An Evaluation of Scanner Noise Based upon a Human Visual Model

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Abstract

We propose a novel method of evaluating scanner noise based upon a human visual model. We define scanner noise as the sum of standard deviations in the CIE $L*u*v*$ space, after a color rendition for a display. The method is an extension of our noise evaluation method for various output devices proposed in 1994[1], in which the raw image data from a scanner is converted to an opposite color space through a human visual model and then is multiplied by the luminous and chromatic MTF responses of human eye to simulate the human visual system. Here we adapt this method to input devices, evaluating total film scanner and film graininess noise. The quantified values obtained correspond well with subjective perceptions.

Introduction

As digital imaging becomes more widespread, accurate evaluation becomes essential to developing high quality digital imaging devices. In general, the evaluation of an imaging device may be categorized into three elements: color, sharpness, and noise. Colorimetry and MTF are useful in evaluating color and sharpness, respectively. However, a good method of evaluating noise in unspecified devices and media has not been available.

In 1994[1], we proposed a method of device-independent noise evaluation for output devices. This method employs a human perceptual model for color and spatial responses so as to accurately calculate the image information reaching our brain. The method proved to deliver objective values that matched subjective evaluations well.

That method of evaluation had several important features. First, it could deal with the image noise of various printers and displays under the same conditions of evaluation. Second, it calculated the amount of noise independent of the type of output device. Third, through computer computation, it allowed for variation in the distance between an image and the eyes during observation. And, fourth, instead of employing density, the amount of noise was calculated in a uniform color space.

In this study, we turn to the evaluation of noise in input images. In the past, most methods of evaluating input noise applied only to specific devices or media such as particular types of scanners or film. Unfortunately, these methods did not offer a good correspondence between their evaluations and human perception without an adjustment of measurement conditions and a modification of parameters.

To address this problem, we have adapted the method of noise evaluation for output devices described above to establish a device-independent method of evaluating noise for input devices such as scanners and digital still cameras. To quantify scanner noise, we employ the same human visual model used in our earlier method. We calculate noise taking into account the spatial responses of the human eye in the opposite color space. Then, after manipulation, we define scanner noise in the CIE $L*u*v*$ color space.
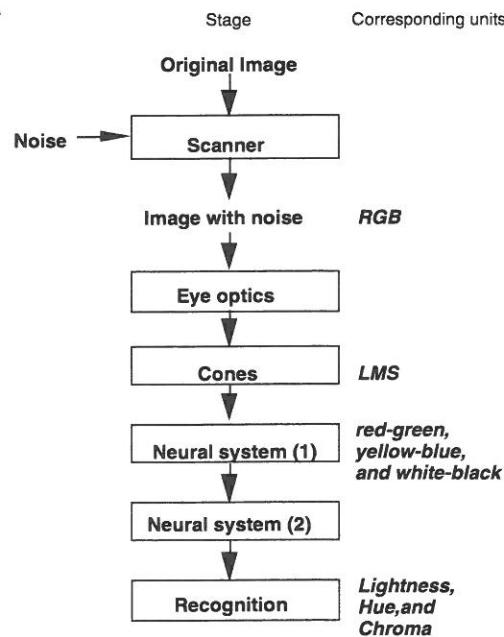

Figure 1. The Human Visual Model

Human Visual Model

In this method, we adopt the following human visual model for noise perception (Figure 1). The model consists of five steps:

(1) A scanned image with noise is observed on a CRT monitor through the optics of the eye.

(2) The image signals are detected by three types of cones: L, M, and S cones.

(3) In the first step of the visual neural system, the detected signals are transferred into the opposite color space, which consists of three sets of coordinates: red-green, yellow-blue and white-black.

(4) In the second step of the visual neural system, each image signal in the opposite color space is filtered by each human visual MTF response.

(5) The result is the human perception of color in the lightness, hue, and chroma coordinates.

Here, we neglect the reduction of spatial responses by the optics of the eye because this reduction is negligible in comparison with that resulting from the visual neural system.

Algorithm of Scanner Noise Evaluation

In order to simulate the above human visual model in a computer, we devised an algorithm for scanner noise, in which calculation of noise follows nine steps:

(1) R, G, and B signals are converted for a specified display. The R, G, and B data of an image are transferred into the tristimulus values, X_D, Y_D, and Z_D by the matrix obtained from the colorimetric characteristics of the display, or CRT.

(2) The CRT white point is converted to illuminant E, which is used in the visual model in the next step. The tristimulus values are transferred into another set of tristimulus values, X_E, Y_E, and Z_E, using the von Kries adaptation model.

(3) These tristimulus values are transferred into the opposite color responses: red-green (R-G), yellow-blue (Y-B), and white-black (W-K) by the following matrix (Equation 1):

$$\begin{bmatrix} R-G \\ Y-B \\ W-K \end{bmatrix} = \begin{bmatrix} 1.0 & 1.0 & 0 \\ 0 & 0.4 & -0.4 \\ 0 & 1.0 & 0 \end{bmatrix} \cdot \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} \quad (1)$$

(4) Using Discrete Fourier transfer, this set of responses is transferred into frequency space: R-G', Y-B', and W-K', respectively.

(5) In the frequency space, each response is filtered by the corresponding spatial responses of the human eye[2, 3] (Figure 2). Here, we use the same response curve for R-G and Y-B, since the choice of the chromatic visual MTF curve is still under discussion.
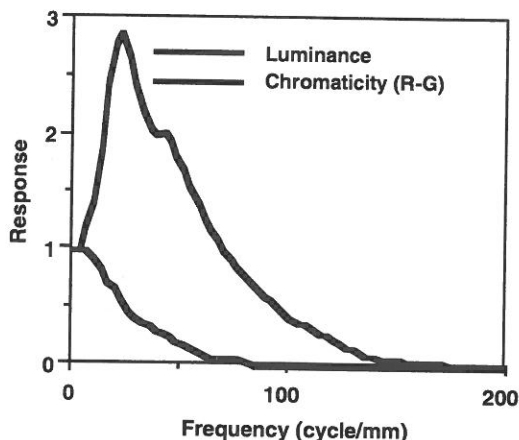

Figure 2. Spatial Characteristics of Human Eyes in Luminance and Chromaticity.

(6) Now the process is reversed. Corresponding to Step 4, Inverse Discrete Fourier transfer is now used, and each compensated response is now transferred into real space.

(7) Corresponding to Step 3, the three opposite color responses are transferred into tristimulus values, X_E', Y_E', and Z_E'.

(8) Corresponding to Step 2, the von Kries adaptation model is used, and each value is transferred into the former tristimulus values, X_D', Y_D', or Z_D'.

(9) Finally, the tristimulus values are converted into the CIE $L^*u^*v^*$ color space. Here, we define color noise as the sum of three standard deviations of the color noises along the L^*, u^* and v^* axes. We use the same coefficients as used in our prior study[1] to combine the three elements into one (Equation 2).

$$ScannerNoise = L * Noise + 0.852 \cdot u * Noise + 0.323 \cdot v * Noise \quad (2)$$

In practical application of these calculations, the following steps are taken:

(1) A test chart with several gray patches, from highlight to shadow, is prepared.

(2) The test chart is photographed with a conventional camera.

(3) The processed film is scanned on a scanner.

(4) The image is evaluated on the specified CRT monitor.

When noise evaluation of the digital image scanned by input device is performed, the noise includes noise from electronic, optical, and mechanical fluctuation. Note that film graininess is included, but that film noise can be avoided by eliminating the photographic step and scanning the test chart directly from a sheet of glass on which the test chart has been fabricated.

An Example of Evaluation

To illustrate the application of this method of noise evaluation, we applied it to a film scanner (Konica Picture MD Writer), using three types of film: ISO100 negative, ISO400 negative, and ISO100 reversal. With each film, we photographed a gray chart and scanned the processed film at 1536*1024 pixels. We then divided the image data into several small patches (about 140*140 pixels). After balancing the patch images to neutral gray, we calculated fluctuation as described above. The parameters for calculation are shown in Table. 1. Here, "Line number of sampling" indicates the number of lines actually used in the evaluation.

Table. 1. Parameters for the scanner noise calculation

Parameter	Value (default)
Sampling number	128 points
Resolution of display	150 DPI
View distance	60 cm
Line number of sampling	32 lines

In our results (Figure 3), the ISO400 film showed the highest noise and the reversal film the lowest, with the mid-tone range of each film being highest in noise. These curves for scanner noise showed good correspondence with our subjective evaluation of the CRT monitor image.
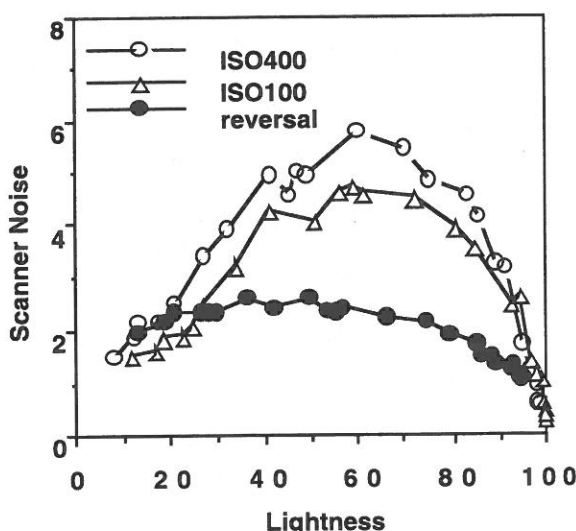

Figure 3. The Evaluation of Scanner Noise for three kinds of films.

The results here are intuitively reasonable. The higher noise in the higher speed negative film is understandable when the relationship between film speed and graininess is considered. Likewise, the low noise of the reversal film in comparison with the negative films is attributable to the differences in color reproduction, since negative film images are recorded in low contrast (low gamma) and reversal film images are recorded in high contrast (high gamma). The scanner adjusts the color reproduction parameter in order to reproduce similar images between negative films and reversal films, so that the graininess of the negative film is emphasized over that of the reversal film.

Conclusion

We propose a novel method of evaluating scanner noise using a human perceptual model. Using this method, scanner noise can be calculated to closely approximate human visual perception for a CRT-displayed image. Since the method does not depend on specific input devices, it can be applied to any type of scanner or digital still video camera.

References

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Image Quality Investigations on a Hybrid Imaging System

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Abstract

Hybrid imaging systems combine the advantages of silver halide (AgX) and digital photography. Using cathode ray tubes (CRT) to expose photographic materials allows an interface between the technologies of AgX and digital photography. In order to optimize image quality, the parameters of the CRT should fit those of the photographic film. Computer-generated test images (density step wedges, color charts, edges or sinusodial patterns) were printed onto different films. A microdensitometer with a charge coupled device (CCD) camera was used to measure modulation transfer function (MTF) and noise power spectrum for these test images. The color transformation was determined by spectrophotometric measurements. The effect of the CRT printer on modulation transfer, noise and color reproduction are discussed.

Introduction

The advent of digital imaging did not displace AgX photography. AgX and digital components complement one another in hybrid imaging systems, with digital imaging providing features which are not available through traditional photography: digital image processing (combination of images, text and graphics; adjustment of contrast and color; removal of image defects; sharpening, inversion and masking of images), copying, storage and transmission via the Information Superhighway. The key advantages of AgX materials are good tone and color reproduction, high