the capture function. Since the adjustment of any slider will affect the channel value for all three patches to some extent, several cycles of adjustment may be needed. Alternatively, white point and black point eyedropper tools with numerical preset targets may be available: use these by setting the presets to the appropriate values for the A and B patches, then click on the A and B patches in the preview. While some scanner software may allow the effects of adjustments to be seen in the preview, the definitive results need to be measured on an actual scan, as the results predicted in the preview can be unreliable.

Implications for Project Capture Workflow

Experience at Berkeley has shown that this methodology can be rather simple and quick to use. In particular, it doesn't require that a scanner or camera operator make subjective judgements about tonality or color, only occasional numerical measurements from the image of the grayscale and (when necessary) adjustments to the scanner or camera software. This alleviates the need for very precise calibration and color profiling of the computer display used at the capture station and for precisely calibrated viewing conditions to compare the original document to the display of the captured image, as would be required to manually perform color-critical editing on the image file. The frequency of recalibration and the effort needed to carry it out will have an effect on capture productivity. Of the capture devices most used at the Berkeley Library, the PhaseOne Powerphase digital camera requires tonal adjustments fairly frequently, especially as lighting or magnification change, while the Epson 836 flatbed scanners tend to remain in calibration for days or weeks before adjustment is required. Fortunately, the Powerphase can be adjusted very quickly using blackpoint and whitepoint eyedropper tools, but the 836 takes several minutes (at least) to recalibrate.

Managing Non-Neutral Colors

If a suitable standard color target is captured with a scanner or camera in its calibrated condition, color profile creation software can be used to create an input profile to characterize the color response of the capture device. This can provide the control over the entire range of colors which this tonal capture protocol otherwise lacks, and allows the project derivative files to be translated into a suitable color space for particular applications such as web viewing.

Conclusion

This capture protocol has been found helpful for standardizing the capture format for digital capture projects, and the resulting master files are capable of being repurposed for a variety of uses.