

A Color Grain Ruler for the Measurement of Print Graininess

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Introduction

In a photographic system, the random variations in otherwise uniform responses to exposing light are referred to as grain. This two-dimensional random noise is characterized objectively by the RMS granularity. The subjective impression of this noise is termed graininess. Bartleson[1] demonstrated that a logarithmic relationship exists between the RMS print granularity and perceived graininess as measured on an interval scale. Subsequently, Maier and Miller[2] described the first grain ruler, a technique whereby graininess can be measured or visualized quickly and directly. Although observers were able to successfully use this technique to directly measure graininess, large interobserver variability was found in actual use.

In this paper we explain the source of this variability and present an improved grain ruler for use with color reflection materials. The KODAK Color Grain Ruler, created via digital image simulation techniques, allows the direct measurement of the graininess of color reflection prints with a minimum of interobserver variability. The KODAK Color Grain Ruler has applications for both conventional photographic prints and, within certain limitations, the assessment of two-dimensional random noise in digitally generated reflection prints.

Granularity and Graininess

Bartleson[1] determined the following relationship between the graininess G_i of a uniform patch and the visual RMS granularity σ_v:

$$G_i = a\log(\sigma_v) + b \qquad (1)$$

where a and b are constants. The visual RMS granularity is given by: [1]

$$\sigma_v = \sqrt{\rho\sigma_R^2 + \gamma\sigma_G^2 + \beta\sigma_B^2} \qquad (2)$$

where σ_R, σ_G, and σ_B are the red, green, and blue RMS granularities, respectively, and $\rho = 0.2368$, $\gamma = 0.6579$ and $\beta = 0.1053$ are constants. Bartleson also determined that the perceived graininess did not depend on the color of the uniform patch, except for samples of very high chroma. Thus graininess was found to be strictly a function of the achromatic channel of the visual system.

The Original Grain Ruler

Based on these findings, Maier and Miller[2] developed the original grain ruler. This consisted of a series of 18 uniform black and white patches at the same average density (0.8), with increasing amounts of graininess, produced using a digital simulation instrument. The RMS granularity of the patches ranged from 0.005 to 0.075. The numerical scale was specified by assuming that a 6% change in granularity (a just noticeable difference in graininess[3]) was 2 units, with a lower limit of 25 and an upper limit of 120. The original grain ruler consisted of two scales, each printed on black and white photographic paper and mounted on a photographic backing material.

Maier and Miller's psychophysical verification experiment consisted of having a panel of judges use the original grain ruler to measure the graininess of a series of 46 neutral and colored stimuli, consisting of flat field prints from a selection of color negative films. Neutral exposures were printed on color photographic paper, as well as on black and white photographic paper. Colored flat field prints were also generated by appropriate printer filtration. The psychophysical scaling was performed by a panel of 21 judges drawn from the research and development community, including both novice and expert image structure observers. The tests were administered in a viewing booth with a 20% gray surround and D5000 illumination. The judges were asked to maintain a normal photographic viewing distance of 350 mm. All judges were tested and demonstrated normal visual acuity and color vision.

The judges were asked to use the ruler to scale the graininess of each flat field print, such that the graininess perceived on the ruler was equal to the graininess perceived on the print. Due to the limitations of the simulation technology at the time, the ruler step increments were neither perceptually nor physically uniform. Nevertheless, the observers were asked to interpolate between ruler steps as necessary in making their judgments.

Using the measured RMS granularity, the average visual density of each print, and the judged graininess values, a regression was performed using the following functional form:

$$G_i = k\ \log(\sigma_v) + k_2 D_v + k_3 \qquad (3)$$

where σ_v is the visual RMS print granularity, D_v is the average visual density and k_1, k_2, and k_3 are constants. For the color neutral prints (at $D_v = 0.8$), the relationship of the RMS granularity to the measured graininess was determined to be:

$$G_i = 100.8\log(\sigma_v) - 44.3 \quad (4)$$

This work was combined with a semi-empirical method for the estimation of the RMS print granularity (σ_v) from the measured RMS granularities of a color negative film. Einhaus et al.[4] demonstrated that it is possible to estimate the granularity of a color neutral print at a specified magnification, from standard RMS granularity measurements of a color negative film. The graininess of such a print can be depicted by the original grain ruler, and quantified on the Print Grain Index[4] (PGI) scale, which is given by Eq. (4). Published values of the PGI are available for professional color negative films, in a variety of film formats and print sizes.

The design of the original grain ruler made the assumption that the black and white grain patterns on the ruler could be used to scale the colored grain patterns resulting from prints of color negative films onto color paper. Also, the shape of the noise power spectrum (NPS) was not taken into account, that is, it was assumed that the ruler could be used to scale noise patterns that are less sharp (such as those exhibited in color prints) than the black and white patterns on the ruler.

In practice, it was found that the ruler was not as precise as expected, and a wide range of graininess measurements was obtained for a given patch. Measurements on colored photographic materials led to the most widely varying results. The non-uniform steps on the ruler and the layout as separate sections led to further difficulties in use.

The KODAK Color Grain Ruler

The difficulties experienced by users of the original grain ruler led to the development of an improved grain ruler appropriate for graininess measurements on color photographic prints. A flow diagram of the overall process used to produce the KODAK Color Grain Ruler is shown in Fig. 1. A random number generator is used to create three sets of random numbers corresponding to the red, green, and blue (RGB) printing densities of the resultant film negative. The random numbers, representing the RGB noise patterns to be written on the film negative, are normally distributed, spatially uncorrelated, and channel-independent. The standard deviation of the random numbers is calibrated to arrive at the desired RMS print granularity on the KODAK Color Grain Ruler steps, as described later. The standard deviation of the random numbers in the blue channel is twice that of the red and green channels, in accord with the proportions of red, green, and blue granularity in typical color negative films.

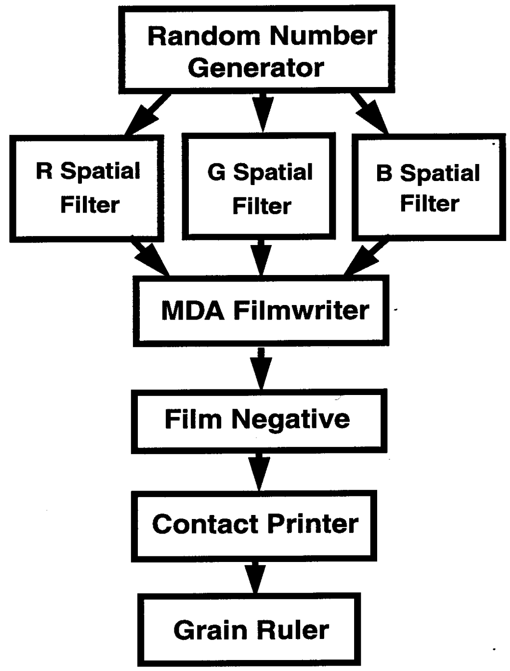

Figure 1. Image Processing Path

The RGB noise patterns corresponding to each step of the KODAK Color Grain Ruler are next modified by spatial filters, using well-known techniques of discrete convolution. The spatial filters introduce spatial correlation into the noise patterns. The spatial filters are designed so that their spatial frequency responses, when combined with the cascaded modulation transfer function (MTF) of the subsequent elements of the image simulation system, yield the desired NPS shapes on the KODAK Color Grain Ruler steps. The desired shape on the Ruler is such that, at low graininess levels (corresponding to low magnification prints from low speed color negative film), the NPS has a broad spatial frequency bandwidth, commensurate with a sharply focused, high-quality enlarging lens used at low magnification. Conversely, at high graininess levels (corresponding to high magnification prints from a high-speed color negative film), the NPS should have a much lower spatial frequency bandwidth, commensurate with the lower optical MTF of the enlarging lens as used at higher magnifications. A smooth transition occurs between the fine noise pattern of the lowest step and the coarser noise pattern of the highest step, as would occur in a series of prints at increasing magnification.

The model for the MTF of the enlarging lens as a function of magnification is a composite of data from high quality enlarging lenses used in the trade. Figure 2 shows the model lens MTF at magnifications of 4X and 20X. At intermediate magnifications, the model lens MTF is obtained via interpolation of representative MTF curves at 4X, 8X, 12X, 16X, and 20X. The FIR filters are adjusted to obtain the desired NPS shape, when combined with the MTF of the remaining elements of the image processing chain.

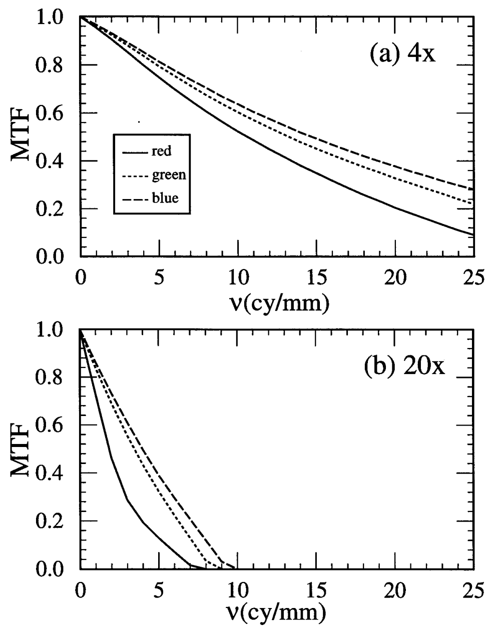

Figure 2. Model Lens MTF

Figure 3 shows the measured NPS of selected grain ruler steps. As intended, the red NPS exhibits substantially less noise at higher spatial frequencies than the green NPS (reflecting the poorer enlarging lens MTF in the red channel, compared to the green and blue channels). Also, as the noise level increases, the NPS rises much faster at low spatial frequencies than at higher spatial frequencies (reflecting the lower printing lens MTF at higher magnifications).

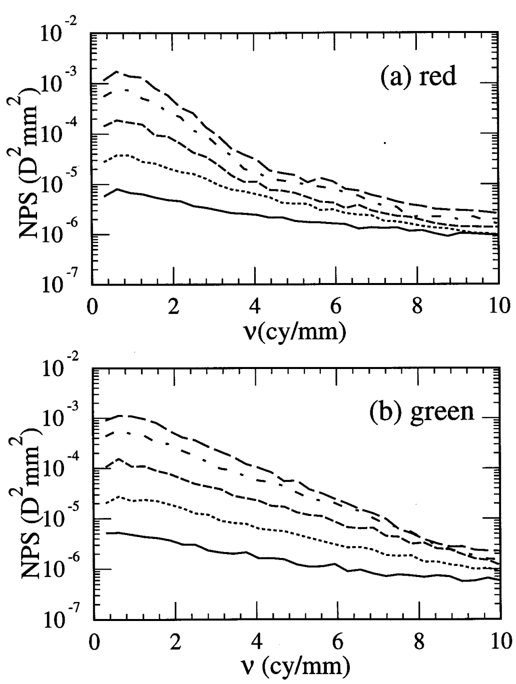

Figure 3. Noise Power Spectra of Selected Steps

A schematic of the KODAK Color Grain Ruler is shown in Fig. 4. This Ruler consists of 22 color neutral patches, all at a mean visual density of 0.8, ranging in visual RMS granularity from 0.0036 to 0.0245. The corresponding range of graininess is similar to a 4X print from KODAK EKTAR 25 Film at the low end, to a 20X print from KODAK EKTAPRESS GOLD II 1600 Professional Film at the high end. The steps are perceptually uniform and correspond to 2 JND changes in print graininess, or roughly 12% changes in visual RMS granularity. The KODAK Color Grain Ruler is manufactured by digitally recording the noise patterns at 1270 dots per inch onto a film negative, which is subsequently contact printed onto color photographic paper.

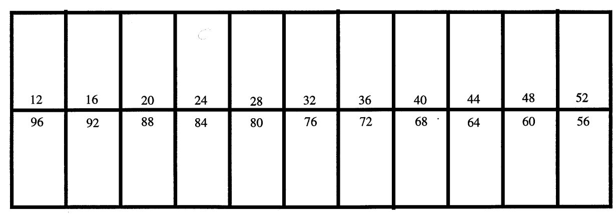

Figure 4. Schematic of the KODAK Color Grain Ruler

A psychophysical verification experiment using the stimuli and protocol of Maier and Miller was used to evaluate the KODAK Color Grain Ruler. Of the 21 judges recruited by Maier and Miller, 14 of those judges also participated in this experiment, with a total of 66 observers.

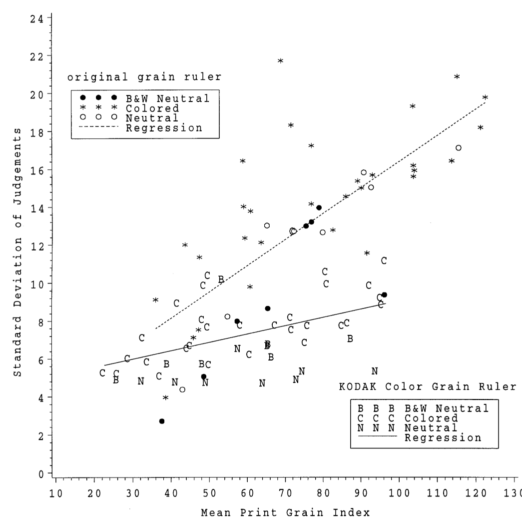

Figure 5. Results of Psychophysical Verification

A graphic representation of the precision as measured by the standard deviation (s.d.) for each of the 46 samples is shown in Fig. 5 for both rulers. The letters "C" for colored stimuli, "N" for neutral stimuli on color paper, and "B" for stimuli on black and white paper are used to indicate the different categories of stimuli for the KODAK Color Grain

Ruler The corresponding data for the original grain ruler is also shown in Fig. 5, where the results are represented by an asterisk for colored stimuli, and open circle for neutral stimuli on color paper, and a solid circle for stimuli on black and white paper. The s.d. for the original grain ruler generally increases as the mean graininess increases. The colored stimuli appear to have a larger s.d. independent of mean graininess with black and white stimuli having the smallest s.d. The neutral stimuli on color paper are an intermediate category.

For the KODAK Color Grain Ruler, the increase in s.d. with increasing mean graininess approximately constant over a range of 5 to 12 units. The colored stimuli lead to more variable measurements as observed by the number of "C"s with larger s.d.. Neutral stimuli on color paper lead to the least variable measurements with the neutral stimuli on black and white as an intermediate category. This is the reverse of what was observed for the original grain ruler; however, we would expect judges to be able to use the KODAK Color Grain Ruler with similar looking colored noise to make more precise measurements. Thus neutrals on color paper would be most precisely measured by the KODAK Color Grain Ruler, and stimuli on black and white paper are most precisely measured on the original grain ruler.

Table 1. Root Mean Square Error from Regression of Eq. (3)

Stimuli	Original Ruler	Color Ruler	Change (%)
All	14.88	9.60	-35
Colored	15.81	9.64	-39
Neutral, Color Paper	13.04	5.48	-58
Neutral, B&W Paper	10.01	7.38	-26

Table 1 shows the root mean square error (RMSE) from a regression of Eq. (4), using the psychophysical judgments G_i and the granularity σ_v of the stimuli to determine the constants k_1, k_2, and k_3. Note that for the KODAK Color Grain Ruler, the RMSE is reduced substantially for all types of stimuli. As expected, the greatest reduction in variability is achieved for the color neutrals on color photographic paper, for which the ruler was designed.

Summary

The KODAK Color Grain Ruler is a tool for quantifying and visualizing perceived graininess in photographic systems. It is optimized for use with color photographic materials and provides a significantly more precise characterization of the graininess of uniform patches than the original grain ruler. Its features include: (1) digital simulation of colored noise patterns; (2) calibrated, perceptually uniform steps; and (3) continuously varying NPS shape, commensurate with the dependence of enlarging lens MTF on printing magnification. The concepts underlying the KODAK Color Grain Ruler are extensible to digital and softcopy applications as a method of perceptual noise characterization and visualization.

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