A Printer Point Set Gamut Model Based on BP Neural Network

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Abstract

In the color management system, device gamut is an important prerequisite for effective color management. Currently, device gamut is described by convex hull model. In this method, electronic standard color card is output on certain media, the chromatic values of the color blocks of the color card are measured as vertices to build the three-dimensional space of convex hull. In spite of the simplicity of the description method in manipulation, the factors that can't be ignored are as the following, the relatively representative of the color blocks on the color card and the device gamut has something to do with the factors such as device feature, as well as the surrounding light and device parameters. Near the edge of the convex hull, the device limit color points perhaps locate inside and outside the edge of the convex hull, so the convex hull model can't describe the device gamut exactly. In the research, based on mapping relation of digital image pixel value and its corresponding printed color, printer characterization model is established based on BP neural network with exactitude to a perfect certainty. Then, digital image pixel values with kinds of intervals are taken to calculate the color point sets by the printer characterization model, and the device gamut could be described by the color points sets. By visual method, both the convex hull model and the point set model are compared. The experiment shows that the point set models describe the printer gamut more precise than the convex hull model.

Introduction

The color gamut is represented by the color range of collection of all colors in the color space or equipment, it is the basis and fundamental of color management, appropriate gamut model is essential to carry out effective color management flow. At present, in the color management system, there are two kinds of gamut description models, they are point set model and convex hull model respectively.

Point set model. It is the most simple and effective gamut model. It represents the gamut by the discrete points in the color space. Essentially, it is a discrete space and its accuracy is restricted by sample interval. Only in the case of sampling a sufficiently large number, the model could describe the gamut accurately enough. If the number does not meet the application needs, it should be reestablished.

Convex hull model. The convex hull is an outline of some set of points, it is the most common in computational geometry and the most basic kind of geometry, it is the study of one of the many other effective tools geometry. Base on point set model, it describe three dimensional polyhedron models by geometric method to get an accurate description of the surface. If the gamut shell is convex hull and the sampling point is more than enough, the convex hull algorithm could describes the three dimensional shell gamut precisely.

The color gamut model should meet the following principles. Model can be constructed and be achieved under current conditions; model represents the gamut accurately to serve as the basis of calculation; model should be closely related to the application, to create convenience for the application; model description should be as far as possible simple in order to improve the operation efficiency.

According to the mentioned above, a large number of color samples is needed to establish practical gamut models. To the convex hull model, vast color samples, special network, convex hull nature and a large number of three-dimensional space computing is needed to construct the model.

Meanwhile, under the current circumstances, the color information is represented by digital method, so does the color distribute in both the original gamut and destination gamut, the colors in the gamut above are all discrete. Although the color errors between adjacent points do always exist, the color difference between them is less than that the human eye can perceive, a continuous visual effects would occur, regardless its performance is discrete or continuous. Therefore, in the study, a point set gamut model is adopted to describe the printer gamut.

Printer gamut is the most important factor in the performances, and it plays a vital role in color management system. Printer gamut expresses on paper under certain condition [1], such as ink, paper performance and printer drives. Maxim cyan, magenta, yellow and black ink and some spot color and their secondary colors' chroma values are measured by spectrometer, and the data is drawn on the color circle to present the printer gamut. This method is easily to operate, and its experimental data is much less, but its accuracy is not enough, thereby the hexagon drawn could not reflect the printer gamut fully. It is a classic method of convex hull gamut. In the study, the color is recorded and shown in CIE 1976 $L^*a^*b^*$ uniform color system [3].

In the study, for the good linear characteristics, self-learning and adaptive capacity [4], a point set color gamut model based on BP neural networks is established, with the model, a considerable number of color samples is calculated by limited experimental data, in order to describe the printer gamut through software to calculate more fully, and by visual method, the convex hull gamut and point set gamut of printer is compared.

Determination of the BP Neural Network

By neural network theory, BP neural network capacity and the number of hidden layer and hidden layer neurons is closely related. In general, the more the number of hidden layer and the hidden layer neurons are, the stronger the capability of the neural network is [4]. The to-be-setup neural network input data (RGB format digital image pixel values) and output data (printer printed $L^*a^*b^*$ values) distribute in [0, 255] and [-100,100] dispersedly. To complete the nonlinear transformation between the data with such features, it is necessary to increase the network hidden layers and the number of hidden layer neurons, i.e. to use stronger neural networks of approximation capability [5].

In the further study, it found that simply relying on single-hidden layer network to increase the number of neurons can not make the capacity of neural networks to certain requirements, but also training time increases considerably, even long time training leads to slow convergence and can not end the training [6], thus not only the number of hidden layer neurons increases, but also does the level of the neural network, a three layer hidden layer BP neural network is adopted [7] [8].

In addition, the experimental data which is used to setup the model is of 1000 sets. By BP neural network theory, a neural network with stronger capability is needed to process so much data [9]. After repeated experiments, the network approximation capability of training time and other factors considered, the BP neural network is determined, and its structure from the input layer to output layer neurons of each layer is 3-30-20-30-3 [2], input layer and output layer neurons is both 3, which correspond to the RGB format digital image pixel values and the $L^*a^*b^*$ color values. The BP network structure is shown in Figure1. Hidden layer neuron activation functions are all Sigmoid () functions, the output layer neuron activation function are all pure linear purelin() functions [10].

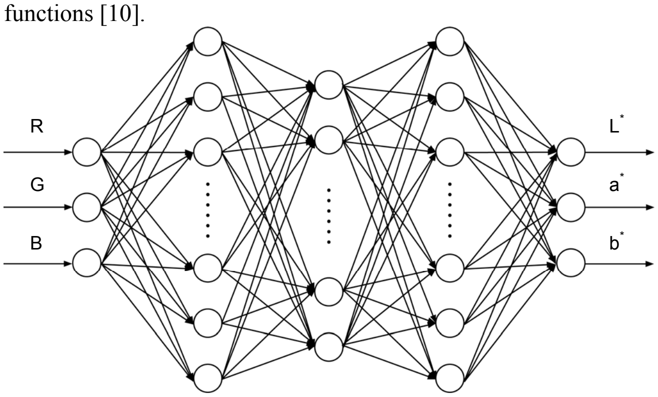

***Figure 1**. BP neural network structure*

Samples Data Acquiring for Neural Network Training of Printer Gamut Models

Color blocks are generated in MatLab 7.0 software and the BP neural network is setup by using Neural Network toolbox included in MatLab. Color blocks are generated based on 24-bit color RGB format digital image pixel values. RGB values are selected as the interval of 10 values namely 0, 26, 52, 78, 104, 130, 156, 182, 208, 234 and 255, three RGB digital image pixel values are in each combination of values, 10^3 i.e. 1000 pixel digital image value and its corresponding print color blocks and its $L^*a^*b^*$ color values are gotten as the BP neural network training data.

24-bit color BMP format image files contains 1000 blocks of color is displayed on EPSON Stylus 7600 printer, on the photo class paper with print resolution of 720×720 dpi, with Photoshop CS software without its color management function module activation. When ink dried, X-Rite 528 spectrometer is used to measured, in D65 light source with 10° field of view mode, and with the X-Key software, and the experimental data is recorded as Microsoft Excel 2003 file via the X-Key software attached software Color Shop and computer COM2 interface by data cable.

Establishing Printer Characterization Model

Printer characterization model describes the transformation between the printer input data and the color chroma value the printer prints. In steady state, the printer could be regarded as a black box, and black box theory is used to describe the relation between the input digital image pixel values and output RGB color $L^*a^*b^*$ values. In the study, BP neural network is setup to describe the transformation.

After experimental data acquiring and the determination of the BP neural network structure, in MatLab 7.0 software, its neural network module is used to establish a BP neural network, and data is normalized to range of [-1,1] or [0,1], and then the neural network is trained to achieve the target in a relatively short period of time [9].

Printer Gamut Samples Data Acquiring by Printer Characterization Model

As mentioned above, take the printer as a black box, its function is to print the input image pixel to the corresponding color. Therefore, in order to obtain more data within the printer gamut, the number of pixel values is increased to get more color samples of the printer gamut.

Color printer gamut sampled are selected in 24-bit color RGB format RGB digital image of the pixel value, RGB values are 0, 5, 10, 15, ……, 250 and 255, the number of value of digital image RGB data sets is 52^3 i.e.140608, which is used to input the BP network printer characterization model to get the corresponding printed color chroma value to describe the printer gamut more fully and exactly.

Experimental Results and Analysis

The purpose of this study is get more gamut samples and construct both convex hull model and point set model and compare them through calculation methods in the printer by software within the wider gamut to facilitate the evaluation of the printer gamut, the printing quality control and color management for printing.

Printer and Its Characterization Model Evaluation

Printer Repeatability and Stability Testing

Representative colors such as white, black, C, M, Y, K, R, G, B, 20% gray, 40% gray, 50% gray, 60% gray, 80% gray are used to form color block to print, their corresponding CMYK digital image pixel values are (0,0,0,0), (0,0,0,100), (100,0,0,0), (0,100,0,0), (0, 0,100,0), (0,100,100,0), (100,0,100,0), (100,100,0,0), (20,20,20,20), (40,40,40,40), (50,50,50,50), (60,60,60,60), (80,80,80,80), color blocks with pixel value as above is printed for three times in three color blocks. Each kind of color blocks is measured and calculated. The average color of all color blocks as 0.71878, which indicates the printer has a higher repeatability and stability.

Evaluation of the Printer Characterization Model

1000 sets of printer experimental digital image color values are input into the BP neural network, 1000 sets of chroma values are calculated.

The color error between the two kinds of data are as the following respectively. The mean color error is 2.088, the maximum color error is 9.452, and the minimum color error is 0.1691. The number of color with its color error greater than 6 is 8. It shows that the printer characterization model achieves high accuracy, and it can be used to calculate a wider color gamut of printer gamut chroma values.

Comparison between Convex Hull Model and Point set Model of Printer

Gamut Drawing Based on Experimental Data

1000 sets of discrete experimental data distribution are shown in Figure 2, i.e. the printer point set gamut.

R, G and B with maximum drives values and their secondary colors chroma values are drawn on to describe the printer gamut in Figure 3, i.e. convex hull gamut.

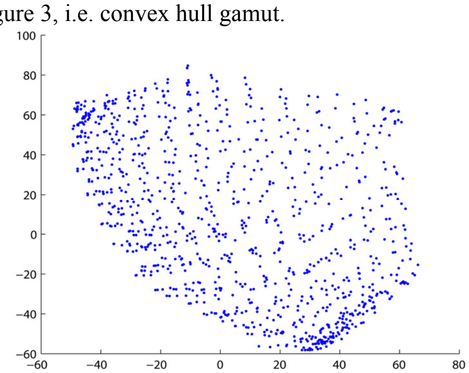

***Figure 2**. Discrete experimental data distributions*

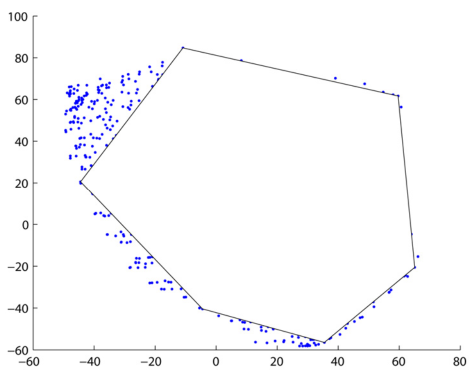

***Figure 3**. Gamut polygons drawn with three channel full drive value and secondary colors chroma values*

From Figure 3, the printer gamut drawn by traditional method with hexagon does not contain all the experimental data, because this method does not consider chroma value of secondary color of different percentage process inks. For the experimental data is of great quantity, which is of 1000 sets, based on the CIE 1976 $L^*a^*b^*$ color range and its a^*b^* plane, take the coordinate origin (0,0) as the center and hue angle range, the plane is divided into ranges, range in each hue angle range obtained from the origin point of the furthest color samples, and hue angle for each color range samples are recorded as color gamut polygon vertices. By this way, a^*b^* plane is divided into 20, 40, 60, 80, 100, 120, 140, 160, 180, 200 slices, and convex hull gamut polygons are obtained and shown in Figure 4, with hue angel number of 20, 40, 100 and 200.

From Figure 4, the arrange of color gamut polygons covering the range of experimental data points expands with the a^*b^* plane division of the shares increases, when the slice number reaches 20, the maximum coverage achieves, and it reaches to 100, the convex hull polygons coverage shrinks and the shape also became apparently irregular. This shows that, based on point gamut, if the experimental data is limited, only by increasing hue angle printer convex hull gamut can not be completely described.

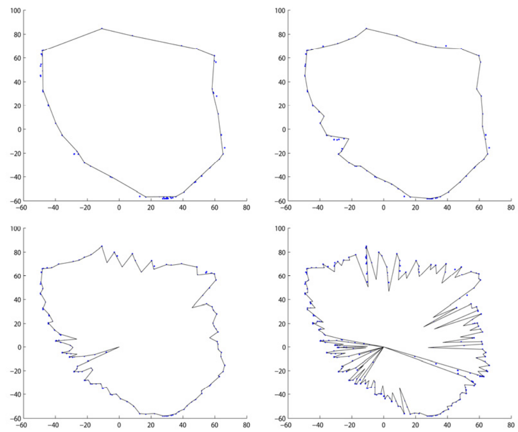

***Figure 4**. Gamut polygons with hue angel number of 20, 40, 100 and 200 with*

Gamut Drawing Based on Data Calculated By Printer Characterization Model

140608 sets of printer data calculated by printer characterization model are shown in Figure 5, i.e. convex hull gamut.

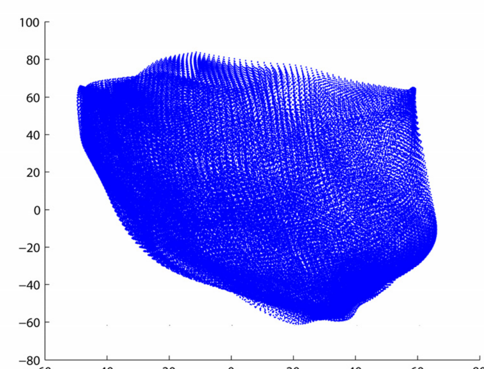

***Figure 5**. Discrete calculated data distributions*

Solid cyan, magenta and yellow and their secondary color chroma values are drawn on to describe printer gamut in Figure 6.

From Figure 6, the printer convex hull gamut hexagon drawn by traditional method can not contain all the calculated data either. Similarly, the CIE 1976 $L^*a^*b^*$ color range a^*b^* plane is divided into more hue angle range, and printer convex hull gamut polygons could be drawn. Parameters with the former ones, printer gamut polygons are shown in Figure 7, with hue angel number of 20, 40, 100 and 200.

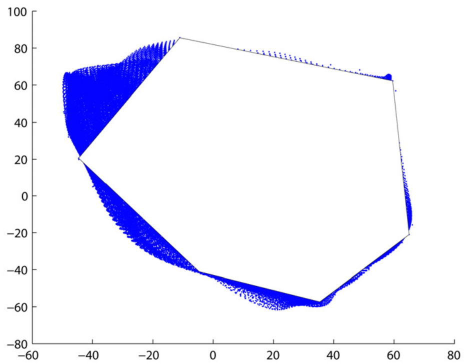

Figure 6. *Gamut polygon drawn with process ink and its secondary colors chroma values with calculated data*

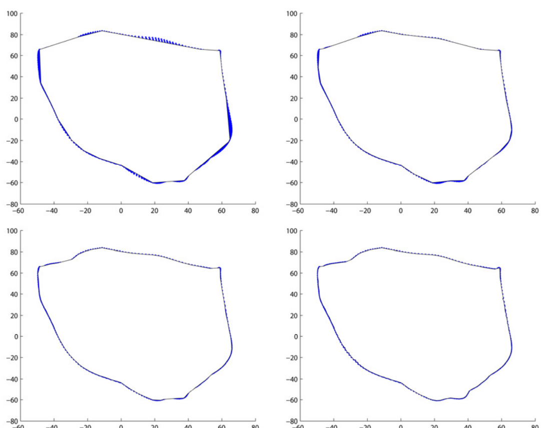

***Figure 7**. Gamut polygons with hue angel number of 20, 40, 100 and 200 with calculated*

From Figure 7, coverage of convex hull gamut polygon calculated data expands with the a^*b^* plane hue angle ranges increases from 6 to 20, but when the division of the shares increases continually, although more and more close to the contour discrete data of the edge of the coverage has increased but has been nearly imperceptible different. When the shares are more than 100, the gamut polygon coverage and its shape is almost not changed. This shows that the calculated data is enough, only if the number of color hue reaches some extent, the printer gamut could be described fully. The fundamental reason is that sufficiently large number of color samples has a more realistic representation to describe printer gamut.

Conclusion

In the study, BP neural network with additional variable learning rate and momentum factor and improved training methods is adopted, printer characterization is established based on BP neural network to describe printer gamut with both point set gamut and convex hull gamut. Because of BP network's good nonlinear approximation properties, characterization model completes the transition of the digital image pixel value and the printing color value. Based on experimental data, more gamut samples are calculated. On this basis, the CIE 1976 $L^*a^*b^*$ color range a^*b^* plane is divided into more hue angle range by a large number of calculations, and the printer convex hull gamut is drawn. Because the conversion method is based on black box theory and BP neural network, calculated data reflects the printer gamut more adequately.

Printer gamut generated by experimental data and printer characterization model calculated data differs because of the number of the former is more than the later in a great extent, and the CIE 1976 $L^*a^*b^*$ color range a^*b^* plane does not need to be divided into more ranges, the vast majority of color samples could be covered, the printer gamut could be described fully. But the description capability of printer gamut polygon based on the former data the graphics, along with the expansion of the number of hue angle, does not increase but decrease. To describe the printer gamut more precisely, by convex hull gamut method, the outline number should be chosen appropriately, and the fittest number can't be generated without several times of test. But with point set gamut method, for its discrete nature, it could describe the gamut precise, if the sample date is enough, in the study, the data is produced by both experimental data and printer characterization model. In addition, because of the experimental conditions, in study only a qualitative evaluation method of graphics is conducted.

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