THE CHARACTERIZATION MODELS FOR MULTI-COLORED CMYKRGB PRINTING PROCESS

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Abstract: Three models for characterizing 7-ink CMYKRGB printing process, using FM screening for extending color gamut, were derived. The models were the refinements of characterization models described by the authors at a previous TAGA conference. These are two masking types of 2nd order polynomial algorithms (named 2^{nd}-wGCR and 2^{nd}-nGCR) and Cellular Neugebauer equations (named CN). Based on the results of earlier preliminary study, the 2nd model was further modified using some critical, and highly saturated colors having less gray contents. Moreover, an extension of GCR algorithm with the requirement of gray balance was also included in the process of characterization (using 2^{nd}-wG^{1}CR model). The characterization models derived had been implemented to produce the optimal separations for rendering complex color images. The fidelity of printing reproductions, processed by three 7-ink characterization models (i.e. 2^{nd}-nGCR, 2^{nd}-wGCR and CN) using FM screen method and a conventional

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4-ink characterization model using CMYK inks with AM screening method (named Con-CMYK), was also [2]assessed by a panel of about 20 observers using the paired-comparison method.

The results showed that the 2^{nd}-wGCR employing GCR algorithm performed the best amongst the models tested. It also indicates the importance of gray balance requirement in the characterization of a muti-colored printing process.

INTRODUCTION

Due to the limitation of color gamut achieved using the conventional 4-ink CMYK printing process, there is a considerable need by Graphic Arts industry for high color fidelity images to be reproduced using more than 4-color CMYK primaries. To achieve this, a approach (using 7-ink CMYKRGB printing process) based on the scheme suggested by Harold Boll (1993) was carried out using two characterization models (i.e. 2^{nd} and CN) and disclosed in a 1997 TAGA paper (Lo et al.)

Pobbrovsky, in a 1966 TAGA paper, proposed two methods for calculating the ink amounts that would produce a scale of neutrals with any ink set. It was concluded that the method using the 2^{nd}-order masking equations had better performance than the one using the Neugebauer equations (Neugebauer 1937). From our previous results shown in the 1997 TAGA paper, the highly saturated colors (having less gray contents) gave the worst predictions amongst the samples studied in the data set for deriving the characterization models of 7-ink CMYKRGB printing process. It was also found that the neutral and near-neutral colors needed to be characterized using a separate test target to further improve the accuracy of predictions for the models derived. Therefore, an extension version of 2nd model, i.e. 2nd-wGCR, was derived. The 2nd-wGCR was modified from the old 2nd model (i.e. 2nd-nGCR) using those highly saturated samples. It was further revised using a separate test target, composed of the neutral and near-neutral colors (named gray balance data set latter), to implement a GCR algorithm. The GCR algorithm applied the method, employing the 2nd-order masking equations, disclosed by Pobbrovsky as mentioned above. These two 2nd models and a Cellular Neugebauer model derived earlier (Lo et al. 1997) were included in the test of performance using complex images.

EXPERIMENTAL PREPARATION

Printer Characterization

A printing device, Toyo Ink Proof, was characterized and used to produce a new set of characterization samples. The samples were divided into two sets: the cube and the gray balance printer characterization data sets.

The samples in the gray balance data set were arranged in a 12 x 10 array. In the first row, a gray scale was produced using only black ink with FDAs (Fractional Dot Areas) ranging from 10 to 100 with a 10 unit interval. In row 2, a near-neural scale was made of three colored inks (C, M, Y). For rows 3 to 12, samples in each column had the same C, M, Y FDAs as those in row 2 but varying in black contents, Their FDAs are listed below. For example, the sample in row 5 and column 4 had 40, 28, 27 and 30 for C, M, Y and K respectively.

Column		1	2	3	4	5	6	7	8	9	10
	C	10	20	30	40	50	60	70	80	90	100
	M	8	14	21	28	38	46	56	65	79	89
Row	Y	7	13	20	27	33	43	51	61	74	86
2	0	0	0	0	0	0	0	0	0	0	0
3	10	10	10	10	10	10	10	10	10	10	10
4	20	20	20	20	20	20	20	20	20	20	20
5	30	30	30	30	30	30	30	30	30	30	30
6	40	40	40	40	40	40	40	40	40	40	40
7	50	50	50	50	50	50	50	50	50	50	50
8	60	60	60	60	60	60	60	60	60	60	60
9	70	70	70	70	70	70	70	70	70	70	70
10	80	80	80	80	80	80	80	80	80	80	80
11	90	90	90	90	90	90	90	90	90	90	90
12	100	100	100	100	100	100	100	100	100	100	100

The cube data set was composed of six subsets including KRYG, GKYC, KGCB, BKMC, KBMR, and RKYM. A 6×6×6×6 matrix color chart was output for each subset of 4-ink grouping. Those 6 charts were designed to evenly sample the respective printing gamut considered.

The procedure of printer characterization is as follows:

1. Print both cube and gray balance printer characterization data sets using Toyo Ink Proof.
2. Measure each sample from previously produced data sets in terms of the spectral reflectance values (R_λ) across the visible spectrum 360-740 nm with 20 nm interval using a Macbeth Color-Eye 3100 spectrophotometer. The tristimulus values were then calculated against a real D50 light source in the viewing cabinet used for a psychological experiment in a latter stage.

3. Derive a gray component replacement (GCR) algorithm (Lo 1995) using the gray balance data set. The GCR algorithm was implemented to predict FDAs of CMYK inks used for producing neutral or near-neutral colors. A 2^{nd}-order masking model derived from Pobboravsky (1966) was also included in the GCR algorithm to determine the dot areas of CMY primaries for gray balance requirements.
4. Derive three printing characterization models described earlier using the cube data set.

As mentioned in our previous TAGA paper, each subgamut reproduced using the corresponding inkset was characterized individually as a conventional CMYK color gamut. The computational procedure used in the reverse 2^{nd} model, also using the subset of KRYG as an example, will be described in Figure 1 (the forward model had been shown earlier). The XYZ of KRYG inks and the FDAs of K ink are the input values. The XYZ of KRYG are first converted to $(D_r, D_g, D_b)_{4c}$ using log density functions (described in earlier paper). The FDAs of K ink is used to obtain the red-, green, and blue- colorimetric densities of the key component $(D_r, D_g, D_b)_k$ via the LUT. Subsequently, a reverse 2^{nd} model using key component replacement (KCR) algorithm is applied to predict the three-color component $(D_r, D_g, D_b)_{3c}$ of RYG. Then, the amounts of three primaries (i.e. $D_{r\text{-}R}$, $D_{g\text{-}Y}$, $D_{b\text{-}G}$) are calculated using a reverse 3^{rd}-order masking model. Finally, the predict FDAs of RYG inks are obtained via LUT. Figure 2 illustrates the computational procedures of the full reverse 2^{nd} model used for complex images. Two types of 2^{nd} model were derived, i.e. the 2^{nd}-nGCR and the 2^{nd}-wGCR. The former model only uses KCR algorithm in the supergamut CMYKRGB, produced using six subset inks

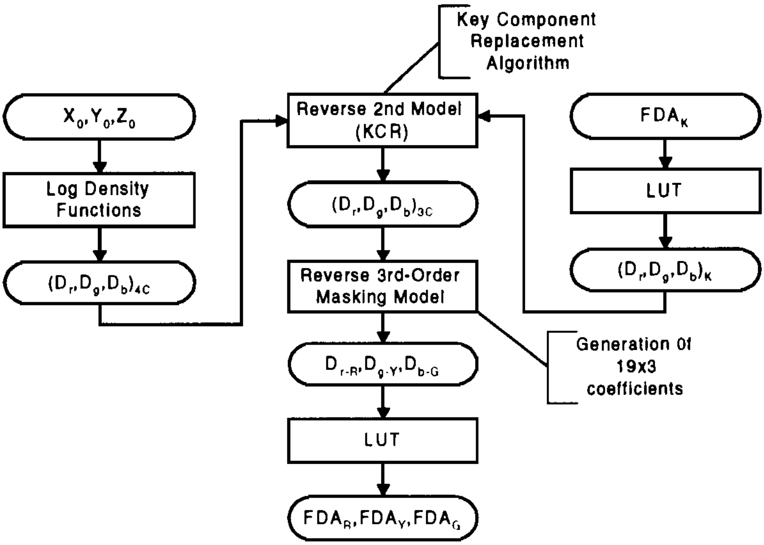

Figure 1. The computational procedures used in the reverse 2nd model.

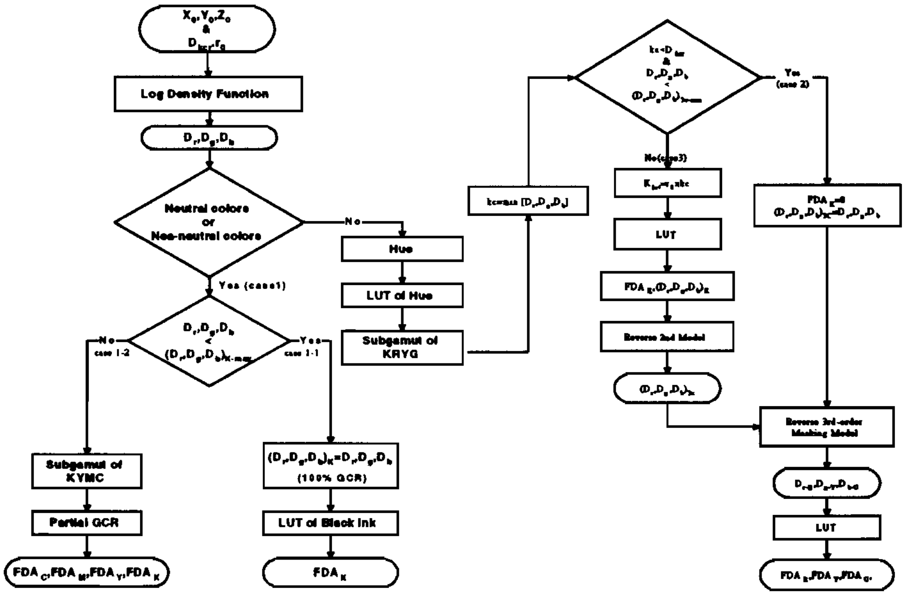

Figure 2. The computational procedures of the full reverse 2nd model used for complex images tested.

including KRYG, GKYC, KGCB, BKMC, KBMR, and RKYM.. For the 2^{nd}-wGCR model, both of GCR and KCR algorithms are applied in the neutral (or near-neutral) color gamut (produced using CMYK inkset) and the supergamut CMYKRGB (produced using six subset inks including KRYG, GKYC, KGCB, BKMC, KBMR, and RKYM) respectively. The XYZ values of a target color are first entered and then converted into CIE 1976 *a*, *b* hue angle, h_{ab} and (D_r, D_g, D_b) (via the log density functions). The next step is to determine the case applied. Cases 1-3 and Cases 2-3 will be used in the 2^{nd}-wGCR and the 2^{nd}-nGCR models respectively. In GCR algorithm (Case 1), 100% GCR will be used (i.e. Case 1-1) if the color considered is neutral and its red-, green-, and blue- colorimetric densities of (D_r, D_g, D_b) are less than the respective channels of solid black ink (i.e. (D_r, D_g, D_b)$_{k\text{-}max}$ known previously); otherwise the partial GCR algorithm (Case 1-2) is adopted to predict the FDAs of CMYK inks for those colors neutral or near-neutral and their (D_r, D_g, D_b) larger than the respective channels of solid black ink. In KCR algorithm (Case 2 or 3), the subset of 4-ink grouping, used for producing the target color, is then determined via LUT of hue (through h_{ab}). Then, Case 2 or 3, using the same procedure and method described in earlier TAGA paper, will be chosen accordingly.

The performance of three models derived was again tested using the new characterization sample set used to derive these models. It was found that the results obtained here were very similar to those in previous studies. Overall, the 2^{nd}-wGCR model (with the mean CMC ΔE value of 1.25) performed the best amongst three models derived. The 2^{nd}-nGCR model (with a mean CMC ΔE value of 2.98) gave slightly accurate predictions than the CN model (with a mean CMC ΔE value of 3.22).

Scanner Characterization

A flat-bed scanner HP 4C/T, applying CCD technology, was previously characterized using the Agfa IT8/7.1. A 2^{nd}-order making type of characterization model, including both forward and reverse processes, was derived. The forward process predicted tristimulus values from a set of RGB primaries, i.e. RGB to XYZ. The reverse process transformed tristimulus values into a set of RGB primaries, i.e. XYZ to RGB. The predictive performance was tested using the samples in the Agfa IT8/7.1 for the forward model. A mean CMC ΔE value of 1.3 was found in this study. It indicates that the forward scanner characterization model derived gave quite a satisfactory prediction performance. Therefore it was used to transform the scanner RGB intensities to the original XYZ values for image preparation and processing in a latter stage.

Image Preparation and Processing

Seven transparency complex images were selected including three scene-content types: man-made object, people, and natural scenes. Plate I shows these seven images: "Colorfulness", "Sharpness1", "Bride", "Autumn", "Sky & Tree", "Tone & Gray", and "Sharpness2" (from top left to bottom right).

These images were digitally scanned using the scanner mentioned earlier to obtain image data in terms of RGB format with a resolution of 200 dpi. The forward scanner characterization model derived previously was used to correlate the scanner's RGB intensities to the original XYZ values on a pixel by pixel basis for each of seven images tested.

Image processing software was developed to include three reverse printing characterization models, i.e. the 2^{nd}-wGCR, the 2^{nd}-nGCR and the CN as described earlier. It was applied to transform the XYZ values of seven original images to the CMYK or the corresponding subset inks (in terms of FDA format) on a pixel by pixel basis for each particular model considered. A set of color separations for each resultant digital image were then output using an Imagesetter Aventra44 with FM screening, with the Agfa CristalRaster technique. Additionally, a set of color separations, optimized using conventional 4-color CMYK process (denoted Con-CMYK), were also produced using AM screening method for each of seven images tested. The reflection prints required in the psychological experiment were then produced using the characterized Toyo proofing system as mentioned earlier. In total, 4 reflection prints were produced for each of 7 tested images. Therefore, four models, including the 2^{nd}-wGCR, 2^{nd}-nGCR, Cellular Neugebauer, and Con-CMYK, were tested.

PSYCHOLOGICAL EXPERIMENT

Experimental Set-Up and Viewing Configuration

The experimental set-up involved a original image (transparency) and two tested reflection prints with the same contents, simultaneously displayed in the same viewing cabinet illuminated using D50 real light source (see Figure 3). The viewing cabinet, SOFT-VIEW D5000 Transparency/Print Viewer having both transmitted (T) and reflected (R) illumination, was specially designed to make comparisons between transparencies and reflection prints. The experiment was carried out in a darkened room. The transparency image and the reflection hardcopies were located side by side and coplanar. The order of the hardcopy image pair was randomized in each observing session to avoid possible trends in the comparisons.

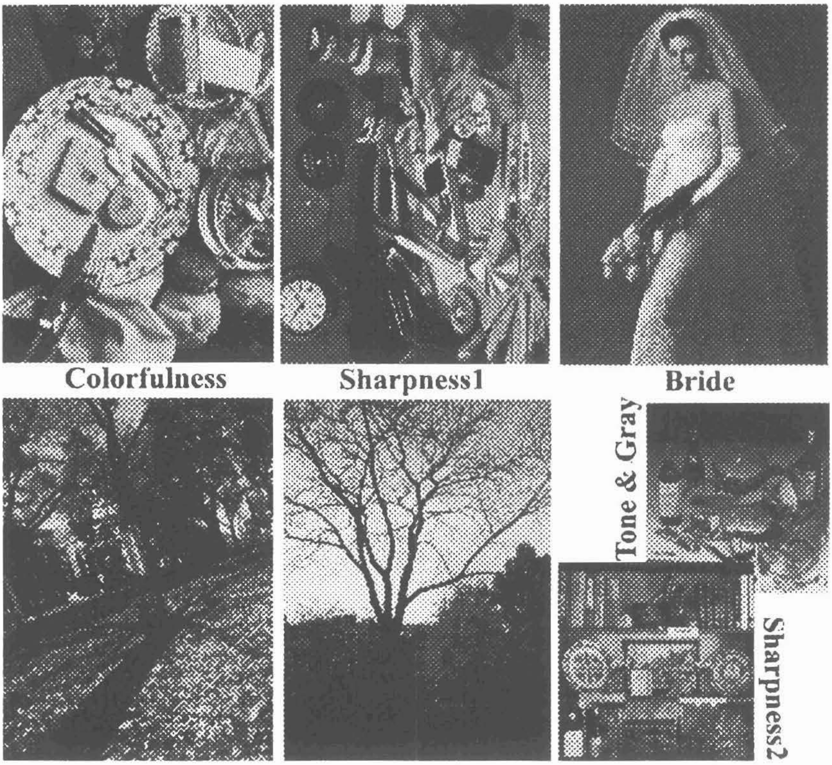

Plate I. Seven complex images selected for testing models' performance.

Data Analysis

A forced paired comparison method was employed in the experiment. A panel of 20 observers viewed a pair of displayed hardcopy images, and judged which of the two gave a better match to the transparency image (original). Data analysis was carried out using the paired comparison method, derived from Thurstone's law of comparative judgement (Thurstone 1927).

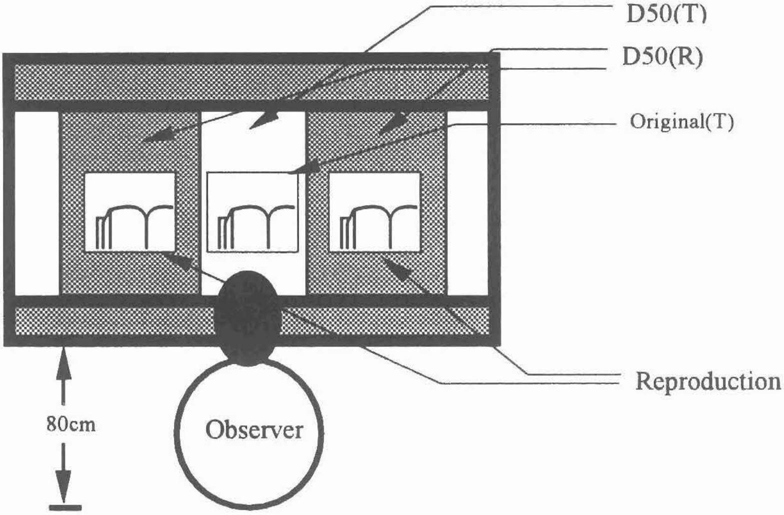

Figure 3. The experimental viewing configuration used in the paired comparison method.

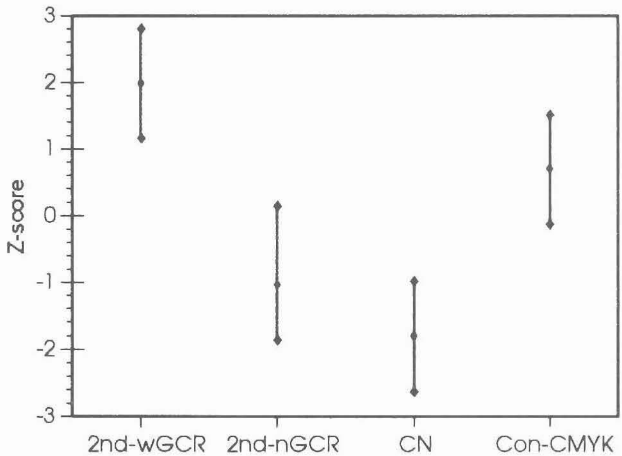

Figure 4. Models' performance evaluated using the paired comparison results.

RESULTS AND DISCUSSION

The paired comparison results in terms of the z scores together with 95% confidence limits for each image and the 7 six images combined are summarized in Table 1.

Table 1. The paired comparison results in terms of z-scores together with 95% confidence limit for each image and the seven images combined.

Model	2^{nd}-wGCR	2^{nd}-nGCR	CN	Con-CMYK	95%CL
Colorfulness	3.59	-3.95	2.80	-2.44	± 1.24
Sharpness1	3.55	0.19	-4.50	0.76	± 1.24
Bride	1.40	-3.29	-2.68	4.57	± 1.24
Autumn	1.28	-1.28	-6.54	6.54	± 1.24
Sky & Tree	3.47	0.89	-6.00	1.64	± 1.24
Tone & Gray	2.51	-1.03	-1.77	0.29	± 1.24
Sharpness2	1.52	0.46	0.76	-2.74	± 1.24
Total	2.02	-1.00	-1.76	0.73	± 0.82

The results combined from seven images are also plotted in Figure 4. Each point in this figure represents the z score, and a line is also drawn indicating its range within 95% confidence limits.

Overall, the 2^{nd}-wGCR models performed the best amongst all the models tested. The results also clearly show that the 2^{nd}-wGCR model gave much better performance if tested using the images with highly saturated colors (e.g. Image "Colorfulness" and "Sky & Tree") or more gray tones (e.g. Images "Sharpness1", "Tone & Gray") than using the others with less colorfulness and less gray tones. This strongly indicates the importance of gray balance requirement in the characterization of multi-colored printing process. Moreover, the highly colorful colors should be included in the characterization data set, and effectively used in the derivation of the characterization models to improve the accuracy of predictions.

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