Spectral colour calibration for multi-ink printer

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Received 7 March 2014, www.tsi.lv

Abstract

To implement colour calibration during outputting multispectral images on a multi-ink printer, a new spectral colour calibration method is proposed. Firstly, by uniform sampling in the multi-ink printer colour space, measuring the spectral reflectance of the samples and then transforming the reflectance data to a low dimension spectral space, a forward look-up table is created. Then by sampling in the low dimension spectral space and using a nonlinear optimization to calculate the mapping points of these samples in the printer colour space, a backward look-up table is established. Meanwhile, to improve the optimization accuracy and shorten the computing time, an algorithm is designed to determine the optimization parameters based the samples. Finally, a multi-linear interpolation method is carried out on the forward and backward look-up table to achieve the spectral colour calibration of the multi-ink printer. Experiments show that the new method not only takes advantage of the high calibration precision and less time-consuming of the look-up table, but also solves the problem brought by the high dimension of the spectral data to the look-up table method by utilizing the nonlinear optimization and dimension reduction. Compared with the spectral colour calibration model methods, the new method improves the colorimetric and spectral precision obviously. It also raises the time efficiency of the inverse calibration significantly.

Keywords: spectral colour calibration, multispectral image, multi-ink printing, look-up table

1 Introduction

Multispectral images are those whose pixel values are spectral reflectance of source scenes. They are captured by multi-channel cameras, and mainly used for the accurate and consistent colour reproduction of source scenes under different illuminant. Now they have been widely used in high-end imaging fields such as art archiving [1, 2], medicine [3, 4], military target imaging.

The hard-copy of multispectral images is achieved by printing on a multi-ink printer. During the image printing process, colour calibration is a crucial part. Colour calibration is used to compensate the colour distortion resulted by the nonlinear characteristic of printers and to achieve accurate and consistent colour reproduction of the images on various devices. The data of multispectral images are spectral reflectance and they are narrow sampled in the range of visible light. This leads to the fact that the dimension of image data is high and the amount of the data is large. Moreover, the channel number of the multi-ink printer is more than 6. All these result in that the colour calibration methods designed for the colorimetric images cannot be applied to the reproduction of the multispectral images. Thus, designing new spectral colour calibration method becomes the key in the process of the hard copy of multi-spectral images.

The existing spectral colour calibration methods for the multi-ink printing include Yule-Neilson Spectral Neugebauer (YNSN) model [5, 7], Celluar YNSN model [8, 9], Kubelka-Munk colour mixing model [10], and so on. All these methods can directly calibrate the spectra by creating the mathematical printing model through the analysis of the physical printing process. The printing accuracy using the model methods is determined by the precision of the model. Since the device is nonlinear and the printing process is changeable, the spectral printing models cannot accurately simulate the actual printing process. This makes the accuracy of spectral colour calibration low. Furthermore, the inverse calibration is implemented by using nonlinear optimization real time. This results in that the consuming time is very long and the efficiency is low. The calibration method commonly used for chrome images is look-up table (LUT). The LUT can be created beforehand. It can avoid the calculating bottleneck in the colour calibration. In addition, its precision is high. Nevertheless, the chrome image is 3-channel image and the printer used for it is 4-ink printer. Thus, the chroma calibration only needs 3-dimension look-up table and tri-linear interpolation. For the multi-ink printing of the multispectral images, the low-dimension LUT cannot meet the requirements obviously. Thus, the high dimension LUT must be established and the multi-linear interpolation must be used. All these become the difficulty when the LUT method is used for spectral colour calibration.

In this paper, a spectral colour calibration using look-up table for multi-ink printing is presented. During the creation of the LUT, a low-dimension spectral space is introduced. The mapping between the low-dimension spectral space and the multi-ink printer colour space is established. It solves the problem that the high dimension spectral data cannot be directly used to create the LUT.

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During the creation of the inverse LUT, a non-linear optimization is adopted to gain the mapping of the samples from the low-dimension spectral space to the printer colour space. An algorithm to determine the optimization parameters based on the samples is designed to improve the precision and efficiency. This makes the generation of the inverse calibration sample set and the creation of the inverse look-up table become possible. Finally, the multi-linear interpolation is used to achieve the spectral colour calibration. The new method can not only solve the problem brought by the high dimension of the spectral data, but also take the advantage of the high accuracy and efficiency of the look-up table method. It improves the precision and efficiency of the spectral colour calibration effectively.

2 Spectral colour calibration

The colour space of chromatic input/output devices is different and nonlinear. So the colour calibration becomes necessary when images are produced on hard copy devices. Colour calibration is an important step in the Colour Management. When the data in the source device colour space is mapped to the destination device colour space, the Colour Management uses the colour calibration to transform the source data to the device-independent colour space firstly and then transform them to the destination colour space. When images are printed out, it mainly relates to the transformation between the printer colour space and the device-independent colour space. For multi-spectral images, the spectral reflectance space can be utilized as the device-independent space.

Given a point $\boldsymbol{c}$ in the printer colour space, the corresponding spectral reflectance $\boldsymbol{s}$ can be measured by a spectrophotometer. Defining

$$\boldsymbol{s} = \mathcal{F}_{print}(\boldsymbol{c}), \qquad \boldsymbol{c} \in \boldsymbol{\Omega}_{print}, \quad \boldsymbol{s} \in \boldsymbol{\Omega}_{spec}, \tag{1}$$

where $\mathcal{F}_{print}(\bullet)$ is the nonlinear mapping from the printer colour space to spectral reflectance space. $\boldsymbol{\Omega}_{print}$ is printer colour space and $\boldsymbol{\Omega}_{spec}$ is the spectral reflectance space. Correspondingly, for the spectral reflectance that can be printed by the printer, $\mathcal{F}^{-1}_{pint}(\bullet)$ is used to transform it to the printer colour space. That is,

$$c = \mathcal{F}^{-1}_{pint}(s), \qquad s \in \boldsymbol{G}_{print}. \tag{2}$$

$\boldsymbol{G}_{print}$ is the spectral domain of the printer that the spectra in it can be printed but those out of it cannot be printed. It can be denoted as

$$\boldsymbol{G}_{print} = \left\{ s \in \boldsymbol{\Omega}_{spec} \,\middle|\, \exists c \in \boldsymbol{\Omega}_{print}, \quad \mathcal{F}_{print}(c) = s \right\}. \tag{3}$$

The spectral colour calibration is to gain the forward mapping $\mathcal{F}_{print}(\bullet)$ and the backward mapping $\mathcal{F}^{-1}_{pint}(\bullet)$, thereby, to achieve the calibration transformation between the printer colour space and the spectral space.

3 Spectral colour calibration for multi-ink printing based on LUT

There are two kinds of methods to achieve $\mathcal{F}_{print}(\bullet)$ and $\mathcal{F}^{-1}_{pint}(\bullet)$: one is to create the printing model and another is to utilize look-up table. Since the physical printing process is affected by the paper, ink, printing point and many other factors, the printing model cannot simulate the actual printing process accurately. It makes calibration precision low. Moreover, the spectral printing model is usually unable to obtain the analytical inverse model. Using the model to carry out inverse colour calibration needs to utilize the nonlinear optimization in real-time to implement the inverse transformation of the colour space. It leads to that the consuming time of the calibration process is long. The LUT method creates the one-one correspondence of the samples in the source colour space and the destination colour space by sampling in the colour space and measuring the values of the samples. Although this method requires more samples, the actual printing and measuring of the samples makes it better reflect the physical printing process. Thus, the printing precision is high. In addition, the LUT can be established in advance and only needs to utilize the interpolation to execute calibration. Therefore, the calibration can be carried out in real time.

During creating the mapping between the spectral space and the multi-ink printer color space, if the high dimension spectral reflectance data is employed directly, e.g. 31-dimension spectra, the dimension of the LUT will be 31 and the size will be $8 \times 10^{15} GB$ (Given the sampling level per dimension is 6, the printer is 6-ink and the size of the data per channel is 1 byte). Obviously, this makes the LUT cannot be achieved. Therefore, it needs to apply dimensionality reduction to the high dimension spectral reflectance and utilize the low dimension spectral colour space to substitute the spectral reflectance space in the creation of the LUT. Firstly, a low-dimension space $\boldsymbol{\Omega}_{spec\_l}$ is established,

$$\boldsymbol{\Omega}_{spec\_l} = \left\{ r \,\middle|\, \exists s \in \boldsymbol{\Omega}_{spec}, \quad \mathcal{L}(s) = r \right\}. \tag{4}$$

$\mathcal{L}(\bullet)$ is the algorithm of the dimensionality reduction. Correspondingly, $\mathcal{L}^{-1}(\bullet)$ is the inverse transformation from the low dimension space to the spectral reflectance space. The spectral domain of the printer in the new space is

$$\boldsymbol{G}_{print\_l} = \left\{ \boldsymbol{r} \in \boldsymbol{\Omega}_{spec\_l} \middle| \exists \boldsymbol{c} \in \boldsymbol{\Omega}_{print}, \ \mathcal{F}_{print}(\boldsymbol{c}) = \boldsymbol{r} \right\}. \tag{5}$$

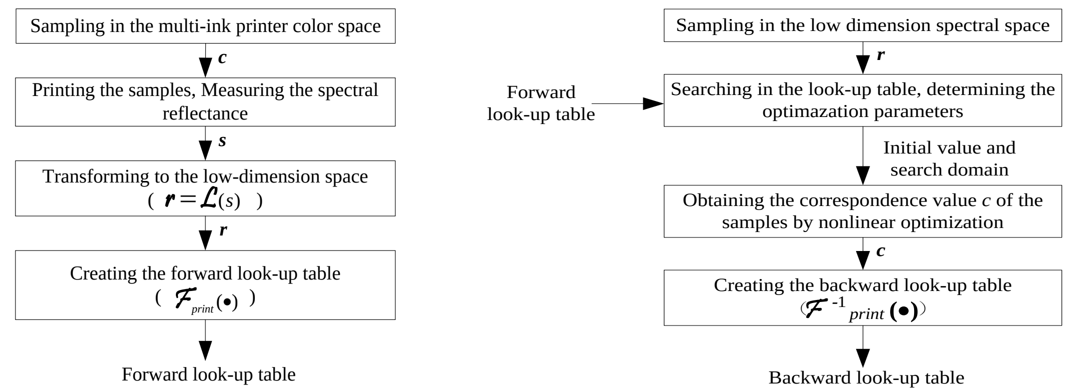
Then the forward spectral colour calibration can be defined as

$$\boldsymbol{r} = \mathcal{F}_{print}(\boldsymbol{c}), \qquad \boldsymbol{c} \in \boldsymbol{\Omega}_{print}, \quad \boldsymbol{r} \in \boldsymbol{\Omega}_{spec\_l}. \tag{6}$$

The inverse model is

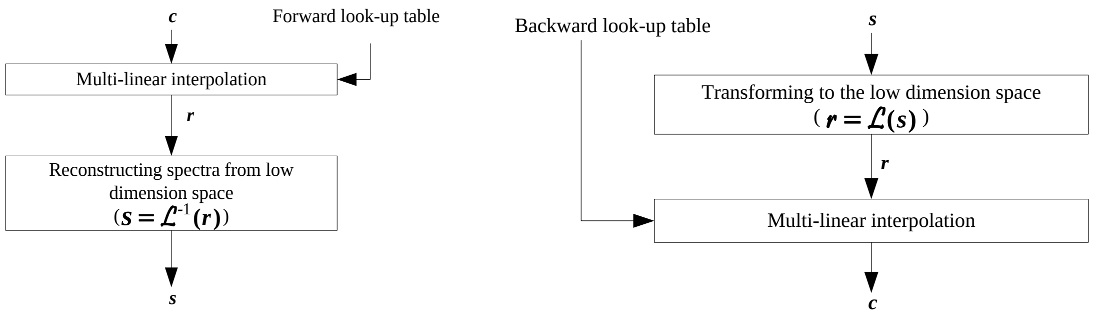
$$c = \mathcal{F}^{-1}_{pint}(r), \qquad r \in \boldsymbol{G}_{print\_l}. \tag{7}$$

The LUT method is to simulate the forward mapping $\mathcal{F}_{print}(\bullet)$ and backward mapping $\mathcal{F}^{-1}_{pint}(\bullet)$ by creating the one-one correspondence of the source and destination space. The process of the spectral colour calibration using LUT is shown in Figure 1 and Figure 2.



a) forward look-up table b) backward look-up table

FIGURE 1 Creation of the look-up table



a) forward calibration b) inverse calibration

FIGURE 2 Spectral colour calibration for multi-ink printing

During the creation of the forward LUT (Figure 1(a)), the samples in multi-ink printer colour space and its mapping points in the low dimension spectral space are utilized to generate the forward calibration sample set. The forward LUT is established based on this sample set. The creation of the backward LUT (Figure 1(b)) is more complex than the forward LUT. Since the multi-printer colour space and the spectral space are different in nature, the mapping points of the samples sampled uniformly in the printer colour space are non-uniform in the spectral space. Thus, the forward calibration sample set cannot be utilized directly to obtain the mapping points in the printer colour space of the samples in the spectral space. Therefore, we sample uniformly in the low-dimension spectral space and then calculate the mapping points of the samples in the multi-ink printer colour space. Form this, the inverse calibration sample set is generated and the backward LUT is created based on it. Experiments show that the convex volume in the printer colour space is non-convex in the spectral space, so the inverse uniformization methods used in the chroma colour calibration [11] cannot be applied. In this paper, a nonlinear optimization method is utilized to establish the backward LUT. Its optimization parameters are determined based on the forward LUT.

After creating the forward and backward LUT, the spectral colour calibration is implemented by interpolation. Experiments show that the non-linear interpolation does not have a clear advantage in the interpolation accuracy compared with the linear interpolation in the colour calibration. Therefore, the multi-linear interpolation is applied in this paper to carry out the LUT search.

4 Key technologies of the algorithm

4.1 DETERMINATION OF THE NONLINEAR OPTIMIZATION PARAMETERS

The framework using non-linear interpolation to establish the backward LUT is show in Figure 3. From Figure 3 we know optimization objective function, initials and the boundary of the optimization variables are the key when using non-linear optimization.

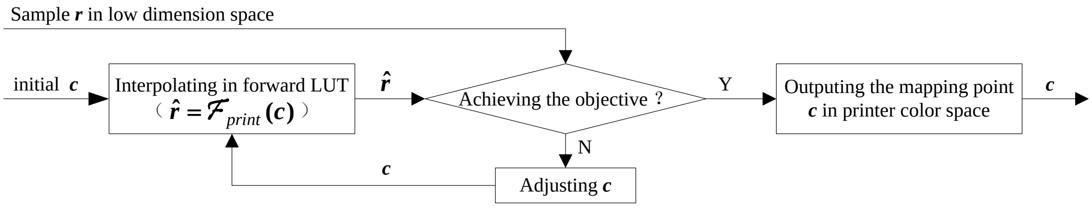


FIGURE 3 Process of generating backward LUT by using non-linear optimization

In order to achieve high quality output of the multispectral images, it is required that the output image and the source image are able to gain a good match in both chrome and spectral reflectance. High chrome precision means that the output image matches the source well under a typical illuminant; high spectral precision means that the output image matches the source well when the illuminant is changed. Therefore, the optimization objective function is set to take into account both the spectral and colorimetric accuracy. We define the function as

$$\begin{aligned} \min\ f(\boldsymbol{c}) &= \alpha \left\| \boldsymbol{r} - \mathcal{F}_{print}(\boldsymbol{c}) \right\|_2^2 \\ &+ \left\| Col(\mathcal{L}^{-1}(\boldsymbol{r})) - Col(\mathcal{L}^{-1}(\mathcal{F}_{print}(\boldsymbol{c}))) \right\|_2^2 , \qquad (8) \\ s.t.\quad & \boldsymbol{c} \in sub\_BPr \\ & sum(\boldsymbol{c}) \le c_{limit} \end{aligned}$$

where $Col(\bullet)$ is the transformation from the spectral reflectance space to the CIELAB uniform colour space. Its transforming process is described in Reference [12]. α is a weight. Experiments show when $\alpha = 50$ that $f(c)$ can better reflect the error of both chroma and spectra. sub_BPr is the boundary of the optimization variable. Its definition is shown in Equation (13). c_{limit} is the limitation of the total amount of ink. If the amount of each primary colour ink is too much, the paper will be not able to hang on the ink. The printing quality will drop.

The optimization initial and variable play a crucial role for the convergence speed of optimization function and optimization accuracy. In this paper the algorithm for determining the initial and the boundary of variable is described as follows.

(1) According to the samples in the forward LUT, obtain the hypercube set in the multi-ink printer colour space. It is

$$P_{hypercubes} = \{P_i\} \quad i = 1, ..., N , \qquad (9)$$

Then gain the minimum circumscribed hypercube set of the mapping volume of each above hypercube in the low dimension spectral space. It is

$$R_{hyperbodies} = \{R_i\} \quad i = 1, ..., N , \qquad (10)$$

where R_i and P_i is one-one correspondence. P_i is a hypercube in printer colour space in forward LUT. R_i is the minimum circumscribed hypercube of the mapping volume of hypercube P_i in the low dimension spectral space. N is the number of hypercube in the forward LUT.

During the creation of the forward LUT, the samples are uniformly distributed in the printer colour space. Using the adjacent sample points in the multi-dimension space as the vertices, a hypercube can be formed. Using the mapping points of the above samples in the low dimension space, the mapping volume in the low dimension spectral space of the hypercube in the printer colour space can be achieved.

(2) For any sample r in the low dimension spectral space, obtain the minimum circumscribed hypercube set it locates in,

$$sub\_Rr = \{ sub\_R \mid sub\_R \in R_{hyperbodies}, r \text{ is in } sub\_R \} , \qquad (11)$$

The hypercube in the printer colour space recorded in the forward LUT is regular convex volume, but its mapping volume in the low dimension spectral space is often non-convex and irregular. This leads to that the hypercube in the multi-ink printer colour space that the mapping point of the sample $\boldsymbol{r}$ located in cannot be positioned directly. The sample $\boldsymbol{r}$ may belong to several minimum circumscribed hypercube.

(3) Find the corresponding hypercube set of sub_Rr in the printer colour space, and calculate the upper and lower bounds on each dimension,

$$sub\_Pr = \{ sub\_P \mid sub\_P \in P_{hypercubes}, sub\_R \in sub\_Rr, \ sub\_P \text{ and } sub\_R \text{ is one-one correspondence} \} , \qquad (12)$$

$$sub\_BPr = \text{Upper and lower bounds of } sub\_Pr \text{ on each dimension} . \qquad (13)$$

Use sub_BPr as the boundary of optimization variable in Equation (8).

(4) For every vertex c_{vertex} of the hypercube in sub_Pr, utilize the following formula to obtain the closest vertices for optimization objective,

$$c_{ver\_closest} = \arg(\min_{c_{vertex}}(\alpha\left\| r - \mathcal{F}_{print}(c_{vertex})\right\|_2^2 + \left\| Col(\mathcal{L}^{-1}(r)) - Col(\mathcal{L}^{-1}(\mathcal{F}_{print}(c_{vertex})))\right\|_2^2)) . \quad (14)$$

Use $c_{ver\_closest}$ as the optimization initial.

(5) Repeat step (2), (3) and (4) to calculate the optimization initial and the variable boundary of each sample r_j in the low dimension spectral space.

In this paper, we choose Quasi-Newton Method as the non-linear optimization method to establish multi-dimension backward LUT.

4.2 MULTI-LINEAR INTERPOLATION

After creating the forward and backward LUT, the spectral colour calibration can be implemented by multi-linear interpolating in the LUT for every sample in printer colour space or low dimension spectral space. Multi-linear interpolation is the generalization of linear interpolation. The function of linear interpolation is

$$\mathcal{F}_{Fit}^{[m]}(x) = u_0^{[m]}(x) \bullet \mathcal{F}(x^{[m]}) + u_1^{[m]}(x) \bullet \mathcal{F}(x^{[m+1]}) , \quad (15)$$

where $m = 0,1,..., M-1$ is serial number of the samples on $\boldsymbol{x}$, the sample numbers is M. $\mathcal{F}(\boldsymbol{x}^{[m]})$ is the value of the samples. It can be gained by the forward and backward LUT. $\boldsymbol{u_0^{[m]}(x)}$ and $\boldsymbol{u_1^{[m]}(x)}$ are basic function. They are designed to make the following equation hold,

$$\mathcal{F}_{Fit}^{[m]}(x^{[m]}) = \mathcal{F}(x^{[m]}), \quad \mathcal{F}_{Fit}^{[m]}(x^{[m+1]}) = \mathcal{F}(x^{[m+1]}) , \quad (16)$$

Obviously,

$$u_s^{[m]}(x^{[m]}) = 1-s, \quad u_s^{[m]}(x^{[m+1]}) = s \quad \left(s \in \{0,1\} \right), \quad (17)$$

meets the requirement. Moreover, from Equation (15) we know $\boldsymbol{u_0^{[m]}(x)}$ and $\boldsymbol{u_1^{[m]}(x)}$ is linear function about x. Thus we design

$$u_s^{[m]}(x) = (1-s) + (2s-1)(x - x^{[m]}) / (x^{[m+1]} - x^{[m]}) \quad \left(s \in \{0,1\} \right) , \quad (18)$$

Multi-linear interpolation is to apply linear interpolation on each dimension. Given a N-linear interpolation, the sampling level on each dimension is M_1, M_2, …, M_N, and $m = \left(m_1, m_2, ..., m_N\right)$ is the serial number of samples on each dimension. Then according to Equation (15), the n-linear interpolation function is defined as

$$\mathcal{F}_{Fit}^{[m,n]}(x) = u_0^{[m,n]}(x) \bullet \mathcal{F}_{Fit}^{[m,n-1]}(x_1, x_2, ..., x_{n-1}, x_n^{[m_n]}, x_{n+1}, ..., x_N) + u_1^{[m,n]}(x) \bullet \mathcal{F}_{Fit}^{[m,n-1]}(x_1, x_2, ..., x_{n-1}, x_n^{[m_n+1]}, x_{n+1}, ..., x_N) , \quad (19)$$

where $n=1,...,N$, $x = \left(x_1, x_2, ..., x_N\right)$. Let

$$\mathcal{F}_{Fit}^{[m,0]}(x) = \mathcal{F}(x) , \quad (20)$$

from Equation (18) we gain

$$u_s^{[m,n]}(x) = (1-s) + (2s-1)(x_n - x_n^{[m_n]}) / (x_n^{[m_n+1]} - x_n^{[m_n]}) \quad \left(s \in \{0,1\}\right) \quad (21)$$

Then

$$\mathcal{F}_{Fit}^{[m,n]}(x) = \sum_{s_1, s_2, ..., s_n \in \{0,1\}} \left(\prod_{j \in \{1,...,n\}} u_s^{[m,j]}(x) \right) \bullet \mathcal{F}(x_1^{[m_1+s_1]}, x_2^{[m_2+s_2]}, ..., x_n^{[m_n+s_n]}, x_{n+1}, ..., x_N) \quad (22)$$

When $n = N$, we achieve n-linear interpolation function

$$\mathcal{F}_{Fit}^{[m,N]}(x) = \sum_{\substack{s=\{s_1, s_2, ..., s_N\} \\ s_j \in \{0,1\}}} u_s^{[m]}(x) \bullet \mathcal{F}(x^{[m+s]}) , \quad (23)$$

where

$$u_s^{[m]}(x) = \prod_{j \in \{1,2,...,N\}} u_s^{[m,j]}(x) , \quad (24)$$

When using the above interpolation method to implement spectral colour calibration, x is a point in the printer colour space or the low dimension spectral space, and $\mathcal{F}(\bullet)$ is $\mathcal{F}_{print}(\bullet)$ or $\mathcal{F}_{pint}^{-1}(\bullet)$, which is determined by doing forward or backward spectral colour calibration

5 Experiments

In experiments, the multi-ink printer used is HP designjet 130nr. This printer is a 6 ink printer, including C(cyan), M(magenta), Y(yellow), K(black), c(light cyan), m(light magenta). The spectral measurement device is GretagMacbeth SpectroScan Transmission spectrophotometer. The measured value is spectral reflectance. The spectral range is from 380nm to 730nm and the interval is 10nm. Thus the spectral reflectance is 36 dimension data.

When creating the forward LUT, the calibration sample set used is sampled in the CMYKcm colour space of HP 130nr printer. Each channel of the printer is divided into 6 levels, which is [0 0.2 0.4 0.6 0.8 1]. Then we combine the data of each channel to gain 46656 samples. The low dimension spectral space used is a 6 dimension spectral space LabPQR that is proposed by Mullsell Colour Science Laboratory. This space takes both chroma and spectral characteristics into account. The transformation between it and the spectral reflectance space is simple and the transformation precision is high. Its dimension is adequate. The algorithm about this space is described in [13] and [14]. When creating the backward LUT, we divide each dimension into 6 levels uniformly in this space. Thus, the backward calibration set also includes 46656 samples. Therefore, the LUT in this paper is 6 dimensions LUT.

The test sample set is 1300 samples sampled in the CMYKcm space randomly. By Printing these samples and then measuring their spectral reflectance, we use their colour separation data in the printer colour space and their corresponding spectral reflectance to validate the spectral colour calibration algorithm proposed this paper.

Table 1 shows the experiment result using multi-dimension LUT to implement forward colour calibration for the 1300 samples. Since Yule-Neilsen Spectral Neugebaur (YNSN) model is the most commonly used spectral printing calibration model, Table 1 also shows the calibration result using YNSN model in the same experiment environment. In Table 1, the standard chrome metric ΔE_{ab} of uniform colour space CIELAB is utilized for colour error evaluation. The root-mean-square error Equation E_{RMS} [15] is used for spectral error evaluation. Moreover, the total and mean consuming time using these two methods to execute forward colour calibration for the test sample set is also shown in the table.

From Table 1 we know the accuracy using LUT is much higher than using YNSN model. It is because LUT method uses the sample set measured actually. The sample set in itself embody the various nonlinear facts of the printing process. While the YNSN model applies mathematical method to simulate the printing process, it cannot reflect the nonlinear facts, such as mechanical and optical dot gain, digital half-tone, and so on. Since the LUT method uses multi-linear interpolation and the YNSN model method uses nonlinear mathematical calculation, the consuming time of these two methods is almost equal. The mean consuming time just has difference on the one part in 10^5.

The backward calibration sample set cannot achieve by printing and measuring the samples. Thus, the creation method of calibration sample set becomes one of the key factors affecting the calibration accuracy. Table 2 shows the experiment result of the method proposed in this paper by using sample points to determine the optimization parameters. Moreover, according to the requirement that the data in the destination space must be in [0,1] during the backward colour calibration, Table 2 also shows the result that the boundary of the optimization variable is [0,1] and the optimization initial is generated randomly in [0,1].

From Table 2 we know that the method using samples to determine the optimization initial and the boundary of the optimization variable can improve the accuracy of the creation of the backward LUT obviously. At the same time, since the search, range of the optimization variable is reduced and the initial is set as close to the objective as possible, it makes the speed of creating backward LUT increased greatly.

TABLE 1 Comparison of the forward calibration precision using the tow methods

Methods	**Chroma error(ΔE_{ab} , D65, 2°observer)**				**Spectral error(E_{RMS})**				**Consuming time (second)**
	Mean	*SD*	*MIN*	*MAX*	*Mean*	*SD*	*MIN*	*MAX*	
LUT	2.9524	1.6679	0.2029	11.2935	0.0137	0.0061	0.0029	0.0436	6.11 / 0.0047
YNSN model	4.8695	1.3940	0.4597	9.4172	0.0244	0.0068	0.0037	0.0459	6.11 / 0.0047

TABLE 2 Accuracy of creating backward LUT

Method of determining the optimization parameters	**Chroma error(ΔE_{ab} , D65,2°observer)**				**Spectral error(E_{RMS})**			
	Mean	*SD*	*MIN*	*MAX*	*Mean*	*SD*	*MIN*	*MAX*
According to the samples	0.1477	0.5078	0	6.1242	0.0054	0.0028	0.0001	0.0245
Using [0,1] interval and random initial	0.2924	2.8606	0	56.1349	0.0057	0.0111	0.0009	0.2238

TABLE 3 Comparison of the backward calibration precision using the tow methods

Method	**Chroma error(ΔE_{ab} , D65, 2°observer)**				**Spectral error(E_{RMS})**				**Consuming time (second)**
	Mean	*SD*	*MIN*	*MAX*	*Mean*	*SD*	*MIN*	*MAX*	
LUT	2.1966	1.5810	0.8394	4.9732	0.0140	0.0103	0.0060	0.0352	6.11 / 0.0047
YNSN model	4.5213	1.5624	1.0189	8.4628	0.0237	0.0124	0.0063	0.0731	141.031 / 0.1058

Table 3 shows the experiment result of using backward LUT to implement backward colour calibration for the 1300 samples. The result of using YNSN model is also shown in Table 3. Moreover, the total and mean consuming time applying these two methods to execute backward colour calibration for the test sample set is also shown in the Table.

From Table 3 we know during the backward calibration the LUT method not only improves the backward calibration accuracy significantly but also decreases the calibration time obviously compared with the YNSN model method. This is because the backward calibration only needs multi-linear interpolation in the backward LUT just as the forward calibration. Therefore, its consuming time is almost equal to the forward calibration. However, the YNSN model method utilizes the nonlinear optimization technology real-time to execute inverse transformation on the samples based on the forward model, therefore its consuming time is long.

6 Conclusions

A spectral colour calibration method for multi-ink printing based on LUT is proposed in this paper. The new method makes it possible that using LUT to achieve the spectral colour calibration by introducing a low dimension spectral space and transforming the spectral reflectance to this space. The method utilizes the multi-ink printer colour space and the low dimension space as the calibration space, and takes samples in these spaces to generate the calibration sample set, then uses the sample set to create the forward and backward LUT and finally applies the multi-linear interpolation in the LUT to implement forward and backward colour calibration. During creating the backward LUT, a nonlinear optimization technique is applied. An algorithm is designed to determine the optimization parameters based on the backward calibration sample set. It improves the accuracy and efficiency of creating the backward LUT obviously. Compared with the printing model methods commonly used, the new method has notable improvement on calibration accuracy and time efficiency.

Acknowledgments

Authors gratefully thank the co-workers for concerning the research project and also acknowledge the support of Science Foundation of Shaanxi province in China (Grant No. 2012JM8044), Research Fund of Shaanxi Provincial Education Department (Grant No. 12JK0733) and Research Fund of Xi'an University of Posts & Telecommunications (Grant NO. 1504).

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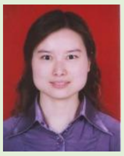

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