Characterization of High-Fidelity Color Printing Devices Using Illuminant-Independent Approaches for Color Imaging Application

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Abstract

*The aim of this research was, optimally to derive a multi-spectrally illuminant-independent type of High-Fidelity (Hi-Fi)multi-color printing device characterization model, which could reconstruct spectra of every color concerned in high-dynamic-range of original images for an accurate color -matching or -reproduction application. In this study, the Adobe RGB color space under the D_{50} illuminant condition was used as the reference working space. To have the ability to adapt the change of light sources, two works were preliminarily carried out. Firstly, an ideal type of CIEXYZ camera characterization model was derived using a spectral reconstruct method, based on basic vector under the D_{50} condition.. Via the estimation and the reconstruction of the spectrum of every pixel in question, the XYZ under any light source considered could be obtained accordingly. Therefore, any Adobe RGB format of Hi-Fi complex color images could be transformed into the multispectral type of images via the CIEXYZ camera model derived. Secondarily, the characterization of 7-ink CMYKRGB printing process, using FM screening technique, was implemented and tested in terms of single stimulus. The superset of CMYKRGB i.e. Hi-fi color set) was divided into seven 4-ink groupings, including KGCB, KBMR, KRYG, RKYM, GKYC, BKMC, and also CMYK. Each subgroup contains three chromatic inks and one black ink. Both the multispectral (MS, i.e. narrowband) and the broadband (BB) types of characterization models, using 3^{rd}-order and 2^{nd}-order polynomial regression equations respectively, were developed in this stage. They all applied singular value decomposition method (SVD) and constructed including both transforms of forward (i.e. fractional dot area (FDA) to XYZ/L*a*b*) and reverse (i.e. XYZ/L*a*b* to FDA) processes for each subgroup. The transform between device-independent data and device-independent data was derived and defined via measuring a number of colors in the IT8.7/4 training/test target produced using each 4-ink grouping subset. An approach of key component replacement (KCR), which is similar to GCR (gray component replacement) applied in traditional CMYK printing process, was integrated to implement the BB type of a multi-ink color separation algorithm. Additionally, in order to reconstruct the spectra and adaptively map to the corresponding tone values (fractional dot area) for every color in test/training datasets, the MS approach in the reverse process was optimized by iterating the KCR components of BB algorithm in terms of the measure of RMSE (root of mean square error). The predictive performances of 2 models derived were tested for each of subgroup in the IT8.7/4 datasets mentioned above. Two measures of both the mean CIEDE2000 (i.e. E*00) and the mean RMSE were used. The results showed that two types of algorithms, used in the printing process of 7-ink CMYKRGB, were successfully proposed. The mean E*00 values are 1.04 and 0.79 in the forward and the reverse processes respectively for the MS type. Also 0.00098 of the RMSE value was obtained for the reverse transform of the MS type. It implies the spectral reflectance of every color in datasets was satisfactorily reconstructed. Subsequently, following the preliminary study, by taking two matters of "metamerism" and "wide-gamuts" in mind, feasible application modules of Hi-Fi multi-color process toward the spectral/complex color images was derived and proposed. Then, Sets of image-processing algorithms were implemented in the process of scanner-to-monitor, and then monitor-to-printer color transform in the study. Eventually, to cross verify performances of models derived, a set of forced-choice paired comparison psychophysical experiments carried out under a viewing phase of CIE D_{50} illuminant.*

Introduction

As well-known, it is not necessarily acceptable that a color reproduction has colorimetrically correct results, as metamerism issue is concerned under all possible illumination conditions happened in real world. Therefore, it is the only actual solution to provide a detailed description of color properties of the color-sample surface considered in terms of its spectra, across color-imaging media. That is to carry out spectral color reproduction and spectrally define each color in terms of wavelength of its light. Then, it can produce the physically identical effect for both an original and its reproduced image under every identical circumstance (e.g. viewed in the same surroundings) if every pixel, with the same spatial coordinate in both original and reproduced images, has the same spectra.

However, in addition to every-color spectra of images as mentioned above, there is another important issue which needs to be addressed to achieve the objective of accurate color reproduction. That is a mismatch problem that different imaging devices have variant color-gamuts. To cope with the tremendous development of optoelectronic age, the restriction of chromaticity gamut in the conventional 4-color CMYK printing process in Graphic Arts can be practicably extended by the use of extra colorants with the conventional CMYK primaries. Thus, via the use of both the spectral approach and extra colorants, a High Fidelity of multi-color printing process with illuminant-independent characteristics can be optimally achieved.

A schematic of Hi-Fi color gamut of CMYKRGB was studied here, as shown in Figure 1. With different hues from standard inks of CMYK, extra colorants of RGB were used to offer the opportunity to extend the printable gamut of standard process. This idea [1] in Graphic Arts was considered, not only to advance the density range, the resolution and the rending of details; but also to profit the representable gamut. Also the lighter or better hues of some saturated colors, as obtained in the conventional CMYK printing process, can be attained. Those colors are such as orange, violet, certain reds, blue, purple and certain greens, which cannot be reproduced by conventional CMYK printing. Indirectly, one can well imagine, then, it also augments the stability of tertiary colors.

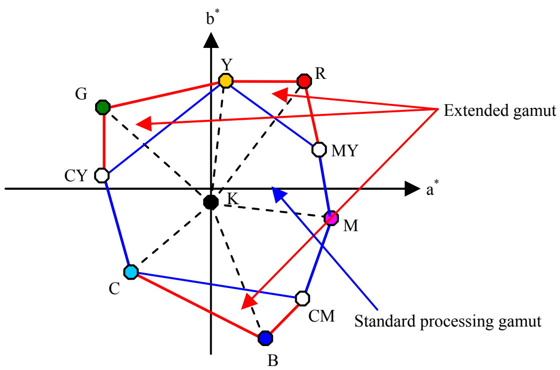

Figure 1. The use of Hi-Fi colorants, R, G,, R to extend the gamut achieved with standard CMYK printing process

Therefore, by keeping two kernels of both “metamerism” and “gamuts” in mind, the focus of this study was to derive a universally well-performing Hi-Fi multi-color printing device characterization model. A feasible technique of FM screening separation was used to process Hi-Fi complex color images by exploring a multi-spectral approach which is independent of illuminants. The conversion between device-dependent data (for instance CMY or CMYK) and device-independent data (i.e. CIE XYZ/L*a*b*) hence, could be determined via the printing device characterization model. Here, the characterization was carried out via the provision of printing training data set of IT8.7/4. Finally it could be satisfactorily applied in the process of cross-media colour transform of Hi-Fi complex color images.

However, there was a necessity to have multispectral types of complex color images as original input images in the process of FM screening separation. Consequently, a simulated multi-spectrally performing camera characterization model was also derived in this research. It is an ideal type of CIEXYZ camera with three-sensors of the 1931 CIEXYZ color-matching functions. An adaptive method of basic vector was firstly carried out, via an SVD (Singular Value Decomposition) method. It was used to estimate the spectral radiances of tested color objects. Then, a set of coefficients was approximated by using the Winner approach [2] via the simulated CIEXYZ camera of CIEXYZ-type spectral sensitivity functions of sensors. Therefore, the spectral energy (radiance) of every pixel in question (on images with known profile of XYZ values; here used Adobe type of images) which the camera sensor picks up with basis vectors under a known light condition (e.g. the D50 illuminat), could be rebuilt by using the Wiener method. The spectral reflectance of every pixel considered on images could be also accordingly computed.

Printing Device Characterization

Modeling Color Behaviour and Subdivision Approach for 7-ink CMYKRGB Printing Process

Following the work derived previously [3,4], A heptatone (7-color) CMYKRGB process was proposed in this study, as shown in Figure 1, to extend the color gamut beyond what can be achieved in the conventional CMYK printing system. The approach was carried out originally based on the scheme suggested by Boll [5]. The derivation of characterization models of 7-ink printing process was carried out by measuring a number of colors in the IT8.7/4 test target produced using each subset of seven 4-ink groupings. These seven 4-ink groupings included CMYK, KGCB, KBMR, KRYG, RKYM, GKYC, and BKMC. Each subset contained 3 chromatic inks and black ink. Six groups of 4-color subsets, except for CMYK subset, represent six adjacent and overlapping subgamuts in the supergamut of a 7-ink CMYKRGB color space. Each 4-ink set was separately characterized, as strictly as a conventional CMYK ink set [4], to define the transform between color (i.e. device-independent data) and ink (i.e. device-independent data) in its corresponding subgamut.. This approach resulted in the production of an inktable wherein every color of images reproduced was inked with a maximum of 4-inks.

Broadband and Narrowband approaches

As mentioned earlier, two issues of “metamerism” and “gamuts” were considered in this research. Therefore, two approaches of broadband and multispectral narrowband were explored in the characterization process of 7-colors of CMYKRGB printing device. Both multispectral and broadband approaches of models numerically applied both a 3rd-order and a 2nd-order with 3rd-order polynomial regression equations, respectively. Those models were all incorporated with a singular-value decomposition (SVD) technique [6]; and each carried out both a forward and a reverse transform processes. The forward process maps the device-dependent data (i.e. FADs, Fractional Dot Areas of four primary inks for a color considered in each subset tested) to their device-independent values (i.e. CIEXYZ, CIELAB, or CIELCH); while the reverse process transforms device-independent values (i.e. CIEXYZ, CIELAB, or CIELCH) into device-dependent data i.e. FDAs). The broadband type of 2nd-SVD model (referred as 2nd-SVD-BB later) was derived from previous work [4, 7-8]. Also, by following a work derived previously, a KCR (Key Component Replacement) algorithm which is similar to the GCR (Gray Component Replacement) technique in theory was also implemented in each of subgamuts in this work for the 3rd-SVD-MS model. The former 4 of seven 4-ink subsets mentioned above all had the key component of black; whereas the latter 3 of 7 subsets (i.e. RKYM and GKYC, and BKMC) had different key components of red, green, and blue respectively. Therefore, The KCR refers, e.g. in RKYM and KRYG subgamuts, to reduce key components R and K respectively (which are produced using paired inks of M & Y, and R & G respectively), and substitute them with colorimetrically corresponding equivalent amounts of red (R) and black (K) inks respectively.

As for the model developed based on the multispectral approach, it was implemented using the 3^{rd}-order polynomial regression equations (recognized as 3^{rd}-SVD-MS later). Table 1 only demonstrates the deriving process of polynomial form for the 3^{rd}-SVD-MS model.

Table 1: The 3^{rd}-SVD Polynomial algorithm, used in the derivation of 7-ink printing device characterization model for the process of forward transform

Orders	Parameters	Matrix Length
3^{rd}-SVD Equation	$R_{\lambda 1}, R_{\lambda 2}, R_{\lambda 3}, R_{\lambda 4}$	$(\sum_{i=0}^{3} H_i^4)+1=35$
Polynomial Equations		
$\sum_{j=1}^{C_3^6} a_j 3^{rd}(R_{\lambda 1}, R_{\lambda 2}, R_{\lambda 3}, R_{\lambda 4}) + \sum_{j=C_3^6+1}^{C_3^6+C_2^5} a_j 2^{nd}(R_{\lambda 1}, R_{\lambda 2}, R_{\lambda 3}, R_{\lambda 4}) + \sum_{j=C_3^6+C_2^5+1}^{C_3^6+C_2^5+C_1^4} a_j 1^{st}(R_{\lambda 1}, R_{\lambda 2}, R_{\lambda 3}, R_{\lambda 4}) + 1$		

Note: e.g. for the subset of KRGB, the $R_{\lambda 1}$, $R_{\lambda 2}$, $R_{\lambda 3}$, and $R_{\lambda 4}$ are the spectral reflectance for the corresponding FDAs of black, red, green, and blue inks respectively. Then, the $R_{\lambda 4c}$ is the resulted spectral reflectance obtained from the overprint of KRGB inks in question. Here H denotes the rule of "Combination with Repetition".

Experimental and Methodology

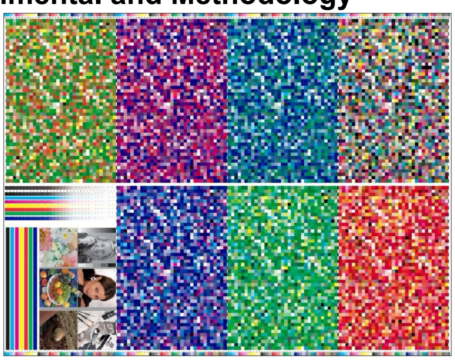

Figure 2. Produced IT8.7/4 CMYKRGB Test Target

A printing device selected was Heidelberg Speedmaster press using 7-color printing process. A printing characterization data set of IT8.7/4 (with 1617 colors) was used in this study as the training and test target, and generated for each of the sets of 4-ink grouping in the 7-ink CMYKRGB printing process (K+E 918 Process Color plus PantoneRGB). A GretagMacbeth SpectraScan spectrophotometer was used in the measurement, performed at 45/0 geometry of illuminating and viewing using CIE 1931 2^0 observer. Samples were taken over the range across the visible spectrum 380-730 nm with a 10 nm interval. There different colorimetric data (i.e. device-dependent data of CIE XYZ, CIE LAB and CIE LCH) were obtained against the CIE D_{50} illuminants.

Additionally, later on, both 4-color CMYK and 7-color CMYKRGB models were all included in the characterization of both of multispectral narrowband and wideband types of printing device separately. Therefore four characterization models were implemented and tested here. Those will be recognized as 3^{rd}-SVD-MS-4c & 3^{rd}-SVD-MS-7c, and 2^{nd}-SVD-BB-4c & 2^{nd}-SVD-BB-7c, respectively for multispectral narrowband and wideband types later. As mentioned above both forward and reverse transforms were implemented for each characterization model derived. Models' performances were evaluated in terms of two measures of Average (i.e. mean E_{00}) and Max (i.e. maximum E_{00}), tested using their corresponding test targets (E_{00} is color difference of CIEDE2000). E_{00} was calculated between XYZ values of the predicted color-patch and those of the original target color-patch in question. (The computational procedures used in both forward and reverse transforms for 3^{rd}-SVD-MS model, based on the multispectral approach can be found in the previous paper [3]).

In the reverse transform of the spectrally-structured 3^{rd}-SVD-MS model as shown in Figure 3, the same algorithm, used in the reverse process of 2^{nd}-SVD-BB based on the broadband approach was integrated into the forward transform of 3^{rd}-SVD-MS model, to iteratively look for the optimal solution of printing device-dependent data (e.g. KRYG FDAs). In Figure 3, the R_λ of a target color are first entered and then converted into XYZ values and CIE 1976 a, b hue angle, h_{ab} under the illumination condition (e.g. D_{50} here). The subset of 4-ink grouping, used to producing the target color, is then determined via LUT of hue (through h_{ab}). The XYZ values are also transformed into $(D_r, D_g, D_b)_{4c}$ using the log density functions given in equation (1). The next step is iteratively to predict the optimal amount of key component and then the FDA of every ink used will be determined. In the optimization of iteration process, every possible solution of considered subset's (e.g. KRYG) FDAs is input into the forward transform of 3^{rd}-SVD-MS model to reconstruct the spectral reflectance of target color of interest in KRYG subgamut. Therefore, the best solution of subset's FDAs would be determined in terms of the E_{00} and also the measure of RMSE (root of mean square error), The RMSE was computed between the iteratively recovered (i.e. predicted) spectra and original reference ones, of every color in the test target, in the 36-dimensional (i.e. 36 spectral wavelengths) space.

$$\boldsymbol{D_r} = \log \frac{\boldsymbol{Xo}}{\boldsymbol{X}},\ \boldsymbol{D_g} = \log \frac{\boldsymbol{Yo}}{\boldsymbol{Y}},\ \boldsymbol{D_b} = \log \frac{\boldsymbol{Zo}}{\boldsymbol{Z}} \qquad (1)$$

Multispectral Characterization of Camera Model

A spectral reconstruct method, based on basis vectors, was applied for the characterization of an ideally simulated CIEXYZ type of camera in this study. The surface spectral radiance of an object under a specific illumination condition (e.g. D_{50} in this study) measured by spectrophotometer ranged in 400-700nm at interval of 10nm, would produce 31 data-points. Therefore, for the GretagMacbeth ColorChecker SG (i.e. CCSG) with 140 color patches considered in this research, it would consist of a 31x140 matrix of color signal data. This color signal matrix can be composed of both basis matrix and coefficients matrix, shown as equation (2).

$$\underbrace{\begin{bmatrix} 31\times140 \end{bmatrix}}_{\text{ColorChecker Color Signal}} = \underbrace{\begin{bmatrix} 31\times3 \end{bmatrix}}_{\text{Basis matrix; one column one basis}} \bullet \underbrace{\begin{bmatrix} 3\times140 \end{bmatrix}}_{\text{Coefficients matrix}} \qquad (2)$$

Three steps of procedure were carried out in the camera characterization. The first, by applying SVD, all the spectral basis vectors, used to reconstruct spectral radiances of objects under the

D50 illumination condition was found. Here, as mentioned above, a GretagMacbeth CCSG was used as a training test target. Subsequently, the coefficients matrix was obtained using the Wiener method. Therefore, the original spectral reflection (i.e. radiance) of objects considered could be rebuilt by multiplication of both basis vectors and specific coefficients obtained. So, finally, the characterization models, derived via spectral reconstruction process using the optimized set/number of basis vectors, could be applied under various illumination conditions.

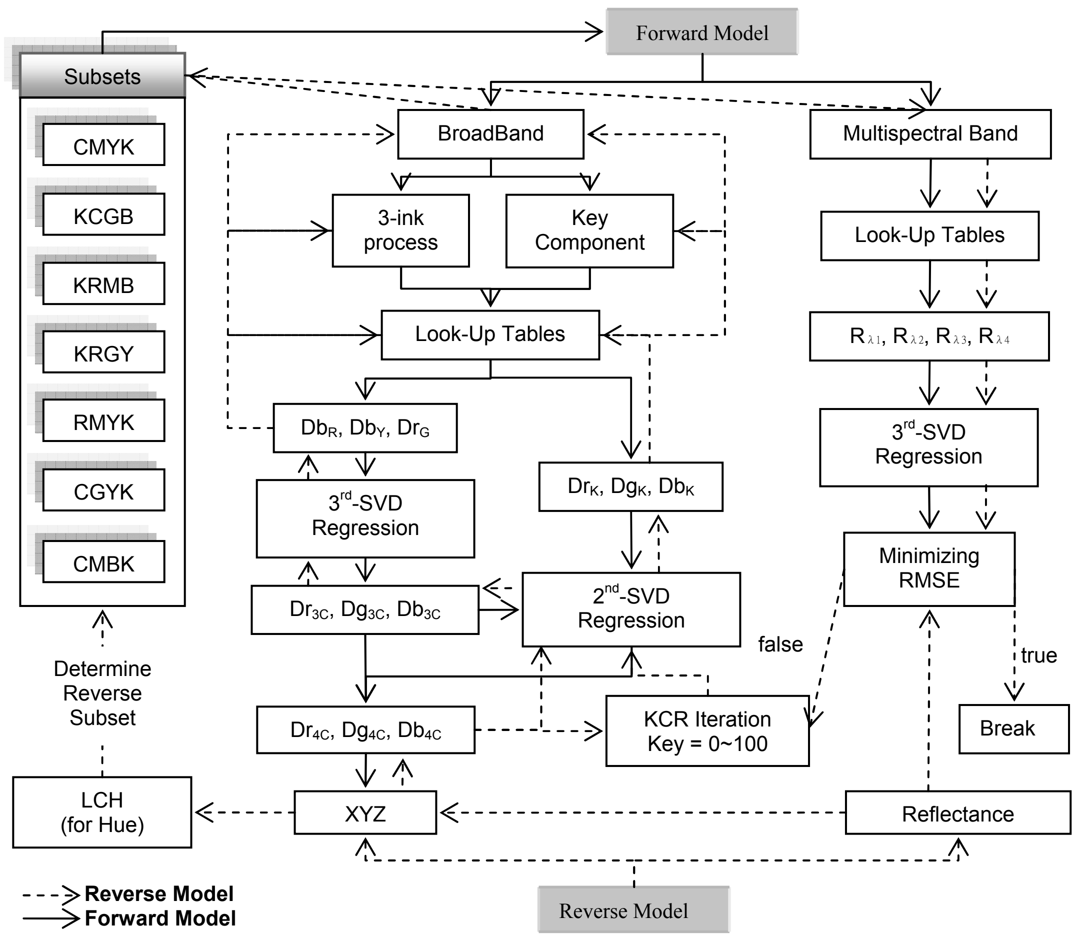

Figure 3. The procedures of the forward and the reverse models used in both the multispectral and broadband types for 7-ink CMYKRGB printing process

Table 2: Prediction performances, in terms of mean ΔE_{00}, of four derived Models for transform processes of both the forward (denoted as F) and the reverse (denoted as R) under D_{50} condition.

CIE$_{00}$ Colour Difference of Models								
	Multispectral Type				Broadband Type			
Models	2^{nd}-SVD-MS-4c		2^{nd}-SVD-MS-7c		3^{rd}-SVD-BB-4c		3^{rd}-SVD-BB-7c	
	F	R	F	R	F	R	F	R
Max	6.29	4.16	7.59	9.30	6.07	5.39	9.40	14.56
Average	1.28	0.70	1.04	0.79	1.38	0.73	1.05	0.73
ΔE_{00} >6 Count	1	0	4	7	1	0	4	23
RMSE (Mean)	0.00145	0.00072	0.00125	0.00098	-	-	-	-

An extensive analysis of color spectra of the full set of Munsell Book Glossy Database of 1600 color patches [9] based on SVD was used in this study. The purpose of this analysis was to statistically look for the most efficient basis number, for a given color set by using basic functions. In the beginning, five basis vectors, considered sufficiently representing the spectral accurately enough, were firstly selected for the analysis. However, from the previous study [2,10], results all showed that three vectors are adequately enough to achieve 93% of the variance of spectra (i.e. spectral radiance).

Additionally, the illuminant D50, as considered practically used in the Graphic Arts, was hypothetical here to provide an ideal modality to build a known database of spectral radiance by the multiplication of its SPD and the spectral reflectance of database of interest (e.g. Munsell Book Glossy Database). Therefore, to simulate the human eyes, a non-real camera using a triad of sensors which had an ideal CIEXYZ type of spectral color-matching responses/functions was chosen in this study. It estimated original RGB (i.e. XYZ values for the ideal CIEXYZ type of camera) under the D50 illuminant, and further multi-spectrally to derive a universal performing camera characterization model. As a consequence, multispectral characterization results could be effectively carry out under various viewing light sources or illuminants with different color temperatures. Additionally, a well-characterised Adobe type of EIZO-CG221 LCD (with ΔE00 of 0.59) was also used here as the source imaging media. Therefore, a set of Adobe RGB format of color complex-images were used in this study as original input images for the 7-ink Hi-Fi printing process. Every-pixel spectra (radiance/reflectance) (on the Adobe RGB format of images with known profile of XYZ values), under a known D50 illumination condition, were firstly estimated using the Wiener method. Then the predicted spectral data were, hence, further used in the color separation of 7-ink printing process mentioned above.

Cross-media Color Transform

While both the forward – CMYK/CMYKRGB to Rλ to XYZ–, and the reverse – XYZ to Rλ to CMYK/CMYKRGB – transforms are of interest to characterize a printer or a press, the inverse transform is of higher importance when it is strongly needed to accurately render Hi-Fi color complex-images on the considered printer or press. Therefore, as mentioned, in addition to both multispectral narrowband and wideband types of 7-color CMYKRGB models, both multispectral narrowband and wideband types of 4-color CMYK models were also considered derived in this study. Also, to cross verify performances of four printer DCMs, four set of corresponding image processing algorithms were developed to implement a cross-media (from camera to monitor, and then to printer) color transform using complex image.

Totally, a set of 5 images, as shown in Fig. 4, were tested and rendered using each of image processing algorithms implemented as mentioned above. These 5 images included GATF, Sofa, Magic, Ski and Boats. Both softcopy Images displayed on the Adobe type of EIZO-CG221 LCD and respective hard-copy images (produced using the DCM methods) were representations of the originals and the reproductions respectively.

Psychological Experiment

Finally, a set of forced-choice paired comparison psychophysical experiments [11] was carried out, to make comparisons of colour appearance matching between the original images (displayed on the LCD) and the corresponding reproduction images (produced using DCMs derived).

Figure 4. *Images used to in the process of monitor-to-printer colour transformation*

A panel of 10 observers viewed a paired of reproductions randomly presented, and judged which of the two gave a better match (i.e. colour fidelity) to an original image in question. They then rated the colour-fidelity quality of each hardcopy image, against its corresponding original softcopy, on a category scale with seven category scales of ordinal values from 1 (“ exact match”) through 4 (“acceptable match”) to 7 (“awful match”). Both every original softcopy and its two corresponding reproduced hardcopies were displayed side-by-side on gray background fields with approximate 50 of L*. A viewing cabinet with a light source of D_{50} simulator was used to display two hardcopies. The colour temperature of the monitor was set to be D_{50} condition.

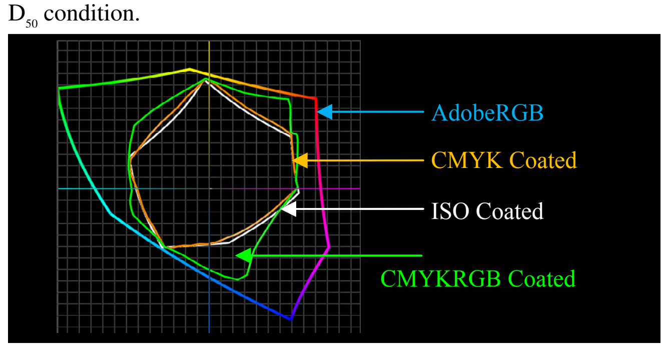

Figure 5. *The color-gamut of 7-ink CMYKRGB (produced on coated paper) comparied to those of Adobe RGB, ISO coated, and CMYK coated.*

Table 3: The gamut volume of 7-ink CMYKRGB (produced on coated paper) compared with those of Adobe RGB, ISO coated, and CMYK coated.

Gamut Names	Gamut Volume
Adobe RGB	1299,180 Units
ISO Coated	398,483 Units
CMYK Coated	420,310 Units
CMYKRGB Coated	569,229 Units

Results and Discussions

Table 2 lists prediction performances of each printer DCMs, obtained using the test data set of IT8.7/4. It seems that the 3rd-SVD-MS-4c and the 3rd-SVD-MS-7c performed very similar. Also, the wideband type of two 2nd-SVD-BB models gave reasonable results. However, as mentioned earlier, it is needed to concern two issues of "metamerism" and "color-gamut" in this study for Hi-Fi accurate color reproduction. So, by using the multispectral approach, the metamerism had been optimally solved out. As for the color-gamut issue, the color-gamut produced on coated paper using the 7-ink printing process was also investigated in this study, via the comparisons with those of Adobe RGB, ISO coated, and CMYK coated media. Both Figure 5 and Table 3 illustrate the comparison results. They clearly show that, except Adobe RGB, the 7-ink CMYKRGB color printing provided a satisfactorily wide color-gamut, and had approximately 35.43% augment to the performance of 4-ink printing color gamut. Summarily, the multispectral type of 2nd-SVD-MS-7c performed the best. Additionally, the results evaluated from psychological experiments also strongly verified that the 2nd-SVD-MS-7c outperformed the others, and gave satisfactorily Hi-Fi rendering quality under all viewing conditions.

Conclusions

The research began with by taking two kernels of the matters of both "metamerism" and "gamuts" in mind, and intended to derive a universally well-performing Hi-Fi multi-color printing device characterization model which could be used in the cross-media color transform for complex images. Therefore, the model derived needs to: 1) solve out metamerism problem to achieve the optimally requirement of illuminant-independent, and 2) produce a color-gamut that could be close to those of displays (used for soft-proofing with high-rendition quality) or real dyes.

Consequently, two types of printing characterization algorithms, used in the printing process of 7-ink CMYKRGB using FM screening technique, were successfully proposed. Those were 2nd-SVD-BB and 3rd-SVD-MS models, applying the 2nd-order and the 3rd-order with 2nd-order polynomial regression equations respectively, via the broadband and the multispectral approaches respectively. Satisfactorily, the broadband type could be used to perform a colorimetrically correct color-matching of color reproduction, but would only under a specified illuminant considered. Since the 7-ink (heptatone) gamut approaches those of the film and high-quality display, the broadband type could be also used to mitigate the problem of mapping unpredictable colors onto printable colors (i.e. gamut mapping). As for the multispectral one, it could be utilized both, not only to extend color gamut in the Hi-Fi multi-color printing system, but also to optimally reconstruct the spectral reflectance of colors in question (to release the problem of color-matching dependent on illuminants).

Acknowledgement

This research has mainly supported by the National Science Council of Taiwan for financial assistance.

References

[1] V. Ostromoukhov, Chromaticity gamut enhancement by heptatone multi-color printing, IS&T/SPIE 1993 International Symposium on Electronic Imaging: Science & Technology, Proceedings Conf. Device-Independent Color Imaging and Imaging Systems Integration, SPIE, 1909, 139-151. (1993).

[2] W. Ge, L. Chang-jun, Z.. Yun-long, and M. R.. Luo, "Improvement in the Estimation of Reflectance Functions Generated Using the Basis Vectors", Photographic Science and Photochemistry, 23(5), 340-350. (2005)

[3] M. C. Lo, C. L. Chen and T. H. Hsieh, Characterization of High-fidelity Color Printing Devices Based on both Multispectral and Broadband Approaches, MCS 2007 Conference: The 9th International Symposium on Multispectral Colour Science and Application, 36-44. (2007)

[4] M. C. Lo, R. Chiang, The Characterization Models for Multi-colored CMYKRGB, TAGA Proceeding, 242-254. (1998)

[5] H. Boll, A Color to Colorant Transformation for a Seven Ink Process. IS&T's Third Technical Symposium on Prepress, Proofing, & Printing, 3, 31-36. (1993)

[6] W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C-The Art of Scientific Computing, 2nd edition, (Cambridge University Press, 1992).

[7] M. C. Lo, J. C.Chiang, and L. Shi, Color Separation for 7-ink Printing Using FM Screening, TAGA proceeding, 716-735. (1997).

[8] M. C., Lo, C. L. Chen, R. K. Perng, and T. H. Hsieh, The Characterisation of Colour Printing Devices via Physical, Numerical and LUT Models, CGIV 2006, IS&T's Third European Conference on Color in Graphics, Imaging, and Vision, University of Leeds, UK, 95-99. (2006).

[9] J. Orava, The Reflectance Spectra of 1600 Glossy Munsell Color Chips. (http://spectral.joensuu.fi/databases/download/munsell_spec_glossy_all.htm)

[10] M. C. Lo, C. L, Chen, and X. Y. Shen, Characterization of Digital Camera Based on Spectral Estimation and Reconstruction, MCS 2007 Conference: The 9th International Symposium on Multispectral Colour Science and Applications, 167-173. (2007)

[11] C. J. Bartleson and F, Grum, Visual Measurement, (Academic Press, Inc, Optical Radiation Measurement , 1984), **5**: 455-467.

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