Evaluation of the Image Permanence of Digital Colour Photographic Prints Based on Colour Difference

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Abstract

The validity of a colour difference approach for evaluating the image permanence of photographic colour prints was determined by comparing its performance with that of optical density analysis, which has been conventionally used in this field. Criteria for determining the endpoints of photographic images are also proposed in this study.

Light-fading tests were conducted for 20 consumer photographic and production prints, which were produced using dye-based inkjet, pigment-based inkjet, silver halide, electrophotography and D2T2 systems. The lives of these prints were evaluated on the basis of both optical density and colour difference data. Furthermore, the faded images were visually assessed by professional observers.

It was confirmed that the colour difference approach produced results that correlated well with those of the visual assessment and that it was an effective measure for evaluating the image permanence of photographic prints. The results also indicated that the colour difference between faded and fresh images, 'ΔE_{76} = 10' or 'ΔE_{00} = 5', was appropriate criteria for determining the endpoints of photographic images.

Introduction

The image permanence of photographic colour prints, including factors such as light fastness[1], gas fastness[2] and thermal/humidity fastness[3], has conventionally been evaluated on the basis of the optical density changes in specific colour/density step patches of the prints[4]. This density approach is appropriate and convenient for the research and development of photographic prints and their components, because each R (red), G (green) and B (blue) density change corresponds to the fading of the C (cyan), M (magenta) and Y (yellow) colourants, respectively. In contrast, this approach has some downsides; for example, the density data cannot be directly correlated with human perception. To resolve this issue, sets of criteria that consider both density changes and density balance, which is related to human perception to some degree, for each colour have been proposed to define the endpoints of photographic prints[5-8]. Another problem with the density approach is that it requires a large number of data points; the density values of many patches, including different densities (0, 0.5, 1.0 and 1.5) for several colours (R, G, B, Y, M, C and grey), are needed to express the image permanence.

In contrast, the colour difference approach, which utilises the International Commission on Illumination (CIE) delta E (ΔE) values for the chromaticities of faded and fresh images, can be directly related to human perception. It is also possible to calculate the average ΔE value for several patches comprising colours with different densities. However, the validity of this approach for evaluating the image permanence of photographic colour prints has not been fully demonstrated, and the criteria for determining print endpoints based on colour differences have not achieved wide recognition.

Purpose

The aim of this study was to demonstrate the validity of the CIE ΔE approach for evaluating the image permanence of colour photographic prints and to provide ΔE criteria for the endpoints of print images.

Experiments

Outline

Light-fading tests were conducted for a total of 20 consumer photographic and production colour prints.

The optical densities and chromaticities of the samples were measured before and after exposure to different amounts of light. The values of the density changes and colour differences, ΔE_{76} and ΔE_{00}, were calculated for each set of fresh and faded samples.

The total quantity of light exposure required to reach the endpoint for each image was also calculated. In this case, the density change and ΔE criteria for the endpoints of the faded images were presupposed.

In parallel, two professional observers conducted visual assessments of the faded images by comparing them with their corresponding initial images.

The correlations between the visual assessments (human perception) and the print lives calculated using the density and colour difference data were then evaluated.

Light-fading tests

Light-fading tests were conducted for the 20 consumer photographic and production colour prints listed in Table 1.

The test method stipulated in clause 7.2 of ISO 18937; 2014 was applied. The test conditions involved the following: a Xe ark lamp light source with a 373 nm half-cut UV filter and an intensity of 78 klx; an atmosphere of 23 °C and 50% RH and a black panel temperature of 35 °C. The total light exposure was 80 Mlx-hours.

Measurements

The densities and chromaticities of the samples were determined before and after light exposure. The durations of light exposure were 3 days and 1, 2, 3, 4 and 6 weeks. A total of 22 patches were measured for each sample: Dmin (white), density = 0.5, 1.0 and 1.5 for Grey, Y, M, C, R, G and B.

For the density measurements, the geometric condition described in ISO 5-4[10] and the ISO Status A density described in ISO 5-3[9] were used.

For the chromaticity measurements, the measurement condition M0 described in ISO 13665[11] was used. The geometry was 45°/0° with a 2° observer for the detector, and the illuminant was CIE Illuminant D50. The colour differences, ΔE, for each initial and each faded sample after exposure to light were calculated. For ΔE, the values CIE 1976 ΔE_{76} (ΔE^*_{ab}) stipulated in ISO 11664-4[12] and CIE 2000 ΔE_{00} were both calculated.

Table 1: Materials for light-fading tests

Printing technology	M	Details
Silver halide (AgX)	A	for professional use
	A	for consumer use
	B	for consumer use
Instant (AgX)	A	for consumer use
Inkjet (home)	C	Dye-based ink / photo-grade porous media
	D	Dye-base ink / photo-grade porous media
	E	Dye-base ink / photo-grade porous media
	C	Pigment ink / photo-grade porous media
	D	Pigment ink / photo-grade porous media
Inkjet (minilab)	A	Dry minilab/ photo-grade porous media
	A	Dry minilab/ photo-grade porous media
Inkjet (production)	A	Dye-based ink / Coated paper for printing
	A	Dye base ink / Coated paper for printing
Electro-photography	D	Liquid toner, for retail and printing
	D	Liquid toner for retail and printing
	D	Liquid toner, for retail and printing
	F	Dry toner, for retail
D2T2 (Dye Diffusion Thermal Transfer)	G	for retail
	G	for retail
	G	for retail

M: Manufacturer

Table 2: Endpoint criteria for faded images

Measurements	Item	Criteria
Density	Density loss	40%
	Colour balance change	20%
Chromaticity	Average *ΔE* value *for* all patches	ΔE_{76}= 10
		ΔE_{00}= 5

Endpoints of faded images

Determination of the criteria designating the endpoint of a faded image is not a simple task. Several factors can influence the judgment of whether the level of fading is acceptable:

a) Apples-to-apples comparison (double stimuli) of a faded image with the initial image or assessment of the faded image without comparison (single stimulus);
b) The purpose and content of the picture and
c) The expectations of the photographer and/or the observer.

In this study, the criteria listed in Table 2 were applied.

For the density measurements, the endpoint was considered to be the point at which any one patch met the criteria. The criteria for the density approach were discussed at length by the ISO/TC 42/WG 5 (ISO Technical Committee for image permanence of photography). Although the committee did not reach an agreement, a 40% loss in density and a 20% change in the colour balance were proposed as one set of criteria (see Table 2).

For the chromaticity measurements, the average of the ΔE values of all of the analysed patches of each material was used. The maximum ΔE value (indicating the most significant fading) was also calculated for reference.

The total quantity of light exposure required to reach the endpoint for each image was calculated using both the density and chromaticity endpoint criteria in Table 2.

Visual assessments

The 20 faded images were visually assessed by two professional observers, who compared them to the corresponding initial images. The two observers each have over 20 years of experience evaluating photographic images and are fairly familiar with consumer expectations for photographic prints.

The details of the visual assessment process are as follows:

i. The initial and faded samples (e.g. exposed to light for 1, 2, 3, 4, 6 or 8 weeks) were placed next to each other for each material, as shown in Figure 1.
ii. Each faded sample was compared to the corresponding initial sample. Larger differences indicated poorer image permanence of the relevant material.
iii. The sets of initial and faded images for each material were then arranged from best to worst based on the visual assessment, as shown in Figure 1.
iv. The fading (image permanence) of each set of two adjacent materials was then compared
v. The degree of fading was rated for each set of two adjacent materials as follows: score = 0 for no difference, 1 for a slight difference, 3 for a moderate difference and 9 for a large difference.
vi. Each material was given a score based on the visual assessment. For example, for five samples (A through E) that are ordered from the worst (A) to the best (E), then:
if no difference (0) is observed for A and B, then A = B = 0;
if a slight difference (1) is observed for B and C, then C = 0 + 1 = 1;
if a moderate difference (3) is observed for C and D, then D = 1 + 3 = 4 and
if a large difference (9) is observed for D and E, then E = 4 + 9 = 13.

Results

Light-fading test results

Overview images of the light fading test results for the 20 materials are shown in Figure 1. In this figure, the materials are arranged from best (upper left) to worst (lower right) in accordance with the results of the visual assessment, as described above.

The changes in the colour difference, ΔE_{76}, as a function of light exposure duration are shown in Figure 2. The Y- and X-axes represent the average ΔE_{76} values for 22 patches measured for each material and the light exposure in Mlx-hours, respectively, and each line represents the data for one of the 20 materials. For each material, the amount of light exposure that led to the endpoint, specifically, ΔE = 10 for ΔE_{76} and ΔE = 5 for ΔE_{00}, was determined using the relevant curve.

Figure 3 shows a comparison of the average and worst (largest) ΔE_{76} values for each material. Here, the X-axis is the amount of light exposure required to reach the endpoint defined by the average ΔE_{76} = 10, and the Y-axis is the amount of light exposure required to reach the endpoint defined by ΔE_{76} = 20. Figure 3 indicates that a relationship exists between the average ΔE and worst ΔE values, and therefore the average ΔE value is sufficient and may be more stable for evaluating the image permanence.

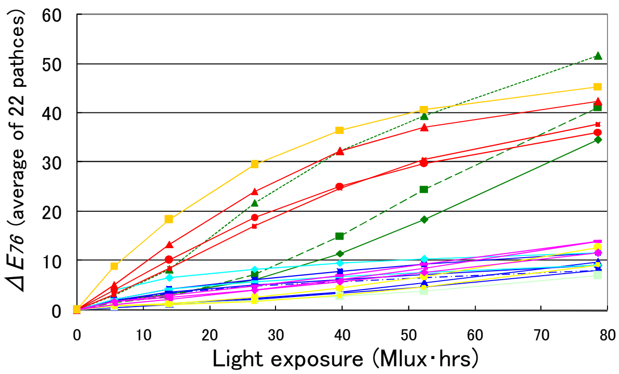

Figure 2 Light-fading test results for 20 samples expressed as average ΔE_{76} for 22 patches.

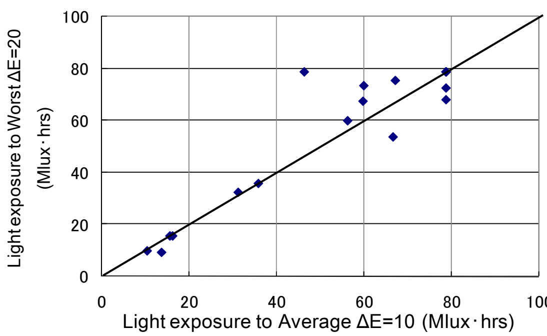

Figure 3 Light exposure required to reach average ΔE vs. light exposure required to reach worst ΔE endpoints for 22 patches in each material.

The density data for a representative material are shown in Fig. 4. From right to left, the graphs correspond to densities of 0.5, 1.0 and 1.5. The top, middle and bottom rows depict the density changes for the grey; C, M and Y; and R, G and B patches, respectively. The endpoints are indicated by the red arrows.

For each material, the amount of light exposure that led to the endpoint listed in Table 2 was determined using the relevant fading curves.

Visual assessments

The results of the visual assessments are illustrated schematically above. There is no significant difference between the assessments of the two observers. The quantitative results of the visual assessments are discussed in the following sub-section.

Visual assessments vs. objective measurements

The correlations between the visual assessments and the print lives calculated from the density and colour difference data were evaluated, and the results are shown in Figures 5a) – c). In these figures, the X- and Y-axes represent the visual assessment score and the amount of light exposure required to reach the endpoint of the print analysed using a) the density approach, b) the colour difference approach with ΔE_{76} = 10 and c) the colour difference approach with ΔE_{00} = 5.

In all three figures, strong correlations between the visual assessment and objective measurement results are observed, although the colour difference approaches (Figs. 5b) and c)) exhibit better correlations than the density approach (Fig. 5a)). On the other hand, no significant difference between the correlations of the different approaches is observed for ΔE_{76} and ΔE_{00}.

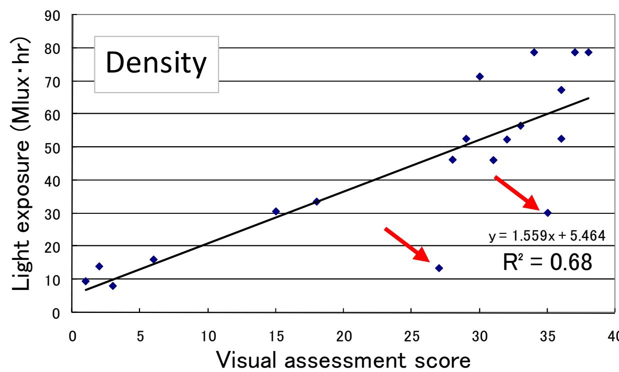

Figure 5a) Visual assessment score vs. amount of light exposure required to reach endpoint stipulated with density criteria.

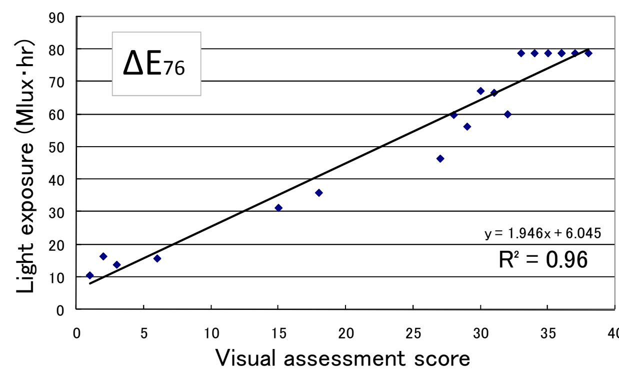

Figure 5b) Visual assessment score vs. amount of light exposure required to meet endpoint ΔE_{76} = 10.

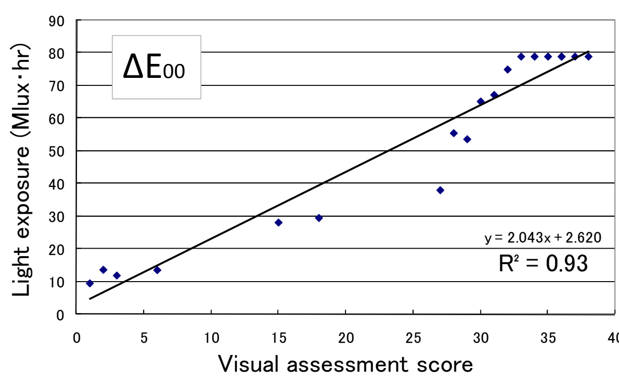

Figure 5c) Visual assessment score vs. amount of light exposure required to meet endpoint ΔE_{00} = 5.

Reasons for the data misfit in Fig. 5a

In the plot of the visual assessment results versus the light exposure required to reach the endpoint (Fig. 5a)), several points do not fit the line, particularly the two points indicated by the arrows. Several possible factors can explain these results:

- These samples reached one of the endpoint criteria, but the overall fading was not significant, except for in the one patch that met a criterion.
- The direction of the colour shift was toward yellow and thus did not result in a negative impression during the visual assessment.
- The fading occurred mainly during the early part of the light exposure and then remained stable during the later stages of the test.

For the colour difference approach (Figs. 5b) and 5c)), the misfits are smaller because the average result for the 22 patches was used to determine the endpoint for each material and because human perception was taken into account more appropriately.

Reasonability of the endpoint criteria

Figures 5a)–c) reveal that the quantities of light exposure required to reach the endpoints of the prints are nearly equivalent for all three evaluation techniques. Therefore, the different endpoint criteria indicated in Table 2 correspond to the same level of image fading. As described in the previous section, the criteria for the density approach were discussed at length by the ISO/TC 42/WG 5 committee, and these criteria were proposed considering user expectations; however, the committee could not reach a final agreement.

Considering the strong correlation between the visual assessment and objective results using these criteria, it can be concluded that the endpoint criteria listed in Table 2 are reasonable.

Conclusion

The colour difference (ΔE) approach is valid for evaluating the image permanence of photographic colour prints. The experimental results for faded images on various materials corresponded more closely with the visual assessment results than did the results obtained using the density approach.

Therefore, the ΔE approach can and should be applied for evaluating the image permanence of photographic prints. It is particularly valuable for evaluating print lives based on human perception, while the density approach is valuable for the research and development of photographic prints and their components.

It should also be noted that both the '$\Delta E_{76} = 10$' and '$\Delta E_{00} = 5$' criteria can be effectively used as endpoints for evaluating the image permanence of photographic prints.

Future study

Creating an advanced test chart for the ΔE approach will be an important challenge. One of the advantages of the colour difference (ΔE) approach is that it is possible to obtain an average ΔE value for many patches. Therefore, it is possible to use many patches that reflect the importance or occurrence rates of different colours/densities in different markets[13].

References

[1] ISO 18937: Imaging materials – Photographic reflection prints – Methods for measuring indoor light stability

[2] ISO 18941: Imaging materials – Colour reflection prints – Test method for ozone gas fading stability

[3] ISO 18936: Imaging materials – Processed colour photographs – Methods for measuring thermal stability

[4] ISO 18944: Imaging materials – Reflection colour photographic prints – Test print construction and measurement

[5] Y. Shibahara, M. Machida, H. Ishibashi, H. Ishizuka, "Endpoint criteria for print life estimation", IS&T's NIP 20, p673, 2004

[6] D. Oldfield, G. Pino, R. Segur, S. O'dell, J. Twist, "VOC based end-point criteria for lightfastness of hardcopy prints", IS&T's NIP19, p396, 2003

[7] D. Oldfield, G. Pino, R. Segur, S. O'dell, J. Twist, "Assessment of the current light-fade endpoint metrics used in the determination of print life – Part 1", Jour. Imaging Sci. and Technol., vol. 48, no. 6, p495, 2004

[8] D. Oldfield, J. Twist, "Assessment of the current light-fade endpoint metrics used in the determination of print life –Part 2", IS&T's Archiving Conference, p36, 2004.

[9] ISO 5-3: Photography and graphic technology – Density measurements – Part 3: Spectral conditions

[10] ISO 5-4: Photography and graphic technology – Density measurements – Part 4: Geometric conditions for reflection density

[11] ISO 13655: Graphic technology – Spectral measurement and colorimetric computation for graphic arts images

[12] ISO 11664-4: Colorimetry – Part 4: CIE 1976 L*a*b* Colour space

[13] Y. Shibahara and N. Uchino, "ISO standardization activities regarding test methods for image permanence of photographic prints", PPIC (Pan-Pacific Imaging Conference), p340, 2008

Author biography

Yoshi Shibahara obtained a master's degree in engineering from Japan's Kyoto University in 1978 and subsequently joined Fujifilm. His work has focused on the *R&D of imaging materials and systems* and the *study of imaging quality and permanence.* Currently *he is an advisory staff* member for *Fujifilm with* a *focus on the promotion of International Standards. He holds important positions in the ISO and IEC,* including *Secretary of the IEC/TC 110 (electronic display devices*) and *Convenor of* the *ISO/TC 42/WG 3 (image measurement)* committees *and* is *an Expert of* the *WG 5 (image permanence*) committee. *He was awarded the HP Image Permanence Award from IS&T and the Industrial Standardization Award from the Minister of Economy, Trade and Industry of Japan, in 2013*

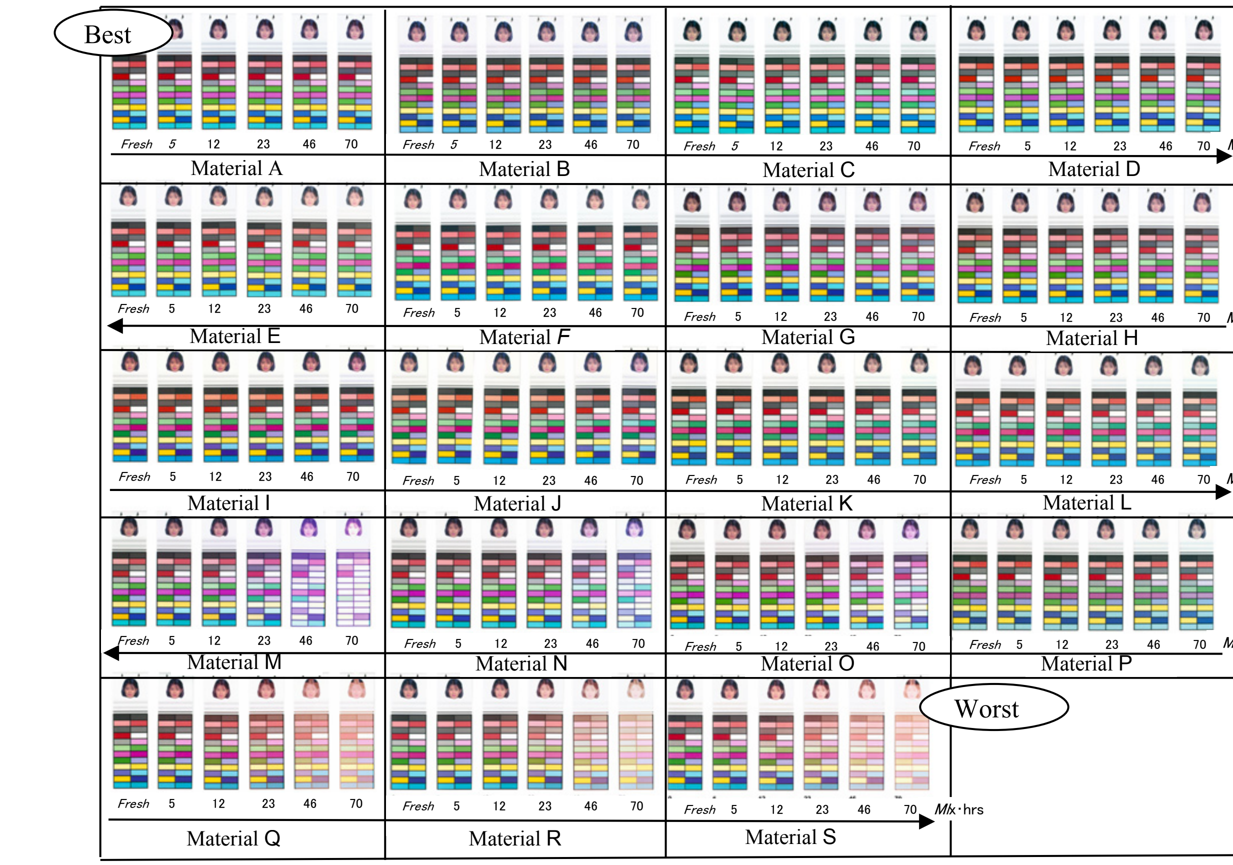

Figure 1 Overview images of the light fading test results of 20 materials. For each material, fresh, 1, 2, 4, 6, and 8 weeks from the left to the right. The materials are rearranged from the best (upper left) to the worst (lower right)

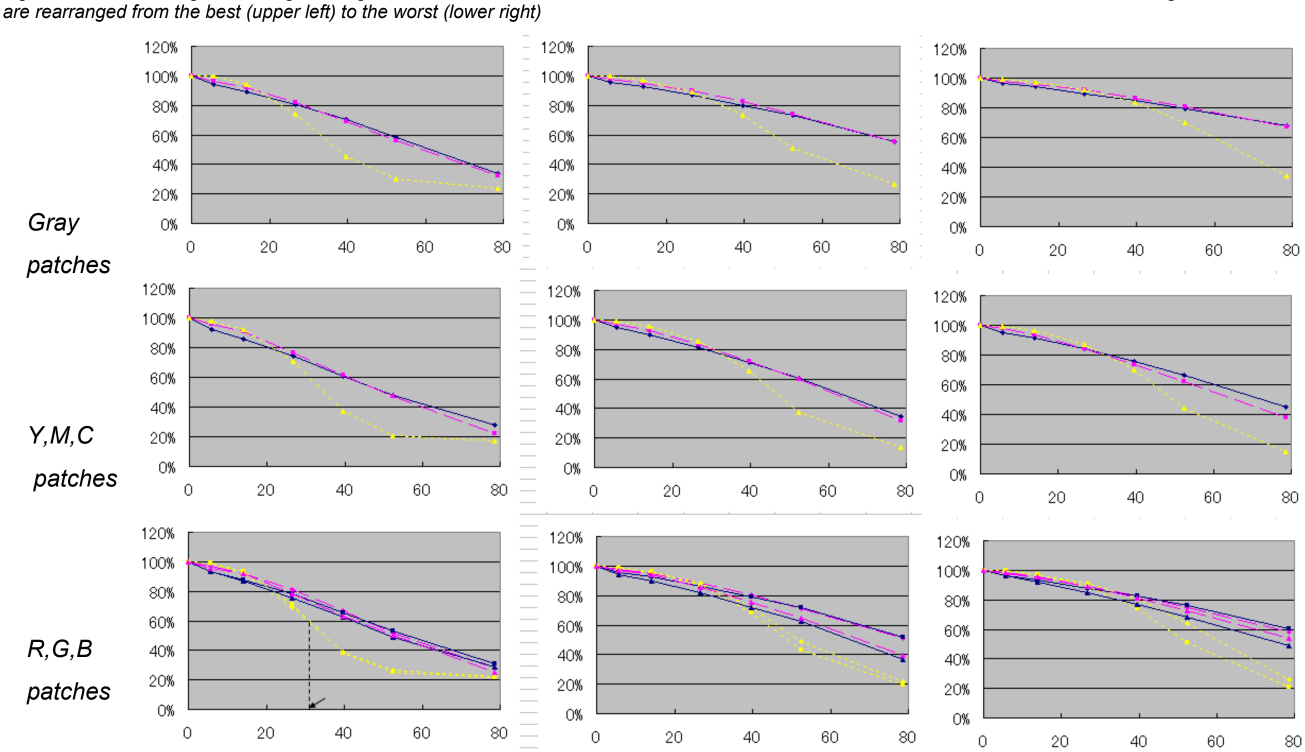

Figure 4 Density measurement results of patches with density = 0.5 (left), 1.0 (center) and 1.5 (right)