Endpoint Criteria for Print Life Estimation

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Abstract

Endpoint criteria for image permanence of color hard copy prints are studied based on a psychophysical study, using a set of color prints which have systematically altered densities and colors. Acceptable range of the density and color balance change from the original in various scenes are discussed. We confirmed that the current ISO criteria are useful in some degree as a simple estimation but we propose a new set of criteria which reflects human visual sense more accurately. The new criteria are applied to image stability evaluation of inkjet, xerography, D2T2, thermo-autochrome, Pictrograpy and silver halide color printing materials.

Introduction

The proliferation of consumer images has led to the use of various hardcopy systems for photo printing. Image permanence is one of the most important aspects for these printing materials. It is important to accurately and clearly inform consumers of the level of performance. Test methods and specifications of image permanence of color hard copy materials have been studied in the task group-3 of the ISO/TC42/WG5 for several years. The endpoint criteria for the print life specifications are one of the issues for the group.

In respect of end point criteria for color reflection prints, the current ISO[1] specifies a 30% loss of density of any primary colors, a 15% color balance change of neutral patch and 0.10 density increase in Dmin as the illustrative endpoint. The WIR 3.0[2] specifies the end point parameter for each color considering the human eye sensitivities for the each color. The new N' method[3] was also proposed, which combined density losses, color balance shifts and Dmin changes and estimated the total performance of deteriorated images.

These criteria have been applied to the evaluation of various hardcopy materials such as inkjet, xerography, D2T2 and silver halide color printing materials. We reported that the print life estimated using the ISO criteria for density loss plus color change of neutral patch corresponded well to the psychophysical evaluation of light fastness of several printing materials.[4] On the other hand, it was reported that the current endpoints were inadequate and under-predicted the print life based on the VOC study of actual faded prints.[5,6]

The objective of this paper is to create a set of endpoint criteria which reflect consumers' preferences. The acceptable range of the density and color balance change from the original in various scenes will be discussed using a set of color prints which have systematically altered densities and colors. We will add some consideration to the results including the correspondence on the CIELAB space.

The new set of criteria will be employed in image stability evaluation of inkjet, xerography, D2T2, thermo-autochrome, Pictrograpy and silver halide color printing materials.

Method

1. Scene Selection

The scenes used for this study are shown in table 1 and Fig. 7.

Table 1. Scenes for Psychophysical Study

No	Name	Classification
1	3 girls & a cruiser	Landscape + Figure (Snap shot)
2	A woman & plants	Plants + Figure (Snap shot)
3	2 women & building	Landscape + Figure (Monotone)
4	Group photo	Persons (Small faces)
5	Wedding	Portrait (Long term preserve.)
6	3 women	Portrait (White, black, Asian)
7	Wool (SHIPP P3)	Still life (Colorful objects)
8	Harbor (SHIPP P2)	Landscape
9	Pot and color patch	Still life (Highlights to shadows)

These scenes were selected based on the following perspective;

1) Corresponding to the ratio of objects in consumer photo shown in Table 2
2) Including important scenes for long time preservation such as wedding photo.
3) Containing highlight to shadow, colorful to monotone objects and various colors.

Table 2. Ratio of Objects in Actual Consumer Photo (in Japan)

Scene	Person	Landscape	Still life	Plants	Animal
Ratio (%)	49	13	25	7	7

2. Creation of Faded Print Images

The initial and faded images of the above scenes were printed using Fujifilm's digital printer Frontier and silver halide color print paper Fujicolor Crystal Archive Paper Type 1. The faded images' data were created with computer simulation described below.

The following assumption is applied, although most of the actual printed images behave in a more complex manner, especially in case of inkjet materials;

<General assumption> Fading amount is proportional to analytical density which corresponds to the amount of substance present.

<Assumption A> Fading ratio of each primary color is same in all initial colors and densities.

<Assumption B> Fading ratio of each primary color is different depending on the initial color.

The each blue(B), green(G) and red(R) analytical reflection densities were calculated based on the spectral density distributions of dyes of Crystal Archive Paper. The reflection densities were converted to transmission density. It was assumed that density changes due to fading followed the linear equation shown in the equation (1) for the case of no Dmin change;

$$Dage = (D0 - Dmin0) \times (Residual\ ratio) + Dmin\ 0 \quad (1)$$

Here, Dage is faded density, D0 is initial density and Dmin0 is initial Dmin density, and in the equation (2) for the case of Dmin change;

$$Dage = D0 \times Kage + (Dmin\text{-}age - Kag \times Dmin0) \quad (2)$$

Here, Dmin-age is faded Dmin and Kage is ratio of change expressed in

$$Kage = (Dmax\text{-}age - Dmin\text{-}age)/(Dmax0 - Dmin0).$$

Here, Dmax-age is faded Dmax and Dmax0 is initial Dmax density. Figure 1 demonstrates these density changes depending on each case.

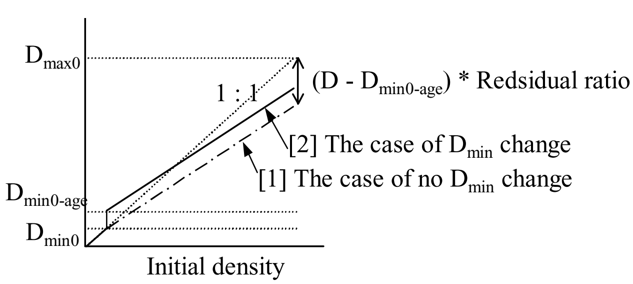

Figure 1. Density changes with fading

The calculated transmission densities were converted to the reflection density again and a set of 1D LUT was made. In the same manner, each dye loss ratio and Dmin increase was input and 1D LUTs were created for the each fading level. The image data were converted to faded image data using the 1D LUT from the data of initial image, and were converted to Frontier printing data using the 3D LUT for Frontier printing.

In case of the assumption B, the following case was examined, that is primary color fade while gray does not fade. The color of intermediate fade as a function of color density(Dclr) and gray density(Dgray), as described in the equation (3);

$$Dgray = \min(R,G,B)$$
$$Dclr\text{-}age = Dgray \times Kgray + (Dclr - Dgray) \times Kclr \quad (3)$$

Here, Kgray is the change ratio of gray component and Kclr is the change ratio of color patch. In this paper, Kgray was set to 1.0, which means no change.

3. Sample Preparation for Psychophysical Study

A total of 9 scenes x 41 fade levels = 441 samples were prepared. The fade levels were shown in Table 3 to 6;

4. Psychophysical Testing

The 441 printed samples were evaluated psychophysically by 20 employees of the research laboratories of Fujifilm, who have experience of testing photographic materials for consumers, and they can tell the preference of general consumers.

Each faded sample and the initial sample were presented at the same time for each scene. These evaluators were told that they were looking at changes that occur in aging prints. They were instructed to think about how acceptable each faded print would be. A simple 6-level category sort was used to rate each of the prints. They were asked to rate the overall image quality relative to acceptability based on the comparison with the initial samples. The categories employed were:

(1) the difference is significant and completely unacceptable.
(2) the difference is somewhat disturbing and moderately unacceptable
(3) marginally unacceptable
(4) marginally acceptable
(5) the difference is not small but moderately acceptable
(6) the difference is minimal and completely acceptable

The viewing conditions were about 1000 lux with F8 light source. The evaluators were free to hold the images at any viewing distance or viewing angle.

Table 3. Density Loss without Color Balance Change

Sample name		Fr	G15	G30	G45	G60
Density loss (%)	R	0	15	30	45	60
	G	0	15	30	45	60
	B	0	15	30	45	60

Table 4. Dmin Density Increase with / without Color Balance Change

Sample name		SG 01	SG 02	SG 03	SG 04	SY 01	SY 02	SY 03	SY 04
Dmin increase	R	0.1	0.2	0.3	0.4	0	0	0	0
	G	0.1	0.2	0.3	0.4	0	0	0	0
	B	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4

Table 5. Density Loss with Color Balance Change

Sample		R92	R85	R78	G92	G85	G78	B92	B85	B78	Y92	Y85	Y78	C92	C85	C78	M92	M85	M78
Density loss (%)	R	8	15	22	0	0	0	0	0	0	8	15	22	0	0	0	8	15	22
	G	0	0	0	8	15	22	0	0	0	8	15	22	8	15	22	0	0	0
	B	0	0	0	0	0	0	8	15	22	0	0	0	8	15	22	8	15	22

Table 6. No Change in Gray, and Only Pure Color Component Fade (Assumption B, Equation 3)

Sample		PR80	PR60	PR40	PG80	PG60	PG40	PB80	PB60	PB40	PY80	PY60	PY40	PC80	PC60	PC40	PM80	PM60	PM40
Density loss (%)	R	20	40	60	0	0	0	0	0	0	20	40	60	0	0	0	20	40	60
	G	0	0	0	20	40	60	0	0	0	20	40	60	20	40	60	0	0	0
	B	0	0	0	0	0	0	20	40	60	0	0	0	20	40	60	20	40	60

Results and Discussion

1. Density Loss without Color Balance Change

The results are shown in Fig. 2. On average, it falls to the unacceptable level at 23% density loss. Regarding the scene dependence, the wool scene was ranked lowest. It is considered that the wool scene contains deep shadows and it loses the value with density loss easily.

2. Dmin Stain Growth

The results are shown in Fig. 3. In case of B, G and R density increase keeping neutral gray (Fig 3a), it gets into unacceptable level at 0.21 density increase on average. In case of solely B density increase (Fig 3b), it reaches to unacceptable level at 0.13 density increase on average. Regarding the scene dependence, the harbor scene was ranked lowest in case of Fig 3a and the pot and color chart scene got the lowest score in case of Fig 3b.

3. Density Loss with Color Balance Change

The results are shown in Fig. 4. On average, it falls to the unacceptable level at 13% dye loss in case of cyan shift, 13% for magenta shift, 14% for yellow shift, 16% for red shift, 12% for green shift and 18% for blue shift. The allowance range is narrower for green and magenta shift and broad for blue and red shift. Regarding the scene dependence, the portrait of 3 women and wedding scene were ranked lower. It is considered that the green or magenta skin colors are not acceptable.

4. Density Loss in Pure Color Patch and No Loss in Neutral Patch

This test was to analyze the influence of dye loss in the pure color patch to the total impression. According to our experience, dye loss in pure color patch is not so important compared to dye loss in neutral patch as shown in section 4. In addition, this case simulates printing systems which use UCR (Under Color Removal) and the black colorant used for the UCR is completely stable.

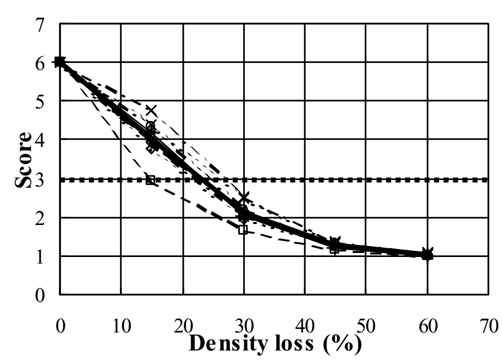

Figure 2. Psychophysical ranking for density loss without color balance change

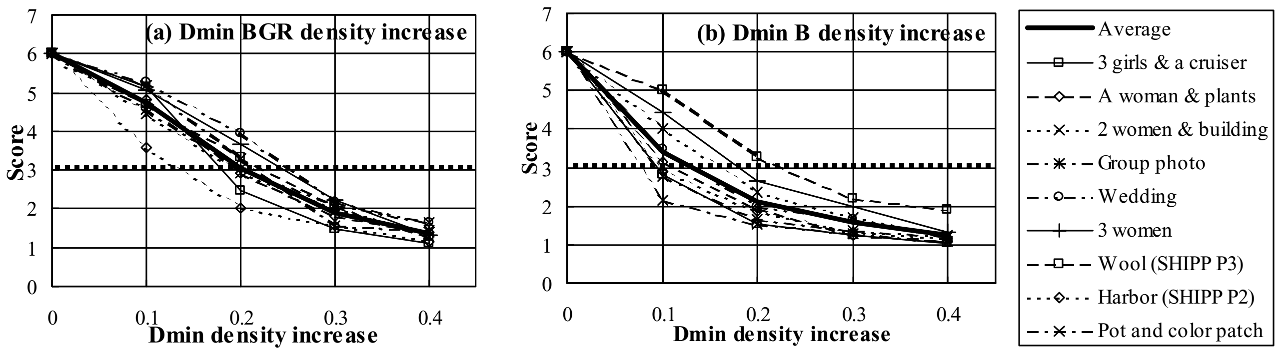

Figure 3. Psychophysical ranking for Dmin density increase

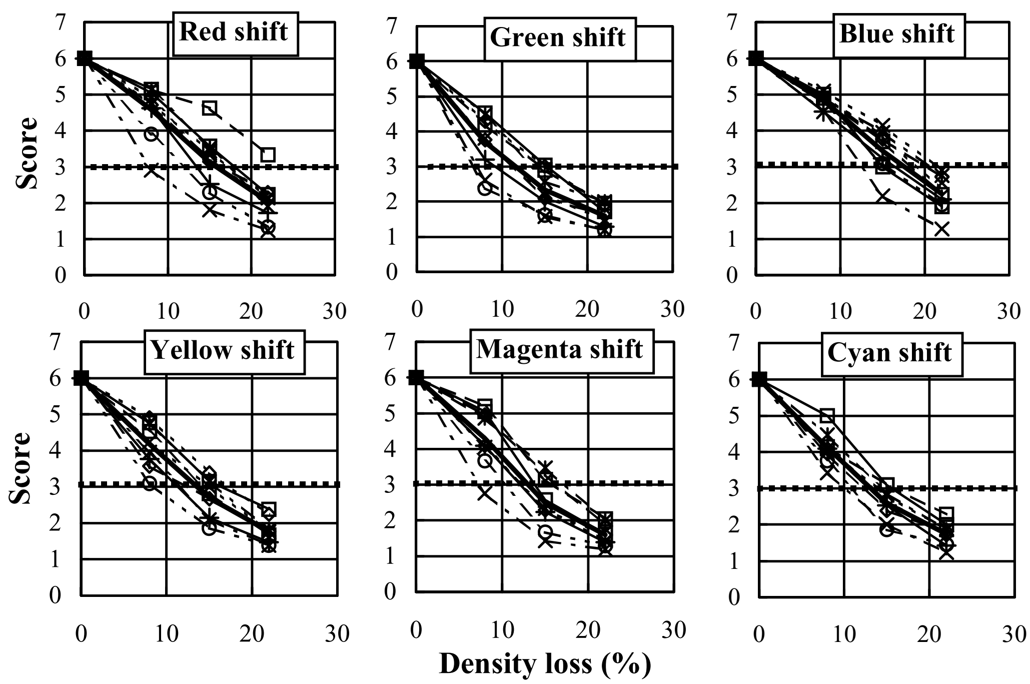

Figure 4. Psychophysical ranking for density loss with color balance change

The results are shown in Fig. 5. On average, it falls to the unacceptable level over 40% dye loss. Especially, R density loss in pure color patch is acceptable to 77% dye loss, which can be explained by the fact that skin color contains less R density compared to G and B densities.

5. Summary of the Test Results for Endpoint Criteria

We propose a new set of endpoint criteria based on the aforesaid test results. They are summarized in Table-7 comparing to the ISO and WIR criteria. At the same time, we propose simpler criteria which would be convenient for standardization in the right-hand column of Table-7.

We would conclude that;

1) The current ISO criteria are useful in some degree as a simple estimation.
2) Using the proposed new set of criteria shown in Table-7, more accurate estimation would be accomplished.

6. Application of the Criteria to the Actual Fading Test

The criteria are applied to image stability evaluation of inkjet, xerography, D2T2, thermo-autochrome, Pictrograpy and silver halide color printing materials. The results are shown in Fig. 6. The root mean square of error is reduced to half with our endpoint compared to the ISO endpoint.

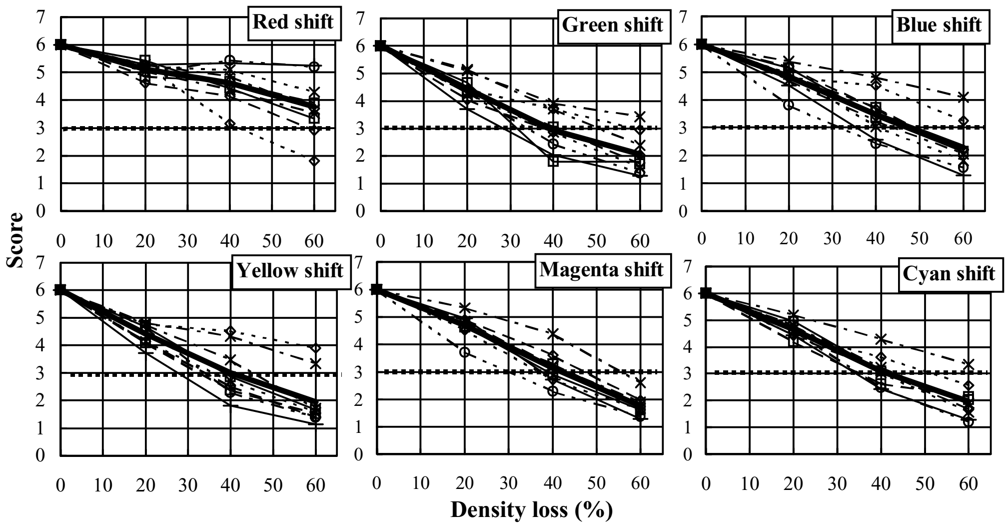

Figure 5. Psychophysical ranking for the case of no density loss in neutral patch and density loss solely in pure color patch

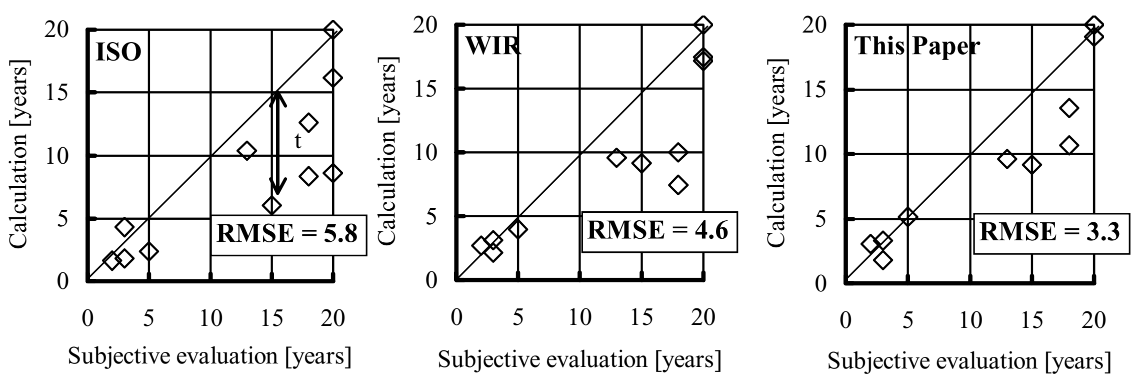

Figure 6. Light fastness of various printing materials. Subjective evaluation vs. calculated with endpoint of the current ISO (left), the WIR (center) and this paper (right).

Table 7. Summary of Endpoint Criteria

Attribute			Current endpoint criteria		This paper			
Patch	Attribute	Color	ISO	WIR	Color shift	Results		Recommen-dation
Pure patch	Density	Cyan	30%	30%	to red	78%		40%
		Magenta	30%	25%	to green	39%		
		Yellow	30%	35%	to blue	48%		
		Red	NS	NS	to cyan	42%		
		Green	NS	NS	to magenta	42%		
		Blue	NS	NS	to yellow	40%		
Neutral patch	Density	R	30%	25%		23%		23%
		G	30%	20%		23%		
		B	30%	35%		23%		
	Color balance	R-G	15%	15%	to green	12%	13%	15%
					to cyan	14%		
		G-R	15%	12%	to red	17%	16%	
					to magenta	14%		
		R-B	15%	18%	to blue	19%	17%	
					to cyan	14%		
		B-R	15%	18%	to red	17%	16%	
					to yellow	15%		
		G-B	15%	18%	to blue	19%	17%	
					to magenta	14%		
		B-G	15%	18%	to green	12%	13%	
					to yellow	15%		
Dmin	Density	R	0.10	0.06		0.21		0.20
		G	0.10	0.06		0.21		
		B	0.10	0.15		0.21		
	Color balance	|R-G|	0.06	0.05		NS		0.13
		|R-B|	0.06	0.10		0.13		
		|G-B|	0.06	0.10		0.13		

NS= Not specified

Conclusion

Endpoint criteria for image permanence of color hard copy prints were studied based on a psychophysical study, using a set of color prints which have systematically altered densities and colors. Acceptable range of the density and color balance change from the original were discussed in various scenes. We propose a new set of criteria shown in Table 7 which reflects human visual sense more accurately, while we confirmed that the current ISO criteria were useful in some degree as a simple estimation. It was confirmed that the new set of criteria functioned well in image stability test of inkjet, xerography, D2T2, thermo-autochrome, Pictrograpy and silver halide color printing materials.

References

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1) 3 girls and a cruiser

2) A woman and plants

3) 2 women and a rawmen shop

4) A group photo

5) Wedding

6) 3 women

7) Wool (SHIPP P3)

8) Harbor (SHIPP P2)

9) Pots and color patches

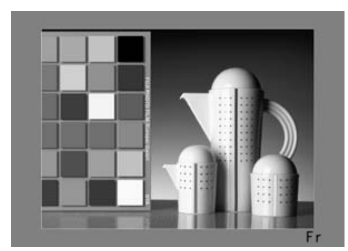

Figure 7. Scenes for psychophysical study

Biography

Yoshihiko Shibahara received his M.A degree in engineering from the Kyoto University in Japan in 1978. Since 1978, he has worked in the research laboratory at Fuji Photo Film in Japan. His work has primarily focused on the research, development and evaluation of imaging materials. He is a Japanese expert of ISO/TC42/WG5.