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A minimal Munsell value error based laser printer model

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ABSTRACT

The image printed by laser printer may be nonlinearly distorted by dot gain and dot loss. In this case, printer model is usually built to suppress this nonlinear distortion and to make sure the printout result is the same as input image. The parameters of the printer model which will directly affect the printout result are key. In this paper, the chroma or density values of printout result is changed into Munsell value, and optimal parameters of printer model are calculated via the calculation of minimal error between Munsell value and input gray value. And then the minimal-Munsell-value-error-based laser printer model (MMVEBLPM) is established and applied in the green noise halftone method. Experimental results showed that the optimal parameters can be calculated fast and the nonlinear distortion of laser printer is suppressed significantly with the proposed model.

1. Introduction

Because of the physical diffusion and optical diffraction of toner, there are dot gain and dot loss in the outputs of laser printer. These two phenomena are known as the nonlinear distortion of printer result and the printout result may not linearly reflect the tone of input image [1].

In order to suppress the nonlinear distortions of printer, the researchers simulate the characteristics of the printed dots and the printing mechanism to establish printer model. Roetling et al. [2] first proposed a hard circular dot (HCD) model. Assuming that printers produced smooth round points with a constant absorption rate, the overlaps of a point and its near points were calculated through a logical relation “OR”. Based on the HCD model, Pappas et al. [3] proposed three parameters to describe the interrelationships of local dots and calculate the visual gray value caused by dot gain. Since the parameter settings of HCD directly affect the results of printer model, Pappas et al. [4] solved the constrained optimization problems by printing a specially-designed binary template and macroscopically measuring its optical absorptance, and finally optimized the parameters of HCD model. Lin and Wiseman [5] presented a stochastic dot model, using Gaussian distribution to simulate the occurrences of toners, because the HCD model does not predict the nonlinear distortions of laser printer very well. Lau et al. [6,7] changed the probability of occurrence of toners into the superposition values of light energy based on Lin's model, and added two parameters to explain and simulate the phenomenon of dot gain and dot loss. To obtain more accurate simulation of the impact of local dot by surrounding dots, researchers created a statistical printer model by establishing a lookup table of distributions of neighboring pixels. Baqai et al. [8] microcosmically measured the absorptances of all dots and put them into the calculation of errors in the DBS algorithm, which suppressed the nonlinear distortion of printer effectively. Goyal and Ju [9–12] improved Baqai's research by expanding the range of the impact of dots to get better simulation result.

Pappas's HCD model gets the optimal parameters via macroscopic measurement, but the process is complex and time consuming, and HCD model has poor adaptability to laser printer. The printer model presented by Lin and Lau measure the density or reflectance of the printout result to calculate the parameters by minimizing the error between the simulated output value and the measured output value. However, neither the density nor the reflectance can linearly reflect the visual effects of human eyes to different gray levels [13]. The acquired parameters cannot suppress the nonlinear distortions of printer well and need to modify by recurrently printing and observation. The printer model proposed by Baqai, Goyal and Ju et al. scan the printouts with high-resolution scanner and get the absorption or reflectance of all gray pixels in template or set of pixels. Although the scanner is characterized in the experiment, the nonlinear distortions of device cannot be completely eliminated. Meanwhile, it costs too much time, computational complexity and storage space when scanning the images, establishing relationships between halftone images

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and scanned images, and searching and replacing the corresponding relationship during the halftone process. The construction method proposed by Pappas, Baqai, Goyal and Ju may not be applicable to the actual requirement. There is nonlinear distortion such as dot gain and dot loss in most laser printers. Lau's stochastic dot model can simulate and explain the phenomena of dot gain and dot loss in laser printer effectively but the optimal parameters are not gotten easily.

Aiming at overcoming the shortcomings of the selection of the optimal parameters in the printer model, the construction method of the minimal-Munsell-value-error-based laser printer model (MMVEBLPM) is proposed. On the basis of Lau's stochastic dot model, the optimal parameters of laser printer model is calculated by minimizing the error between Munsell values converted by printouts and simulated output values, and applied the printer model in the green noise halftone method. Assuming the line from the Munsell value of the 100% dot to the Munsell value of paper white as the ideal curve of the gray tone reproduction, evaluate the linear relationship between the Munsell value curve of printout result and ideal curve of the tone reproduction to evaluate the simulation effect of MMVEBLPM.

The remainder of this paper is organized as follows. Section 2 describes the Munsell value printout conversion, stochastic dot model and parameters selection. In Section 3, we present that MMVEBLPM is applied to green-noise halftone method. Experimental results are showed and discussed in Section 4. Finally, this paper is concluded in Section 5.

2. The construction of the MMVEBLPM

2.1. Conversion method of printouts based on Munsell value

The tone of printout result printed by laser printer will be presented by the toner particles aggregate. Because of low-pass filtering characteristics of the human eye, different distributions of tone particles in a certain area are changed into different brightness in visual system. At present, the reflectance or density of printout result are measured to describe the visual tone of the printouts. Yet, the reflectance or density cannot reflect the human visual effects to different gray levels linearly. So choosing an index reflecting the human visual gray effect linearly to quantize the printout result will help the design and parameters selection of laser printer model more effectively.

The Munsell value is an element which expresses brightness in the New Munsell Indication System [14] organized and systematically measured by Optical Society of America. Through real visual experiments, the New Munsell Indication System selects the just-notified gray as the next level from the standard black to the standard white successively, thus evenly splitting the gray scales between the blackest and the whitest according to visual perception. The Munsell value reflecting the human visual gray effect linearly is establishing through a lot of visual experiment. In this paper, we choose Munsell value to simulate the corresponding gray value of printout result.

According to the luminance factors of the Munsell samples in the CIE (International Commission on Illumination) 1931XYZ system, the relationship between the Munsell value and the luminance factors Y can be established, as Fig. 1 shows. So the chroma or density values obtained by measuring the printout result are converted to Munsell value and then converted to visual gray perception with the normalize calculation. The concrete procedures are as follows:

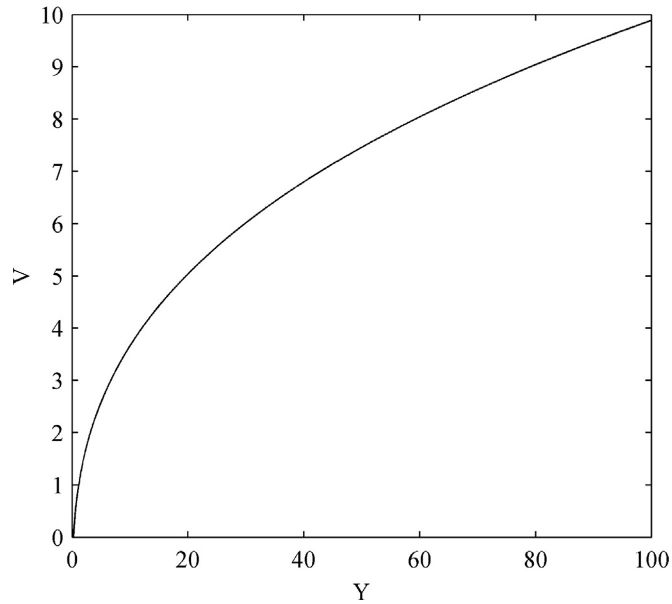

Fig. 1. The conversion relationship between Munsell value V and luminance factor Y.

1) First, convert the measurements into the luminance factor Y of the CIE1931XYZ chrominance system. If the results are measured by colorimeter, go directly to step 2; if they are measured by densitometer, calculate the luminance factor Y of a region from its functional relationship with the optical density D of that region derived from the optical reflection density formula

$$D = \lg[Y_0/(Y\rho_0)] \Rightarrow Y = Y_0/(10^D \rho_0) \quad (1)$$

where $Y_0 = 102.75$ is the luminance factor of the level 10 value corresponding to the whitest point in the Munsell system, $\rho_0 = 1$ is the reflectance corresponding to level 10 value in the Munsell system.

2) Then, convert the luminance factor Y into Munsell value V. Calculate V from its functional relationship with Y as V fitted by Ladd and Pinney [15]

$$V = 2.217Y^{0.352} - 1.324 \quad (2)$$

3) Finally, convert the Munsell value V into the gray level G. The brightness of a visual signal perceived by human visual system depends mainly on the differences in brightness between the signal and its contrast color [13]. As for the outputs of printers, the target gray effective is decided by the blackest and the whitest in the printed image. In halftoning output, the whitest point is the paper white, and the blackest point is the printed result of 100% dot area. Using the Munsell values of paper white V_p and the 100% dot V_s, the Munsell value V is converted to gray level G:

$$G = (V - V_p)/(V_s - V_p) \quad (3)$$

2.2. Stochastic dot model

A single pixel printed by laser printer consists of numbers of toner particles, and the amount of light energy obtained by exposure determines whether a dot adsorbs the toner particles or not. Because human eyes are not sensitive to high-frequency information, the visual brightness effect of single pixel is decided by the coverage area of toner particles in the pixel area. In this paper, a single pixel is divided into several small parts and the average light energy of all small parts of a single pixel is counted as