

Adaptive Color Correction by High-Order CMAC Neural Network

*Jin-Jou Chen and King-Lung Huang
Opto-Electronics and Systems Laboratories,
Industrial Technology Research Institute,
Hsinchu, Taiwan, R. O. C.*

Abstract

A self-learning based color correction system which employs the CMAC (Cerebellar Model Articulation Controller) neural network with B-Spline receptive field functions is proposed. The CMAC neural network learns color input and output characteristics of target printer and models the printer. An inverse printer model is then built based on the CMAC printer model. This scheme is adaptive because the CMAC neural network can model all kinds of printer. Experimental results show that the average color difference between the desired color and the printout can be reduced to 3.7 ΔE_{ab} when a Kodak DS8650PS dye sublimation color printer is used.

I. Introduction

Advances in color printer technology have made the reproduction of color images widespread and easily available. Methods providing satisfactory quality of the printed image are therefore getting more and more attentions.

As far as the color of printed images is concerned, a critical issue is: How to estimate the input color to the printer in order to produce the desired output color? To solve this problem, several methods were used, such as: (1) the analytical printer method, (2) using look-up table with interpolation and (3) neural network method. The analytical method, such as Neugebauer equation, always results in inevitable discrepancy between estimated colors and reproduced ones, due to the phenomenon of printer's non-uniformity and instability in color characteristic. The look-up table with interpolation technique might need a large table and complicated interpolation mathematics to overcome the complexity of color devices. Therefore, a new and novel approach based on neural network was proposed [1].

This paper uses CMAC neural network to implement the color correction of printers. The CMAC neural network is trained to mimic the input and output color characteristics of printer and is used as the printer model. Unlike standard

CMAC's first-order receptive field function [2] which will result in staircase function approximation, B-Spline receptive field function which can approximate nonlinear functions more smoothly is used. Based on the CMAC printer model, the inverse printer model can be built by the LUT. The color printer can be corrected by the inverse printer model. Experiments were done to find an optimal CMAC structure and to test the performance of this scheme.

II. CMAC Neural Networks

As shown in Figure 1, a CMAC neural network [2], is a perceptron-like association memory [3] with overlapping receptive field that can learn arbitrary multi-dimensional non-linear relationship between input and output data. Unlike back-propagation style feed forward neural network which use the entire data set to build global relationship, CMAC uses local weight updating scheme and has the advantage of fast learning.

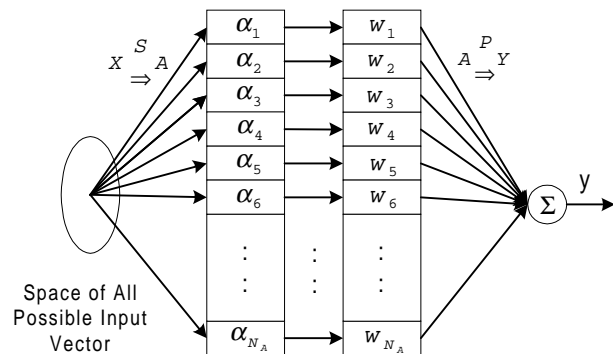


Figure 1. Standard CMAC structure

CMAC approximates a nonlinear function by using two primary mappings:

$$S : X \Rightarrow A$$

$$P : A \Rightarrow Y$$

where X is a continuous M -dimensional input space, A is a N_A -dimensional association cell space, and Y is the output space [4]. The function S maps each point in the

input space X onto an association vector $\alpha \in A$ that has N non-zero elements. These N non-zero elements are called the active associative cells. The $N_i \times 1$ association cell vector is defined as $\alpha = S(x)$. The function $P(\alpha)$ computes a scalar output, y , by projecting the association vector onto a $N_A \times 1$ weight vector, W , whose elements are attached to their corresponding association cells, that is,

$$y = P(\alpha) = \alpha^T W = \sum_{j=1}^{N_A} w_j \cdot S_j(x)$$

These weights are modified using the generalized CMAC learning rule,

$$w_i = w_i + \beta \frac{(y_d - y) S_i(x)}{\sum_{i=1}^{N_A} S_j^2(x)}$$

where β is the training gain that affects the rate of learning and y_d is the desired output with respect to x [5].

Since the rectangle shape of CMAC receptive field functions produces discontinuous staircase function approximations, Lane had developed the high-order CMAC neural network model with B-Spline to learn both function and function derivatives. The details including the learning algorithm can be found in [6].

III. Color Correction Scheme

1. The Training Pattern

To fully extract the color features of a target printer, a set of training patterns is constructed for the CMAC printer model. Each of the training pairs contains a RGB value as the input part and an Lab value as the output. The Lab value is measured from the color printout generated by inputting the RGB value to the target printer. The training patterns are uniformly distributed in the input color space. Because human eyes are more sensitive to the deviations in gray levels, training patterns should contain gray ones in order to make the corrected target printer to print more accurate gray levels.

2. The Printer Model

The printer model is built by training the CMAC with the training patterns stated above. In Figure 2, the RGB value of a training pattern is inputted to the CMAC and Lab^M is compared with Lab^P , where Lab^M is the output of CMAC and Lab^P is the Lab value of the training patterns. The color differences between Lab^M and Lab^P are then used to update the weightings of CMAC neural network. The maximal-error learning rule is used. That is, only one training pattern which generates max error is selected to update weights in every training epoch. When the largest color error is reduced to a certain threshold, the training process is terminated.

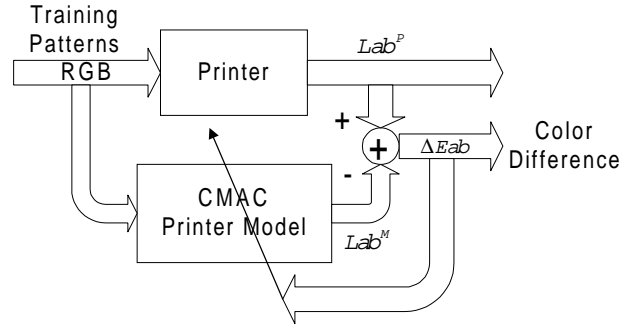


Figure 2. Training process of the CMAC printer model

The CMAC printer model can be tested as shown in Figure 3. Testing patterns outside the set of training patterns are randomly selected to test the learning performance of the CMAC network. Different parameter sets of the CMAC printer model will be tested until the one with the lowest prediction error is found.

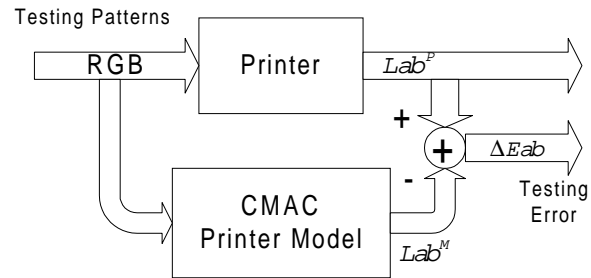


Figure 3. Testing process of the CMAC printer model with prediction testing patterns

3. The Inverse printer model

The inverse printer model is the reversion of the printer model. The input-output mapping of the inverse printer model is one-to-many, because more than one color will be compressed into the same output when they are inputted to a printer. Therefore a three-dimensional look-up table is used as the inverse printer model instead of using CMAC network.

The steps to build the look-up table are listed as follows:

Step 1. Find the Lab range of the printer. The maximum and minimum values in Lab space are recorded as $L_{max}, L_{min}, a_{max}, a_{min}, b_{max}, b_{min}$.

Step 2. Partition the *bounding cube* of the target printer in Lab color space into many sub-cubes of the same dimension. The bounding cube is illustrated in Figure 4. It is the boundary of the printer gamut in Lab space.

Step 3. Select randomly a certain number of RGB values, $RGB^1, RGB^2, \dots, RGB^N$, and input them to the CMAC printer model. Corresponding Lab output value $Lab^1, Lab^2, \dots, Lab^N$ are recorded.

Step 4. Store RGB^i in the sub-cube B^i , where B^i is the sub-cube that Lab^i belongs to and $i=1, 2, \dots, N$. When more than one RGB values produce the same Lab value, an already-stored RGB value will be over-written by another one, because only one RGB color can be stored in a sub-cube.

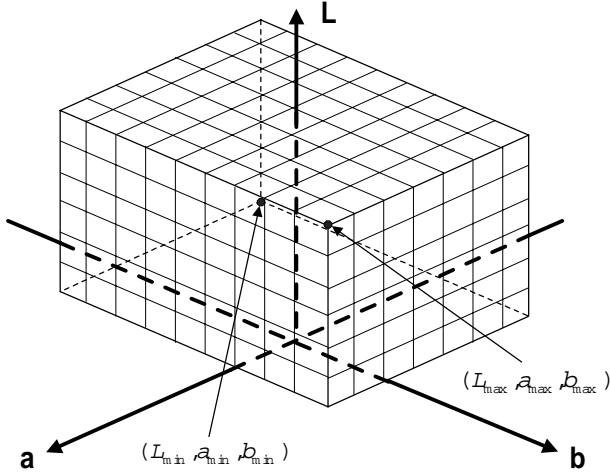


Figure 4. The bounding cube partitioned to serve as the three-dimensional look-up table.

4. Printer Correction

The printer color correction is shown in Figure 5. The flowchart of color correction process is illustrated in Figure 6. There are two possible reasons when no RGB value is stored in the corresponding sub-cube of an inside gamut color Lab^D : (1) The number of selected RGB values in Step 3 is not enough. More RGB values will alleviate this condition. (2) The size of the sub-cubes is too small. Increase the size of the sub-cubes will be helpful, but the accuracy of the corrected target printer will be decreased.

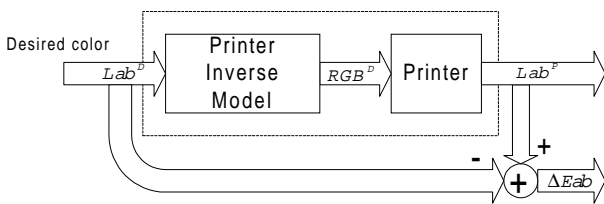


Figure 5. The printer color correction system

The accuracy of color reproduction is determined by the color difference between Lab^D and Lab^P , which is the color of the corresponding print out.

For a color Lab^D which is outside the printer gamut, a clipping method is used. The steps of this method is listed as follows:

- Step1. Lab^D is transformed into Lch^D .
- Step 2. Among all the inside gamut colors which have

the same hue angle as Lch^D , find Lch^R which is the nearest to Lch^D .

Step 3. Lab^R is then computed by Lch^R .

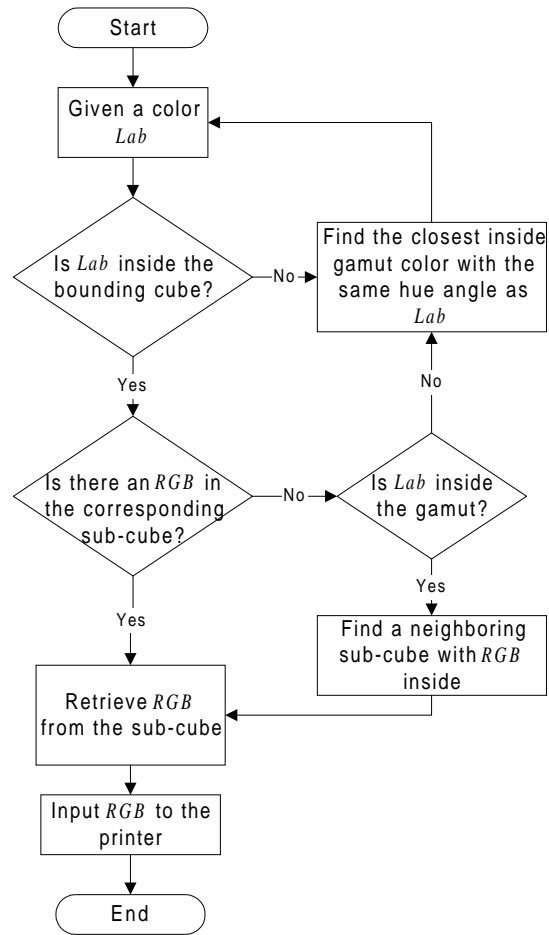


Figure 6. The flowchart of color correction

IV. Experiments and Results

Several experiments are done to verify the color correction performance. Three types of thermal printers are used in experiments: Kodak DS8650PS, Fargo PrimeraPro (dye sublimation) and Fargo PrimeraPro (thermal wax). The measuring instruments is X-Rite 938 spectrodensitometer with D65 light source and 10 degrees observe angle. The input part of the training patterns contains two sets of RGB values: one set of chroma colors and the other one of gray levels. The chroma colors are uniformly distributed in the RGB color space and their RGB are selected from the set: {0, 51, 102, 153, 204, 255}. The RGB of each gray level are the same and range from 0 to 255 in a step of 1. Therefore there are 472 (6x6x6+256) training patterns. The 450 testing patterns are randomly selected from the RGB color space. Several parameter sets of CMAC neural network are used in this experiment and their results are shown as in Table 1 and Table 2. Model 2, 10 and 12 are

then chosen as the printer model for the 3 types of printers, respectively.

Table 1. Training results for several CMAC models. Model ID 1 to 9, 10 to 11 and 12 to 13 are for Kodak DS8650PS, Fargo PrimeraPro(dye sublimation) and Fargo PrimeraPro(thermal wax), respectively.

CMAC Model Specifications					Results
Model ID	Supports	Quantization No.	Learning Rate	Iteration No.	Max Residual Error(ΔE_{ab})
1	2	4	0.1	2056	5.9
2	3	4	0.1	2527	2.9
3	4	4	0.1	2829	4.5
4	2	3	0.1	735	8.6
5	3	6	0.1	3152	2.7
6	4	6	0.1	3411	3.0
7	5	6	0.1	5410	2.7
8	5	9	0.1	3891	2.7
9	4	12	0.1	8967	2.2
10	3	4	0.1	5647	4.0
11	3	6	0.1	2528	3.9
12	3	4	0.1	2333	4.2
13	3	6	0.1	3215	4.0

Table 2. Testing results for several CMAC structures.

Testing Results			
Model ID	Max Prediction Errors(ΔE_{ab})	Min Prediction Errors(ΔE_{ab})	Average Prediction Errors(ΔE_{ab})
1	24.12	0.59	7.10
2	13.01	0.17	3.86
3	13.98	0.74	5.24
4	20.14	2.19	7.79
5	22.12	0.56	5.85
6	14.16	0.63	4.88
7	15.94	0.49	4.96
8	18.14	0.93	6.20
9	100.90	1.70	42.31
10	11.82	0.87	4.61
11	26.08	0.73	6.81
12	24.12	0.92	5.23
13	22.92	0.91	6.37

The ranges of these printer models are listed in Table 3 and their gamut are shown in Figure 7. To build the three-dimensional look-up tables as the inverse printer models, a total number of 2,097,152 (128×128×128) RGB colors were inputted to the printer models. The size of the sub-cubes in Lab space is: $\Delta L=1$, $\Delta a=1$ and $\Delta b=1$.

Table 3. Lab ranges of the three printer models

	Kodak DS8650PS			Fargo PrimeraPro (dye sublimation)			Fargo PrimeraPro (thermal wax)		
	L	a	b	L	a	b	L	a	b
Max	94	70	110	95	69	101	91	63	78
Min	5	-56	-58	11	-70	-47	11	-61	-45

The testing results for the 3 types of thermal printers are shown in Figure 8.

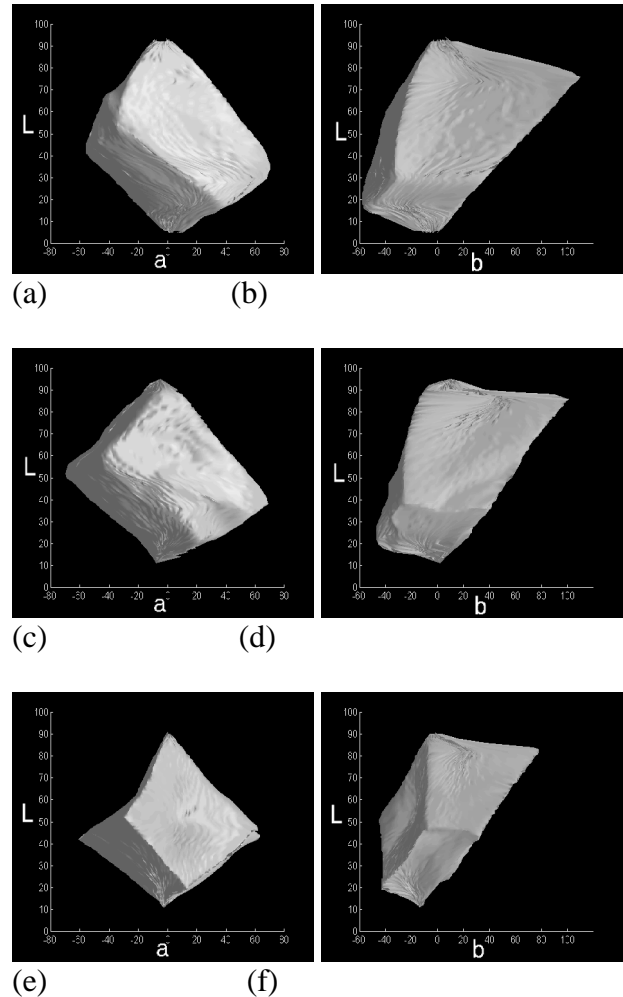
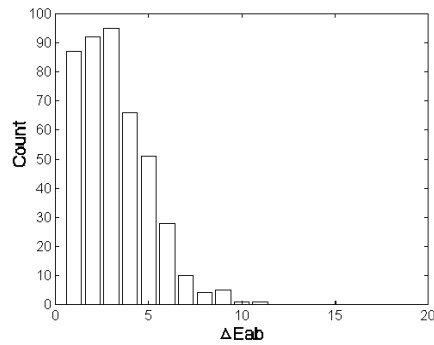
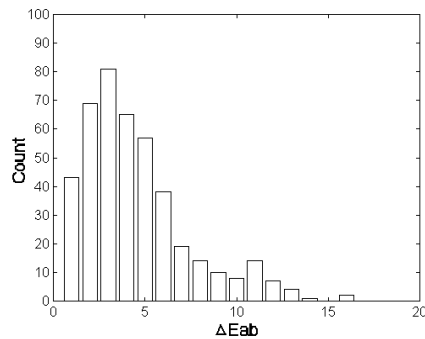


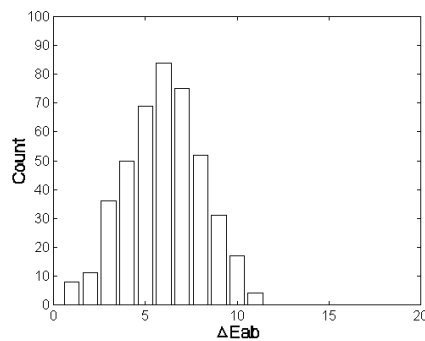
Figure 7. Gamuts computed from the three CMAC printer models. (a) and (b): Kodak DS8650PS, (c) and (d): Fargo PrimeraPro (dye sublimation), (e) and (f): Fargo PrimeraPro (thermal wax)



(a)



(b)



(c)

Figure 8. Testing results of the three corrected target printers. (a) Kodak DS8650PS (Mean = 3.70 ΔE_{ab}), (b) Fargo PrimeraPro (thermal wax) (Mean = 5.22 ΔE_{ab}), (c) Fargo PrimeraPro (dye sublimation) (Mean = 6.53 ΔE_{ab})

V. Discussion and Conclusion

Attention should be paid to how color patches are arranged on printouts. Variances in printer quality, *e.g.*, white spots at the header part of the print out, and excessive color difference (often greater than 8 ΔE_{ab}) between the horizontally opposed sides of the printout which is supposed to be in uniform color, are significant for printers such as Fargo PrimeraPro (thermal wax). Experiments showed that, an auxiliary black strip added before the header of the patches effectively removes the spots, while the color

differences are reduced if the width of the printed area was reduced.

An adaptive color correction scheme of printers is proposed. Using a CMAC neural network as the model of the target printer, the process of building the color correction system is the same for all printers regardless of their types. A three-dimensional look-up table is created as the inverse printer model according to the CMAC printer model. Using this scheme, the average color difference between the desired color and the printout's color can be reduced as low as 3.7 ΔE_{ab} for a Kodak DS8650PS thermal printer.

To print an image using the proposed color correction system, a module that translates the image's color to Lab color space will be implemented in the future.

References

1. Tominaga, S., A Neural Network Approach to Color Reproduction in Color Printers, *IS&T and SID's Color Image Conference: Transforms & Transportability of Color*, 173-177 (1993).
2. Albus, J., A new approach to Manipulator Control: The Cerebellar Model Articulation Controller (CMAC), *Trans. ASME-J. Dyn. Syst. Meas. Control*, 97, 220-227 (1975).
3. Rosenblatt, F., *Principles of Neurodynamics*, Spartan Books, New York (1962).
4. Ker, Jar-Shone, *et. al.*, Hardware Realization of Higher-order CMAC Model for Color Calibration, *ICNN*, 1656-1661, (1995).
5. Ker, Jar-Shone *et. al.*, Enhancement of the Weight Cell Utilization for CMAC Neural Network: Architecture Design and Hardware Implementation, *Proc. of MICRONEURO, Torino, Italy* (1994).
6. Lane, Stephen H., *et. al.*, Higher-order CMAC Neural Networks - Theory and Practice, 1579-1585.