Measuring Scanner Dynamic Range

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Different Methods

The use of scanners to provide digital image files is rapidly growing. Currently there is no standardized method to determine the dynamic range of scanners. Therefore the data reported in technical specifications can be determined using different methods. An ISO 21550 Standard to measure the ability of scanners to reproduce tones especially in the dark areas of the original is currently under development (in an early working draft stage). At the present time most of the manufacturers report the dynamic range calculated from the bit depth of the implemented A/D conversion using the formula:

$$D = log(2^B) \tag{1}$$

D = reported dynamic range given in Densities
B = Bit depth of A/D conversion

This dynamic range is usually higher than the actual capabilities of the scanner because nowadays in most cases the A/D converters are no more the bottle neck in the signal processing chain of a scanner.

Other manufacturers look at a scanned gray scale and report the density of the darkest patch that differs from the next patch with a lower density. If the gray scale does not consist of a density range large enough to determine the capabilities of the scanner some add a film with a uniform density to reach higher density values.

Possible Bottle Necks for the Dynamic Range

Recently the A/D conversion in combination with the scanning speed was the bottle neck. Since these components got cheaper, faster, and better this has changed. Today the light source together with the sensitivity, the quality of the analog components, and flare are the bottle necks especially of film scanners. The dynamic range of scanners for reflective media is usually higher than the density range of the scanned media. Only a few low cost scanners or scanners in multipurpose devices are not capable to reproduce the 2.x densities of the reflective material.

Available Gray Scales and Material Problems

When we started in 1998 it seemed to be easy to measure the dynamic range but a number of problems appeared since then. One difficulty e.g. is to produce a test chart with homogenous patches covering the needed density range on a material similar to the usual film scanned on the specific scanner. A second one is the fact that a number of film scanners show a significant difference in the dynamic range depending on the scanned material.

Commercially Available Gray Scales

The following gray scales are commercially available an the usability for measuring the dynamic range was checked.

1. Agfa reflection silver gray Scale (Type: G6T5E) 23 x 215 mm consists of 20 patches with densities up to 2.0.
2. Agfa transmission silver gray Scale 26 x 162 mm consists of 30 patches with densities up to 4.3.
3. X-Rite silver gray scale (P/N 381-25) for calibration of densitometers 21 x 125 mm consists of 21 patches with densities up to 3.9.
4. IT8 7.1 and 7.2 test charts on RA 4 and E6 based material of different manufacturers for scanner calibration.

Q-factor

When we tested the Nikon film scanners we found that with our Agfa gray scale these scanners were not able to differentiate patches with densities higher than 2.3. A result that we could not believe. From Nikon we got the information that the geometry of illumination may be the reason for the this behavior. So we tried to find a material that has a Q-factor – relation between density measured with parallel illumination and the density with diffuse light source - of about 1. Not taking care about the spectral uniformity of the transmission we tried typical color reversal material in combination with a Filter consisting of a uniform density of 1.5. We found that the dynamic range for E6 material is significantly higher than the one with silver based black and white film. This means that a scanner of this type will cause problems scanning typical black and white film but will lead to good results with material developed in a C41 or E6 process.

Density Range of the Gray Scale on Film

The maximum density of the X-Rite gray scale in some cases is not high enough. The Agfa film scale consists of a maximum density which is high enough for most scanners. The IT8 targets do not consist of a maximum density suitable for measuring the dynamic range. Manufacturers using this chart combine it with a film of a uniform density. The required range is from film base density of about 0.1 up to densities higher than 4.0.

Requirements for Noise Measurements

To measure noise of a scanner the frequency of the grainy structure in the test chart has to be higher than the geometric sample rate of the scanner usually given as resolution in dots per inch or per mm. According to the digital Camera noise measurement (ISO 15739[1]) it should be at least 10 times higher. This will cause problems with actual test chart materials. Especially if the scanner under test is a film scanner of the new generation. A possible work around may be a (molecule based) diffusor filter in the optical way between Chart and scanner.

Summary of the Test Chart Material Characteristics

The test charts for measuring the dynamic range have to fulfill the following requirements:

1. Maximum density higher than 4.0.
2. Density steps between the patches not larger than 0.2.
3. Known Q-factor which shall be reported together with the results.
4. A spectral uniform transmission from 380 up to 780 nm.
5. Fine grain structure for measuring noise.
6. Possible low cost production and a chart layout that allows automatic or at least semi automatic analysis.

How to Measure Dynamic Range and Related Values

For the determination of dynamic range and the related values the test chart has to be scanned. If the Q-factor or/and the absolute Dmax value shall be measured as well scans of the additional charts have to be made. A number of ten scans per chart will minimize errors caused by temporal noise or mechanical tolerances. If the scanner software allows to store the linear raw data this data shall be stored and used for the determination of the different values. Therefore the analysis software has to be able to analyze a color depth of 16 Bit per channel. To avoid mistakes caused by interpolation of the scanner software the scanning resolution shall be:

$$R = Rmax / i \qquad (2)$$

R = scanning resolution
R_{max} = maximum scanning resolution of the scanner
i = integer value

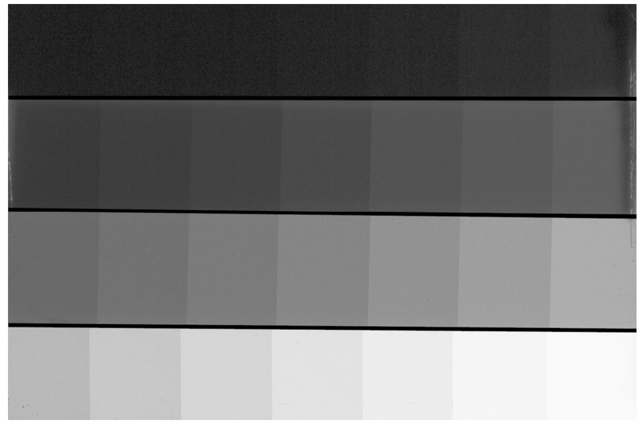

Figure 1. A possible test chartscanned with a scanner which has a good dynamic range (for better visualization the gamma of the scan was enhanced using a value of 2.0)

For each patch of each scan not less than 64 x 64 pixels shall be used to determine the average digital value for the patch and the standard deviation. The standard deviation is needed for measuring noise as explained later.

Dynamic Range

The dynamic range is determined from the function given by the density values of the patches in the test chart and the resulting, averaged digital values from the ten scans.[2]

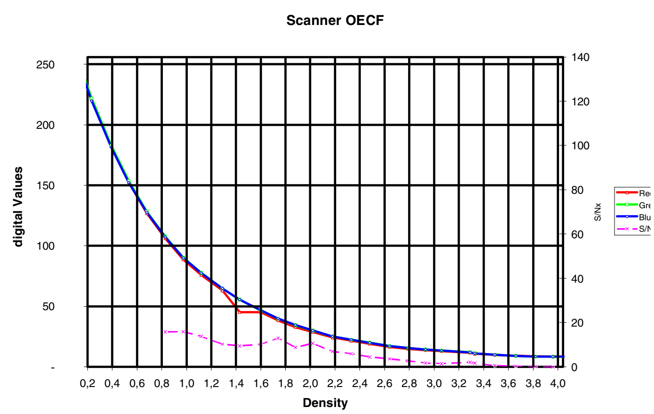

Figure 2. A typical OECF function of an 8 Bit output scanner

If the scanner shows clipped values in the lightest patches of the chart the first patch below the maximum digital value shall be chosen as the minimum density D_{min}. There are three different ways to determine the maximum density D_{max} which have to be discussed among the experts:

1. The darkest patch with a difference in the averaged digital value of at least 1 compared to the next lighter patch.

2. The darkest patch which shows a visual difference in comparison to the next lighter one by using a gamma correction.
3. The darkest patch showing a signal to noise ratio larger than a given minimum value e.g. 1 calculated as shown in the signal to noise section.[3]

The most objective way seems to be the third mentioned. Only the minimum value should be discussed.

The dynamic range DR of the scanner is then given as:

$$DR = D_{max} - D_{min} \tag{3}$$

The dynamic range has to be calculated separately for each Channel R,G, and B. If only one value is reported the different values should be weighted by using the formula:

$$DR = 0.2125 \times DR_{(R)} + 0.7154 \times DR_{(G)} + 0.0721 \times DR_{(B)} \tag{4}$$

Q-factor

If the influence of the illumination shall be determined as well the procedure has to be repeated with a test chart on a material with a high Q-factor. The default chart shall be made off a material with a Q-factor close to 1.

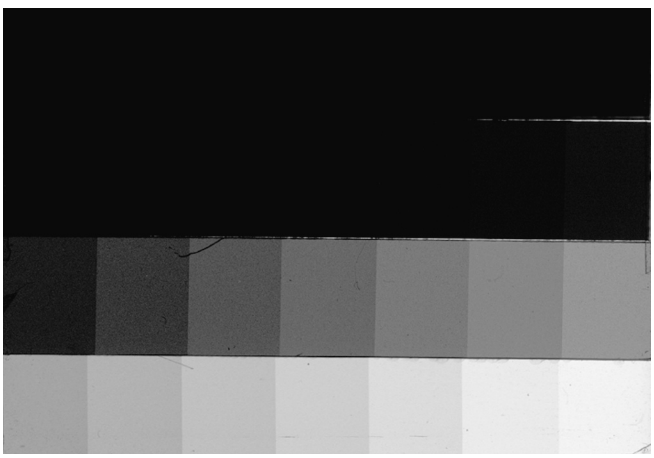

Figure 3. The dynamic range of Nikon scanners is limited to 2.3 densities if a material with a high Q-factor like silver based black and white film is scanned (for better visualization the gamma of the final scan was enhanced using a value of 2.0).

Non linear 8 bit data

If the scanner does not provide linear raw data the automatic adjustment can be used in combination with a gamma modification to lighten the dark areas. The use of a Gamma value of 2.0 in the software lead to good results.

Absolute Dmax

In some cases the maximum density of the dynamic range differs from the absolute maximum density the scanner can reproduce. If the scanner software determines an underexposed slide or an overexposed negative it may be able to adjust the exposure time or the amplification level which does not lead to a reproduction of higher contrasts in one image.

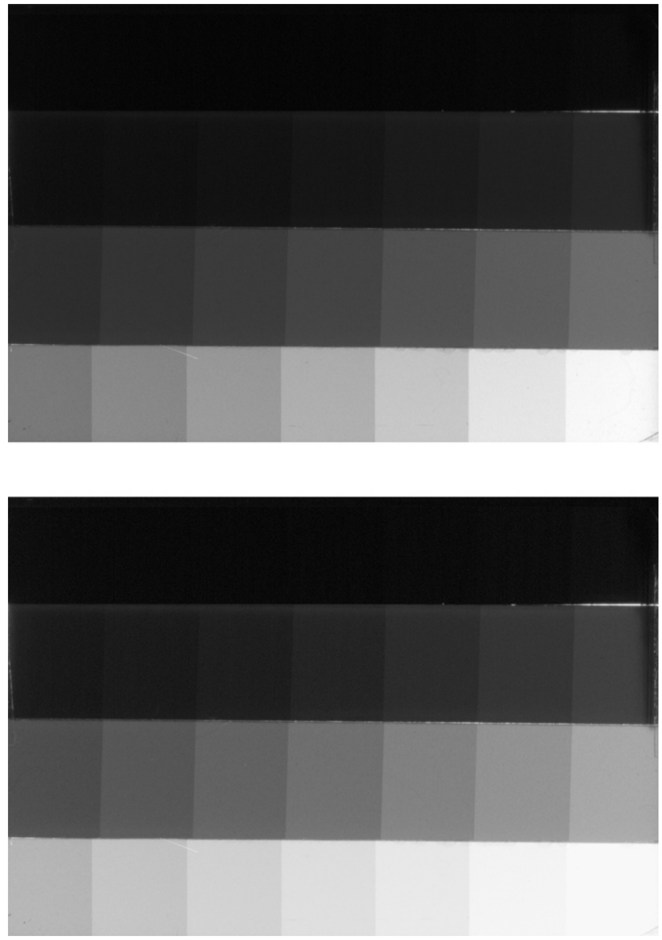

Figure 4. A scan without (upper) and with (lower) a gamma enhancement on raw data using the scanning software.

Therefore the way to combine a test chart with a low maximum density with a uniform density film may lead to wrong results for the dynamic range but leads to the related value of what we call the absolute Dmax.

Signal to Noise

If the Signal to noise ratio is used to define D_{max} for the dynamic range it has to be calculated for every patch using the standard deviation and the average value for each patch. The formula used for the calculation will be defined in the standard and is similar to the formula used in ISO 12232.

$$S/Nx = \frac{D\, g(D)}{s} \tag{5}$$

D = input Density of the patch.
g(D) = average of the incremental gain to the next lower and next higher density (the rate of change in the

output level divided by the rate of change in the input density).

s = standard deviation of the monochrome output level values or weighted color output level values (for color cameras), taken from a 64 by 64 pixel area.

An evaluation had to be made if the formula leads to the same results for different ways to scan the chart. So we tried it on 8 Bit output data with and without gamma correction and found that within in the measuring tolerances the values for the S/Nx are the same.

Looking at the same density/patch for each scanner - which has to be below the D_{max} for all the scanners - the signal to noise ratio for this patch is a useful value to compare the signal quality of the scanners.

Conclusion

To avoid confusion caused by the different published values for dynamic range an ISO standard based procedure for measuring dynamic range and related values is needed. Developing this procedure got more complicated than we thought at the beginning of our work. Especially finding a spectral uniform material with a low Q-factor is a problem that seems to be solvable but is not yet solved. A number of different aspects mentioned in this paper have to be taken into account.

References

1. ISO 15739 Photography - Electronic still-picture imaging - Noise measurements
2. ISO 14524 Photography - Electronic Still Picture Cameras - Methods for measuring opto-electronic conversion functions (OECFs)
3. ISO 12232 Photography - Electronic still picture cameras - Determination of ISO speed, chapter 6.2.1
4. ISO 12641 Graphic technology - Prepress digital data exchange - Colour targets for input scanner calibration.
5. Robert Gann, Desktop Scanners – image quality evaluation, Prentice-Hall 1998

Biography

Dietmar Wueller studied photographic sciences from 1987 to 1992 at the University of Applied Sciences Cologne (Germany). Studies were followed by scientific work in the area of Light- and Colour-measurement at the Institute for Light and Building Technique in Cologne and work in a prepress Company. In 1995 he opened a training an testing centre for digital image processing. Since 1997 Dietmar Wueller has been testing digital cameras and scanners for german magazines and manufacturers. He became the german representative for ISO TC42 WG18 in summer 2000.