

Colorimetric Printer Calibration using Modified Sigmoidal Tone-Curve Function

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Abstract

This paper proposes a tone-reproduction method that uses a neural network and modified sigmoid function to perceptually compensate the characteristics of an output device. An inkjet printer was used as the output device the characteristics of which were analyzed by colorimetric measurement. The measured device-characteristic data for primary inks were then used to model the I/O characteristics of the device and a modified sigmoid function was exploited as the optimal tone-reproduction curve for the printer. In the actual application of the printing process, the mapping function between the proposed tone-curve and the input signal of the device was constructed as an LUT and then used as a preprocessor. As a result, the proposed algorithm produced a detailed color reproduction in the mid-tone range and enhanced the image contrast in the shadow-tone regions.

Introduction

Printing quality depends on so many factors including the mechanical attributes of printers, dot-overlap, registration between primary inks, and halftoning techniques etc. Accordingly, the characteristics of printers are both multi-parametric and nonlinear. In particular, the dot-overlap between neighboring dots produces serious color differences on printing outputs.

Pappas proposed the dot-overlap model that could predict size of dot droplets using an analytical model.[1] However, this model is not sufficiently accurate for an inkjet printer because of the misregistration that occurs in a real inkjet printer.

The polynomial regression model is another method for producing an empirical model. Here, a system is assumed to be a black box, and the coefficients for modeling the system are obtained from the input-output relationships. Yet, this model also is unable to guarantee any other colors except for the sample points.

This paper proposes a colorimetric printer calibration method for compensating printer nonlinearity. Four input-output relationships of CMYK (cyan, magenta, yellow, and black) inks are independently modeled using a neural network, the inputs are the lightness values and color difference values as defined in the CIELAB system, and the outputs are the digital inking values for each primary ink. Accordingly, these colorimetric measurements are used as the measured value inputs for the color patches, thereafter the network determines the appropriate CMYK signals to produce the desired lightness and color difference tone-curves.

A modified sigmoid function is proposed as the optimal tone-curve. According to the human simultaneous contrast phenomenon, it is possible to make dark colors in an image seem darker by making the light colors lighter.[2] Therefore, the optimal tone-curve for printing can be obtained by adjusting the curve of the sigmoid function, which is then inputted into the neural network to determine the CMYK signals.

As a result, with real image printing, the outputs exhibit a linear tone-curve in lightness and color difference in the mid-tone region, plus the image contrasts are enhanced by reducing the heavy compression in the shadow-tone regions.

Printer Characteristics

Tone reproduction attempts to reproduce the relative luminance ratios of the original scene. For most prints, a correct tone-curve is the key to reproducing the natural aspects of the original.

In photography, linear tone-reproduction relative to density is accepted as the standard measure of tone reproduction. Figure 1 illustrates the density change in relation to linear incremental amounts of primary inks. The density curve measured by a densitometer is directly proportional with the linear incremental amount of each primary ink. Therefore, the characteristics of the tone-curves of the inkjet printer are linear to density.

However, the response of the human visual system (HVS) to the linear increment of a stimulus is not directly proportional to the stimulus.

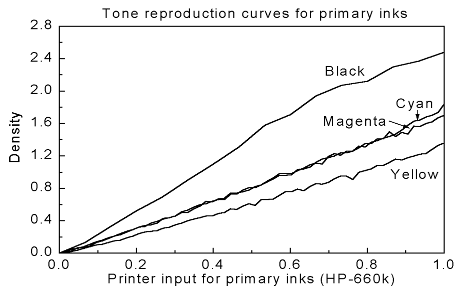


Figure 1. Density curves relative to linear incremental amounts of primary inks.

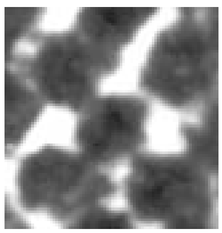


Figure 2. Printed dot-pattern for chessboard input pattern in inkjet printer.

In an inkjet printer, the shape of a printed ink droplet is almost circular as shown in figure 2.

As shown in figure 2, the shape of an ink droplet is circular. As a result, dots have to be overlapped in order to print over the entire area of the printing material. This causes lightness reduction and unwanted color on printing outputs. In addition, the HVS's response to the linear change of a stimulus is nonlinear. An experiment was conducted using black patches generated by an inkjet printer for linear input signals from 0 to 255. In this experiment, these patches were given to 3 observers who were then asked to classify the patches according to their perceived brightness based on a previous category scaling and pair comparison experiment[3]. The results are shown in figure 3.

As shown in figure 3, as the perceived brightness was stronger, the number of patches included in the same cluster was higher. This indicates that the HVS's perception of linear gray inputs in an inkjet printer is nonlinear and approximately logarithmic.

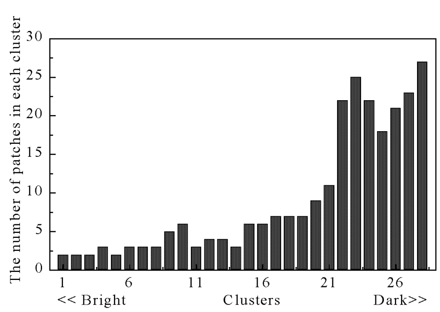
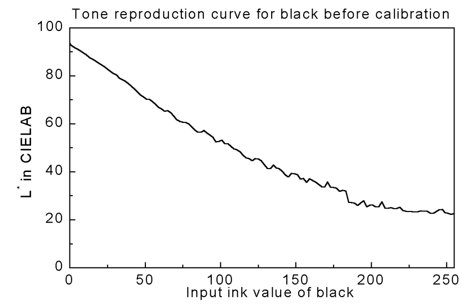
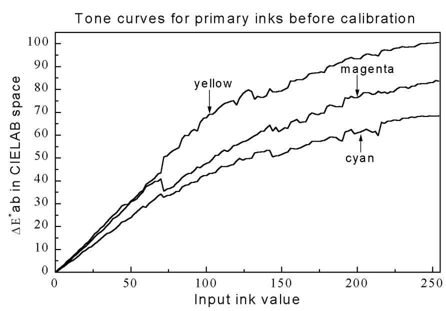


Figure 3. Classification of black patches according to perceived brightness.

In addition, a colorimetric comparison was also utilized to measure the tonal response of printer. Figure 4 shows the lightness and color difference curves relative to the linear CMYK signals in a CIELAB system. These curves indicate that the color difference curve started to be compressed from the mid-gray range and became highly compressed in the low-gray region. Therefore, linear tone-reproduction in terms of density reduces the dynamic range of the image and lessens the visibility of the detail regions of an image due to heavy dot-overlap.



(a)



(b)

Figure 4. (a) Printer tone-curve according to lightness in CIELAB and (b) Printer tone-curve according to color difference in CIELAB.

Sigmoidal Tone-Curve

In this article, a modified sigmoidal tone-curve function is proposed in order to obtain equi-visual tone-reproduction in the mid-tone regions of an image and enhance the contrast in the shadow-tone regions.

$$SIG_i = 2\Delta S \cdot i - S_i \quad if \quad i < median \;\; gray \qquad SIG_i = \Delta S \cdot i \quad else \tag{1}$$

$$S_i = \sum_{n=0}^{n=i} \frac{1}{\sqrt{2\pi}\sigma} \exp\frac{(x_n - x_0)^2}{2\sigma^2} \tag{2}$$

$$\Delta S = \frac{S_{i,\max} - S_{i,\min}}{m-1} \tag{3}$$

Equations (1) to (3) show the proposed tone-curve function for generating lightness and color difference curves. Where m is the total gray level and $S_{j,max}$ and $S_{j,min}$ are the corresponding input gray values for the maximum lightness or maximum color difference and the minimum lightness or minimum color difference, respectively. x_0 and σ control the shape of this sigmoidal function. In this study, x_0s are the median gray values corresponding to the lightness and color difference medians lying between their respective maximum and minimum values. In this case, 80, 76, and 84 in the gray level were chosen as the medians of cyan, magenta, and yellow, respectively.

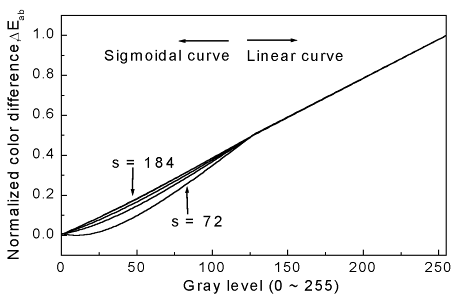


Figure 5. Tone-curves according to σ.

In addition, σ decides the compression ratio of the tone-curve. According to the human simultaneous contrast phenomenon, it is possible to make dark colors in an image look darker by making the light colors lighter. In order to boost the image contrast within the limited dynamic range, the highlights and shadow detail both need to be compressed[2]. However, compression in a highlight-tone region desaturated an image without contrast enhancement. Accordingly, in this article, only shadow-tone region was compressed by only adjusting σ, as shown in figure 5.

As σ increases in a shadow-tone region, the contrast of the output image decreases. From this experiment, when σ was larger than 184, the tone curve was almost linear. 5 images were used to identify the optimal value for σ. Each image was subjectively evaluated by 10 observers. Five σs ranging from 72 to 184 were compared and 128 was chosen as the optimal value.

Neural Network Implementation to Reproduce Sigmoidal Tone-Curve in Inkjet Printer

To obtain the tone-curve of figure 5 on output prints, the transfer function of the printer must be inversely modeled. For each primary ink, corresponding input digital inking values must be determined in terms of its lightness and color difference. In this case, a 1-dimensional direct mapping method can be applied through the use of a comparison based on the least square error between the digital input values and the measured values. However, as shown in figures 4(a) and 4(b), these curves are not monotonic. Therefore, direct mapping, based on a least square error comparison between the digital inking values and the measured data, can generate a saw-tooth gray value curve in the local region of the curve.

In a real half-toning process, the marked area relative to the linear incremental amounts of ink on the print is not monotonic because the curve of the number of marked dots between very close gray levels can not be monotonic. In addition dot-overlap and measurement errors will also influence the size of the marked area.

However, this non-monotonicity in a local region can be removed by averaging the results of a number of measurements. In this study, to avoid excessive measurements, the input and output relationship was modeled using a 1-dimensional neural system.

A multi-layer perceptron with a 1-30-1 structure was constructed to model these four mapping functions, and a back-propagation algorithm was used to instruct the network[4]. After network learning, look-up tables were generated for cyan, magenta, yellow, and black as the mapping functions, i.e. the printer-controllers during the printing process.

The implemented 1-30-1 network structure was as follows:

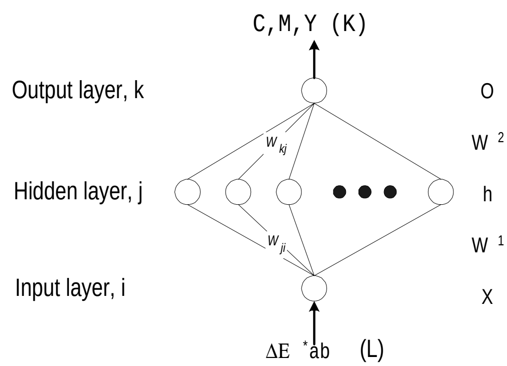


Figure 6. 1-30-1 Network structure.

After network learning, 4 LUTs were used to obtain the input CMYK signals, which then reproduced the sigmoidal tone-curves on output images. The overall structure of the proposed system is as follows:

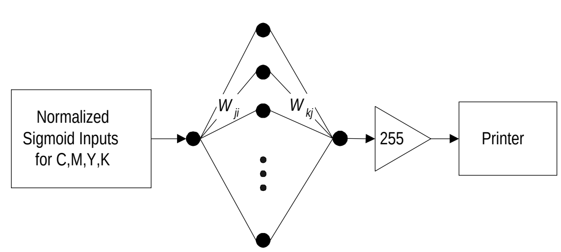
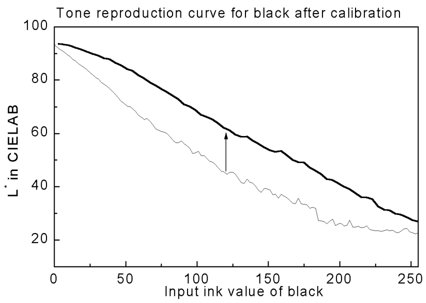
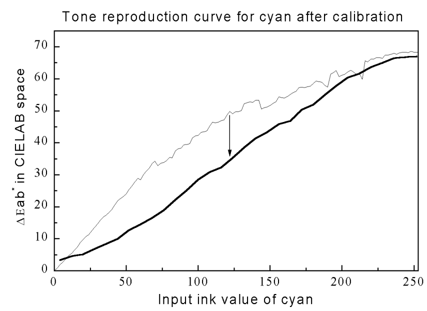


Figure 7. Neural system for sigmoidal tone reproduction.



(a)



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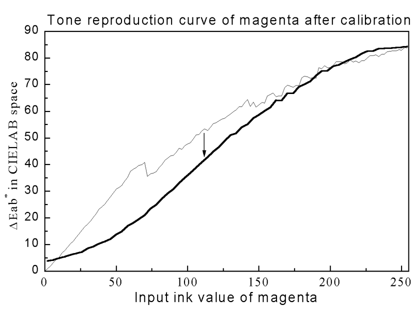
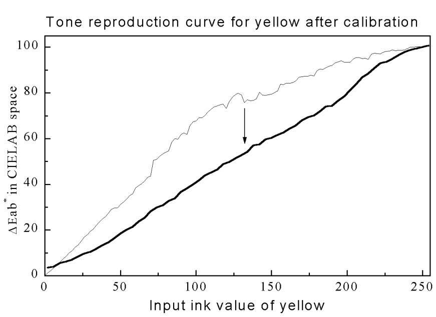


(c)



(d)

Figure 8. Resultant tone-curves (a) black, (b) cyan, (c) magenta, and (d) yellow.

Experimental Results

To evaluate the proposed algorithms, 64 printer patches for each ink were made and measured by a spectrophotometer, CM-3600d. Figure 8 shows the resultant tone-curves for each primary ink. These curves represent the measured values for the generated patches when using the proposed method.

These results indicate that the proposed calibration method can effectively calibrate both printer-nonlinearity caused by dot-overlap and human nonlinear perception using CIELAB metric, thereby enhancing the contrast on the printing output. In addition, the linear tone-reproduction in mid-gray regions produces an excellent representation of detail in the output image.

Conclusion

This paper proposed a tone-reproduction method using a neural network and modified sigmoid function to perceptually compensate printer nonlinearity. The printer characteristics are modeled using colorimetric measurements within a 1-30-1 neural network structure. These measured device-characteristics are then used in the BP learning process.

A modified sigmoid function is proposed in order to produce optimal tone-reproduction curves for the printer. When applying to real images, the mapping function between the proposed tone-curve and the input signal of each device is built as an LUT and then used as input to the printer.

As a result, the proposed algorithms produce a detailed color-reproduction in the mid-tone range plus an enhanced overall image contrast on the printing outputs.

References

1. Thrasyvoulos N. Pappas and David L. Neuhoff, "Printer Models and Error Diffusion," *IEEE Trans. I. P.*, vol. **4**, no. 1, pg. 66-80, Jan. (1995).
2. Gustav. J. Braun and Mark D. Fairchild, "Image Lightness Rescaling Using Sigmoidal Contrast Enhancement Functions," *Color Imaging: Device-Independent Color, Color Hardcopy,, and Graphic Arts IV, SPIE* vol. **3648**, pg. 96-107, (1999).
3. Mark D. Fairchild, Color appearance models, Addison Wesley Longman, pg. 144-146, 217-225 (1997).
4. Richard P. Lippmann, "An introduction to computing with neural nets," *IEEE ASSP MAGAZINE*, pg. 4-22. April (1987).