A Noise Evaluation of Digital Halftone Images Based upon a Human Visual Model

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Abstract

The evaluation of factors contributing to dot noise is essential to continued advances in ink-jet printers. Here a noise evaluation method based upon a human visual model is used to study the effects on dot noise levels of number of quantization levels, resolution, and paper substrate type. Findings suggest that increasing the number of quantization levels may reduce dot noise more than increasing resolution, while varying paper substrate type has little effect.

Introduction

Recent advances in inkjet printer technology promise high quality images at low cost. A major challenge to such advances has been to reduce dot noise, the visual noise caused by dot structure, and two main approaches have been taken. The first has been to increase the number of quantization levels, either by varying dot size through the use of multiple droplet dots or by varying dot densities through the use of various density inks. The second has been to increase resolution by reducing dot size. In addition to these efforts, the effect of paper substrate type on dot noise appears worthy of consideration.

In order to investigate the effects of the number of quantization levels, resolution, and paper substrates on dot noise, we adapted a noise evaluation method based upon a human visual model which had earlier shown useful correlation to evaluations based on subjective perception[1,2]. We found that minimum noise is not necessarily achieved through high resolution with bi-level halftone printing.

Algorithm of Noise Evaluation

In general, the evaluation of an image quality may be categorized into three elements: color, sharpness, and noise. Colorimetry and MTF are long-established tools for evaluating color and sharpness, but there has been a need for a more useful method of evaluating noise. In 1994, a method of device-independent noise evaluation for output devices was proposed,[1] and, in 1996, this method was adapted to the evaluation of noise in input devices such as scanners and digital still camera.[2] In both cases, the method delivered objective values that correlated well with subjective evaluations.

We chose to apply this method here to the evaluation of halftone image because it offers two important features. First, through computer computation, it can simulate variations in the distance between an image and the eye of the observer, which, in turn, allows the simulation of various resolutions. Second, instead of employing density, the amount of noise is calculated and analyzed in a uniform color space. We used the same algorithm presented in 1994,[1] in which calculation of noise follows eight steps:

(1) Fluctuations of density are measured by a microdensitometer under constant conditions.
(2) Density is converted to intensity, and intensity to tristimulus values, X, Y, Z.
(3) The tristimulus values are converted into opposite color responses: red-green (R-G), yellow-blue (Y-B), and white-black (W-K), by the following matrix (Equation 1):

$$\begin{bmatrix} \mathrm{R-G} \\ \mathrm{Y-B} \\ \mathrm{W-K} \end{bmatrix} = \begin{bmatrix} 1.0 & 1.0 & 0 \\ 0 & 0.4 & -0.4 \\ 0 & 1.0 & 0 \end{bmatrix} \bullet \begin{bmatrix} \mathrm{X} \\ \mathrm{Y} \\ \mathrm{Z} \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} R-G \\ Y-B \\ W-K \end{bmatrix} = \begin{bmatrix} 1.0 & -1.0 & 0 \\ 0 & 0.4 & -0.4 \\ 0 & 1.0 & 0 \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (1)$$

(4) Using Discrete Fourier transfer, this set of responses is converted into frequency space: R-G', Y-B' and W-K', respectively.
(5) In frequency space, each response is filtered by the corresponding spatial responses of the human eye[3,4] (Figure 1). Here, we use the same response curve for R-G, Y-B, since the choice of the chromatic visual MTF curve is still under discussion.
(6) The process is now reversed. Inverse Discrete Fourier transfer calculated
(7) The three opposite color responses are converted into tristimulus values, X', Y', Z'.
(8) Finally, the tristimulus values are converted into the CIE$L^*u^*v^*$ color space. Here we define color noise as the sum of the three standard deviations of the color noises along the L^*, u^* and v^* axes. We combine the three elements into one as shown in our prior study[1] (Equation 2).

$$\text{Total Noise} = \mathrm{L^*Noise} + 0.852 \times \mathrm{u^*Noise} + 0.323 \times \mathrm{v^*noise} \qquad (2)$$

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Eqs. 1 and 2 (original in gray) are followed by the revised equations.

Experimental

We prepared two kinds of test chart with several gray patches, from highlight to shadow: one composed of K only, and the other of *Y, M, C*. To evaluate the effects of number of quantization levels and resolution, we simulated halftone printing on silver halide photographic prints, while to evaluate the effects of paper substrate types, we used actual halftone printing on various papers. Parameters for these gray patches are given in Tables 1 and 2.

The parameters used in calculating dot noise are given in Table. 3. Here, " Sampling lines" indicates the number of lines actually used in the evaluation.

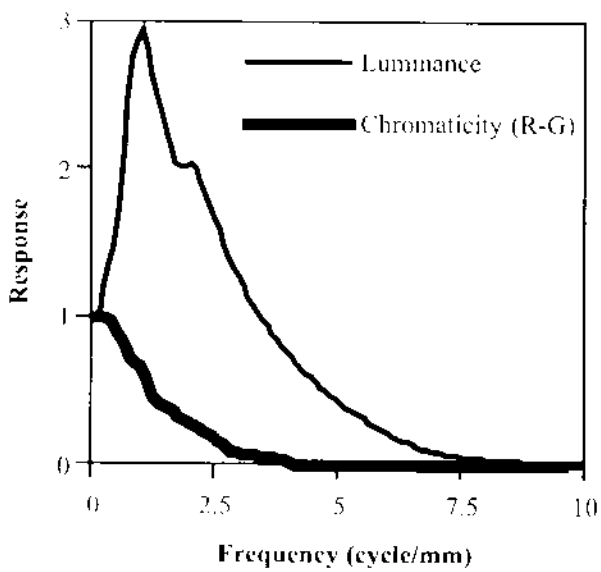

Figure 1. Spatial characteristics of human eyes in luminance and chromaticity(viewing distance = 30cm)

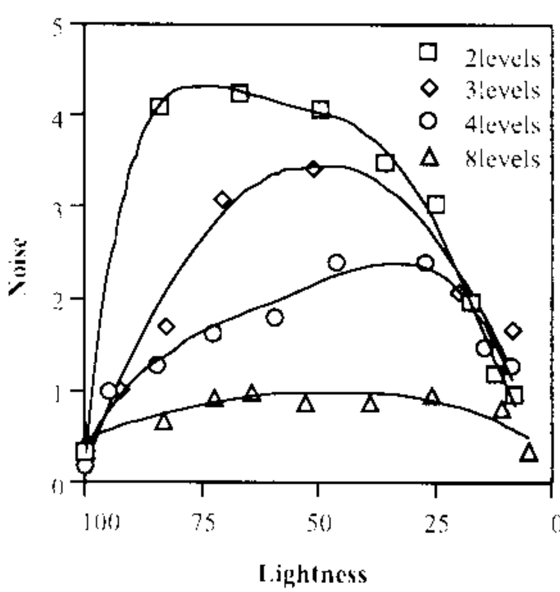

Figure 2. Effect of number of quantization levels on dot noise.

Table. 1. Gray Patch Parameters, Simulated Halftone Printing

Printer	Pictrography 3000
Color Component	1.K 2. Y, M, C
Halftoning	Error diffustion
Resolution	400dpi
Quantization levels	2, 3, 4, 8
Input	0,30,60,90,120,150,180,210

Table. 2. Gray Patch Parameters, Actual Halftone Printing

Printer	Epson MJ-700V2C
Color Component	1.K 2. Y, M, C
Halftoning	Error diffusion
Resolution	360dpi
Quantization levels	2
Input	0,30,60,90,120,150,180,210

Table. 3. Parameters for the Noise Calculation

Aperture size	width 5μm, height 1 mm
Sampling pitch	5 μm
Sampling points	2048 points/line
Sampling lines	3 lines
Viewing distance	30, 60, 90 cm

Results and Discussion

Because results for K and for Y,M,C gray patches were similar, only results for the K gray patches are reported below.

Effect of Number of Quantization Levels on Dot Noise

Figure 2 displays the effects of four numbers of qantization levels on dot noise. (Continuous curves for multi-level printing were obtained by conforming those curves to the peaks of the quantization levels and ignoring the drop-off in noise that occurs at the transition from one level to the next.) At a simulated viewing distance of 30cm, corresponding to a resolution of 400dpi, increasing the number of quantization levels decreased dot noise, as would be expected. Note that this decrease in dot noise was substantial.

Effect of Resolution on Dot Noise

Figure 3 displays the effect of three resolutions on dot noise. Using bi-level halftone printing, viewing distances of 30cm, 60cm, and 90cm were simulated to correspond to 400dpi, 800dpi, and 1200dpi, respectively. While a fair reduction of noise occurs from 400dpi to 800dpi, little reduction in noise is gained by further raising resolution to 1200dpi. Compared with changes in numbers of quantization levels, changes in resolution have less effect on dot noise.

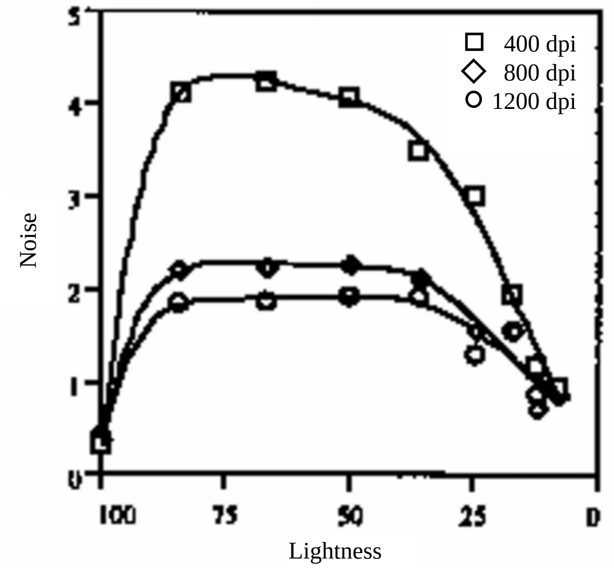

Figure 3. Eject of resolution on dot noise

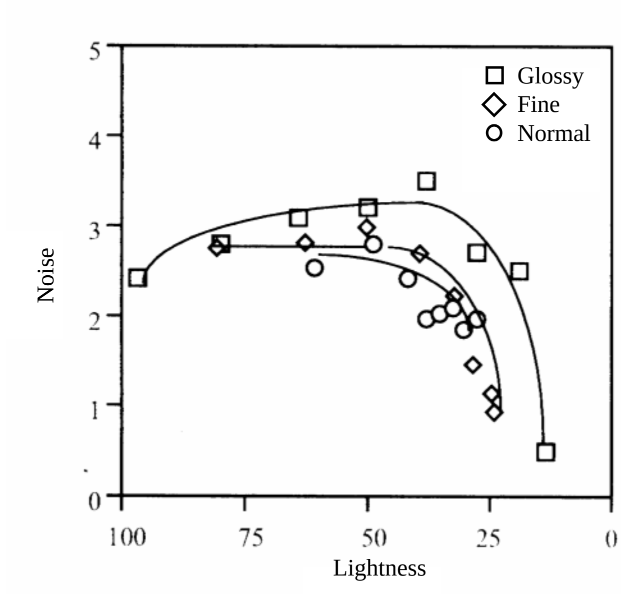

Figure 4. Effect of paper substrate type on dot noise

Effect of Paper Substrate Type on Dot Noise

Figure 4 displays the effect of paper substrate type on dot noise. With bi-level halftone printing at 360dpi, varying the substrate type from glossy to fine to normal achieves little reduction in dot noise. However, note that the same progression of substrate types does have an appreciable effect on dynamic range, which is an important consideration in overall image quality.

Conclusion

Our findings suggest that the effect of the number of quantization levels upon dot noise is greater than that of resolution, while paper substrate type has little effect. It appears that minimum noise is not necessarily achieved through high resolution with bi-level halftone printing, and that adequate noise reduction may be obtained using eight quantization levels at 400dpi.

References

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